

The World Nuclear Industry Status Report 2025



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TABLE OF CONTENTS

ACKNOWLEDGMENTS	14
FOREWORD	16
KEY INSIGHTS	19
EXECUTIVE SUMMARY AND CONCLUSIONS	21
INTRODUCTION	41
GENERAL OVERVIEW WORLDWIDE	44
ROLE OF NUCLEAR POWER.	44
OPERATION, POWER GENERATION, AGE DISTRIBUTION.	49
The IAEA's Operating Reactors Data Revisions	52
IAEA vs. WNISR Assessment.	54
OVERVIEW OF CURRENT NEWBUILD	57
BUILDING VS. VENDOR COUNTRIES	58
CONSTRUCTION TIMES	60
Construction Times of Reactors <i>Currently Under Construction</i>	60
Construction Times of <i>Past and Currently Operating</i> Reactors	61
CONSTRUCTION STARTS AND CANCELLATIONS	63
OPERATING AGE	66
LIFETIME PROJECTIONS	71
FOCUS COUNTRIES	74
CHINA FOCUS	74
Overview	74
China's Nuclear Sector and Ecosystem	77
State-Owned Giants: China National Nuclear Corporation (CNNC) and China General Nuclear Power Corporation (CGNPC or CGN)	78
Targets vs. Reality	79
The Localization of China's Nuclear Industry	81
China's Construction Costs and Capabilities	82
China's Growing Range of Nuclear Technologies	86
Nuclear and Renewable Energy	90
FRANCE FOCUS	92
Overview	92

No Reactor Under Construction in France—Again.	94
Nuclear Unavailability Review 2024.	98
Stress Corrosion Cracking and Thermal Fatigue	102
Decennial Inspections and Lifetime Extensions	103
Financial Issues	107
The 20-Year-Long Flamanville-3 EPR Saga—No End in Sight?.	108
The EPR2 Project	110
Energy Planning	111
Conclusion	112
JAPAN FOCUS	113
Overview	113
Regulatory Measures—First Rejection of Restart Application	116
Legal Cases Against the Restart of Reactors	121
Spent Fuel Management	122
Closed Power Reactors in Japan	125
New Energy Policy and the Role of Nuclear Energy	127
Prospects for Nuclear Power vs. Renewable Energy Deployment	128
RUSSIA FOCUS	129
Overview	129
Lifetime Extensions	131
Nuclear Newbuild	135
Reactor Exports	139
Nuclear Interdependencies and Sanctions	143
SOUTH KOREA FOCUS.	146
Policy Overview: From Nuclear Expansion to Political Uncertainty	147
Operating Fleet	149
Reactors Under Construction and Planned	150
Small Modular Reactors (SMRs).	151
The Czech Dukovany Nuclear Contract	153
Export Ambitions: The Risks of Low Bidding and the ‘On Time, On Budget’ Model	155
KEPCO’s Continued Financial Crisis	158
TAIWAN FOCUS	159
National Politics: Toward a Restart of Nuclear Plants?.	160
International Political Pressure	163

Energy Policy	164
Public Attitudes and Misinformation	167
Reactor Closures and Spent-Fuel Management	169
UKRAINE FOCUS	171
Newbuild Projects	172
Reducing Russia Dependencies	175
Power Sector Under War Conditions	176
Russian Attacks on Nuclear Facilities	178
UNITED KINGDOM FOCUS	182
U.K. Power Mix	185
Nuclear Newbuild	187
UNITED STATES FOCUS	195
Overview	195
Subsidies and Financing for Nuclear Power	197
Other Support Measures for the Nuclear Industry	200
Extended Reactor Licenses	201
Reactor Closures and Proposed Restarts	203
New Reactors: Proposals, Planning, and Policy Developments	205
Industry Restructuring and Emerging Business Models	218
Criminal Investigations of Nuclear Power Corporations	228
Conclusion	230
FUKUSHIMA STATUS REPORT	232
ONSITE CHALLENGES	232
Removing Highly Radioactive Nuclear Fuel Debris	232
Contaminated Water	236
Worker Safety	238
OFFSITE CHALLENGES	238
Disposal of Contaminated Soil	239
Food Contamination Monitoring	240
Legal Cases, Compensation	247
DECOMMISSIONING STATUS REPORT	250
INTRODUCTION	250
Elements of National Decommissioning Policies	250
GLOBAL OVERVIEW	252

Decommissioning Worldwide	252
Overview of Reactors with Completed Decommissioning.	254
Overview of Ongoing Reactor Decommissioning.	255
DECOMMISSIONING IN SELECTED COUNTRIES	274
Country Case Studies.	274
CONCLUSION ON REACTOR DECOMMISSIONING	280
POTENTIAL NEWCOMER COUNTRIES	282
POTENTIAL NEWCOMER COUNTRIES WITH ACTIVE REACTOR CONSTRUCTION	282
Bangladesh.	282
Egypt	285
Türkiye	286
POTENTIAL NEWCOMER NUCLEAR COUNTRIES IN AFRICA	293
Ghana.	295
Kenya	296
Nigeria	297
Uganda	298
CASE STUDIES ITALY AND POLAND	299
Italy	299
Poland	303
OTHER EXAMPLES	313
Ecuador	313
Estonia	313
Indonesia.	314
Jordan	315
Kazakhstan.	316
Saudi Arabia	320
Uzbekistan	322
RUSSIA NUCLEAR INTERDEPENDENCIES	325
RUSSIA'S ROLE IN THE GLOBAL NUCLEAR FUEL SUPPLY CHAIN	325
Framatome and the Lingen VVER Fuel Manufacturing Plant Project.	331
RUSSIA'S DEPENDENCIES AND POTENTIAL SANCTIONS.	333
SMALL MODULAR REACTORS (SMRs)	338
ARGENTINA	339

CANADA	340
CHINA.	344
HTR-PM Design	344
ACP100 Design	345
FRANCE.	345
INDIA	347
RUSSIA	348
Light Water Reactor Designs	348
Fast Neutron Reactor Design	349
Export Prospects	350
SOUTH KOREA	350
UNITED KINGDOM	352
UNITED STATES	354
CONCLUSION	356
CHALLENGES OF INTEGRATING NUCLEAR POWER INTO THE ENERGY SYSTEM	358
INTRODUCTION.	358
RADICAL CHANGES IN THE CONTEXT OF THE COMMERCIAL USE OF NUCLEAR POWER	359
The Context Sixty Years Ago.	359
Increasing Climate Awareness and the Urge for Decarbonization	360
Step-by-Step Liberalization of Electricity Markets	361
New Energy Technologies Start to Disrupt Markets and Systems	361
Widening International Competition.	362
Accelerating Change	363
PHYSICAL PRINCIPLES UNDERLYING THE TECHNOLOGIES	364
Nuclear Energy	364
Photovoltaics	371
New Batteries and Power Electronics	375
Game-changing Upgrades for Older Energy Technologies	378
Conclusions	385
NEW ROLES FOR ENERGY TECHNOLOGIES IN A FUNDAMENTALLY CHANGING ENERGY SYSTEM	386
Powerful Drivers of Change	386
Power Generation: Renewable Electricity Unbeatably Cheap	387
Electricity Use: Electrification Brings Efficiency and Flexibility	391
System Integration: Enhanced Interlinkages Change the Control Paradigm	400

Consequences of Long-Term Trends: Key Characteristics of the Coming Energy System.	403
INTEGRATING NUCLEAR POWER INTO THE ENERGY SYSTEM: INCREASING DIFFICULTIES	403
Nuclear Power in Conventional Energy Systems	404
Remaining Drivers for Nuclear Energy Expansion	408
NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT	410
INTRODUCTION: GLOBAL TRENDS	410
INVESTMENT	413
ELECTRICITY GENERATION COST DEVELOPMENT	417
INSTALLED CAPACITY AND ELECTRICITY GENERATION	421
The Overall Picture	421
Photovoltaics and Batteries—The New Dream Team	424
First Signs of a Boom Behind the Meter	428
Persisting Large Gaps Between Regions	431
STATUS AND TRENDS IN CHINA, THE EUROPEAN UNION, INDIA, AND THE UNITED STATES	434
China	434
European Union.	437
India.	440
United States	441
CONCLUSION: A PIVOTAL YEAR	443
ANNEX 1 – OVERVIEW BY REGION AND COUNTRY	446
AFRICA	446
South Africa	446
THE AMERICAS	452
Argentina.	452
Brazil	456
Canada	461
Mexico	467
ASIA	471
India.	471
Pakistan.	477
MIDDLE EAST	479
Iran	479
United Arab Emirates.	481
EUROPEAN UNION (EU27)	482

WESTERN EUROPE	486
Belgium.	487
Finland	492
The Netherlands	500
Spain	504
Sweden.	510
Switzerland.	516
CENTRAL AND EASTERN EUROPE	521
Bulgaria.	521
Czech Republic	528
Hungary	533
Romania	539
Slovakia.	544
Slovenia	551
FORMER SOVIET UNION.	555
Armenia	555
Belarus	559
ANNEX 2 – CHINESE NUCLEAR REACTOR FLEET	564
ANNEX 3 – RUSSIA NUCLEAR INTERDEPENDENCIES	567
ANNEX 4 - STATUS OF NUCLEAR POWER IN THE WORLD	571
ANNEX 5 – NUCLEAR REACTORS IN THE WORLD “UNDER CONSTRUCTION”	572
ANNEX 6 – ABBREVIATIONS	580
ANNEX 7 – ABOUT THE AUTHORS	584

TABLE OF FIGURES

Figure 1 · National Nuclear Power Programs Development, 1954–2025.	45
Figure 2 · Nuclear Electricity Generation in the World... and China	47
Figure 3 · Nuclear Electricity Generation and Share in National Power Generation.	48
Figure 4 · Nuclear Power Reactor Grid Connections and Closures in the World	49
Figure 5 · Nuclear Power Reactor Grid Connections and Closures World/China	50
Figure 6 · World Nuclear Reactor Fleet, 1954–mid-2025	51
Figure 7 · World Nuclear Reactor Fleet – IAEA vs WNISR, 1954–July 2025	54
Figure 8 · Nuclear Reactors “Under Construction” in the World	57
Figure 9 · Nuclear Reactors “Under Construction” – China and the World	58
Figure 10 · Nuclear Reactors “Under Construction” by Technology-Supplier Country	59
Figure 11 · Average Annual Construction Times in the World	61
Figure 12 · Delays for Units Started Up, 2022–2024	62
Figure 13 · Construction Starts in the World	64
Figure 14 · Construction Starts in the World/China	65
Figure 15 · Cancelled or Suspended Reactor Constructions	66
Figure 16 · Age Distribution of Operating Reactors in the World	67
Figure 17 · Reactor-Fleet Age of Top 5 Nuclear Generators	67
Figure 18 · Age of World Nuclear Fleets.	69
Figure 19 · Age Distribution of Closed Nuclear Power Reactors	70
Figure 20 · Nuclear Reactor Closure Age	71
Figure 21 · The PLEX Projection (not including LTOs)	72
Figure 22 · The Expansion of the Chinese Nuclear Fleet, 1991–2025	77
Figure 23 · Forty Years of Nuclear Constructions in China, 1985–2025	85
Figure 24 · Evolution of Reactor Construction Times in China.	86
Figure 25 · Operating Fleet and Capacity in France	94
Figure 26 · Startups and Closures in France	95
Figure 27 · Nuclear Electricity Production vs. Installed Capacity in France.	96
Figure 28 · Nuclear Electricity Production vs. Nuclear Share in France.	97
Figure 29 · Monthly Nuclear Electricity Generation, 2012–mid-2025	98
Figure 30 · Reactor Outages in France in 2024	99
Figure 31 · Forced and “Planned” Unavailability of Nuclear Reactors in France in 2024	100
Figure 32 · Unavailability of French Nuclear Reactors, 2020–2024	101
Figure 33 · Age Distribution of the French Nuclear Fleet	103
Figure 34 · Construction Times and Project Cost Estimates for Flamanville-3.	109
Figure 35 · Rise and Fall of the Japanese Nuclear Program.	114

Figure 36 · Status of the Japanese Reactor Fleet	115
Figure 37 · Age Distribution of the Japanese Nuclear Fleet	116
Figure 38 · Nuclear Production Versus Installed Capacity in Russia	130
Figure 39 · Startups and Closures in Russia.	131
Figure 40 · Age Distribution of the Russian Nuclear Fleet	132
Figure 41 · Electricity Production in Taiwan, 2000–2024	166
Figure 42 · Histogram of Taiwan Nuclear Fleet.	169
Figure 43 · U.K. Reactor Startups and Closures	183
Figure 44 · Age Distribution of U.K. Nuclear Fleet.	185
Figure 45 · Electricity Generation by Source in the U.K. – The Coal Plunge	186
Figure 46 · Age Distribution of U.S. Nuclear Fleet	196
Figure 47 · Status of License Renewal Applications in the U.S..	202
Figure 48 · Evolution of Average Reactor Closure Age in the U.S..	203
Figure 49 · U.S. Early Reactor Retirements and Some Reversals.	205
Figure 50 · Reactor Startups and Closures in the U.S..	206
Figure 51 · Seventy Years of Nuclear Reactor Constructions in the U.S.	210
Figure 52 · Percentages of Treated Water and Water to be Re-purified	237
Figure 53 · Overview of Completed Reactor Decommissioning Projects	255
Figure 54 · Providers of Nuclear Fuel Services to the E.U.	327
Figure 55 · E.U. Imports of Russian Nuclear Fuel Elements	328
Figure 56 · Learning Curves for Solar and Wind Technologies.	374
Figure 57 · Lithium Battery Price Development, 2013–2024	377
Figure 58 · Levelized Cost of Energy for Various Energy Technologies at Different Locations in Germany	389
Figure 59 · Grid-Size Battery Fleet in the EU27, U.K., and Switzerland, 2015–2024.	397
Figure 60 · Solar Power Overtakes Nuclear Power	411
Figure 61 · Global Investment in Renewables and Nuclear Power, 2004–2024.	414
Figure 62 · Regional Breakdown of Nuclear Power Plant Investments, 2015–2024	415
Figure 63 · Regional Breakdown of Renewable Investments, 2015–2024	416
Figure 64 · The Declining Costs of Renewables vs. Traditional Power Sources	417
Figure 65 · Solar PV Cost and Performance Trajectories in Selected Countries, 2022–2024.	418
Figure 66 · Sharp Decline in Battery Costs After the End of the Lithium Shortage.	419
Figure 67 · Global Wind, Solar, and Nuclear Installed Capacity and Electricity Production.	422
Figure 68 · Nuclear vs. Non-Hydro Renewable Electricity Production in the World	422
Figure 69 · Electricity Generation in the World by Source, 2000–2024	423
Figure 70 · Power Generation in the World, Annual Production Compared to 2014	424
Figure 71 · Growth of Hours with Negative Power Prices	426

Figure 72 · Grid-Connected Battery Storage Additions, 2020–2024.	427
Figure 73 · Wind, Solar, and Nuclear Installed Capacity and Electricity Production in China.	435
Figure 74 · Nuclear vs. Non-Hydro Renewables in China, 2000–2024.	435
Figure 75 · Electricity Generation Mix in China, 2000–2024	436
Figure 76 · Wind, Solar, and Nuclear Capacity and Electricity Production in the EU27	437
Figure 77 · Electricity Generation in the EU27 by Fuel, 2015–2024.	438
Figure 78 · Wind, Solar, and Nuclear Installed Capacity and Electricity Production in India	440
Figure 79 · Wind, Solar, and Nuclear Installed Capacity and Electricity Production in the United States	441
Figure 80 · Nuclear Reactors Startups and Closures in the EU27, 1959–1 July 2025.	483
Figure 81 · Nuclear Reactors and Net Operating Capacity in the EU27	483
Figure 82 · Construction Starts of Nuclear Reactors in the EU27	484
Figure 83 · Age Evolution of EU27 Reactor Fleet, 1959–2024.	485
Figure 84 · Age Distribution of the EU27 Reactor Fleet.	485
Figure 85 · Age Distribution of the Western European Reactor Fleet (incl. Switzerland and the U.K.)	487
Figure 86 · 80-Year Histogram of Belgian Nuclear Program.	490
Figure 87 · Age Distribution of the Swedish Nuclear Fleet	511
Figure 88 · Age Distribution of the Swiss Nuclear Fleet.	517

TABLE OF TABLES

Table 1 · WNISR Rationale for the Classification of 30 Reactors as Non-Operational as of end 2012	56
Table 2 · Nuclear Reactors “Under Construction” (as of 1 July 2025)	59
Table 3 · Duration from Construction Start to Grid Connection, 2015–2024.	63
Table 4 · Total Unavailability at French Nuclear Reactors, 2019–2024 (in Reactor-Days)	99
Table 5 · Fourth Decennial Visits of French 900-MW Reactors, 2019–2025	105
Table 6 · Official Reactor Closures Post-3/11 in Japan (as of 1 July 2025)	126
Table 7 · Status of the Russian Nuclear Reactor Fleet (as of 1 July 2025)	133
Table 8 · Nuclear Reactors Under Construction and Planned in Russia.	138
Table 9 · Power Generation by Source and Share Forecast	148
Table 10 · Spent Fuel at Taiwan’s Nuclear Power Plant Sites	170
Table 11 · Status of EDF’s U.K. AGR Nuclear Reactor Fleet (as of 1 July 2025)	184
Table 12 · Overview of Status of the Decommissioning (as of mid-2025).	249
Table 13 · Overview of Reactor Decommissioning Worldwide (as of 1 July 2025)	253
Table 14 · Target Dates for Decommissioning Milestones in Italy	262
Table 15 · Overview of Decommissioning Progress for Reactors in Germany Closed, 2015–2023	276
Table 16 · Fuel Supply for Soviet-designed Reactors in the E.U. and Ukraine (as of mid-2025)	329
Table 17 · Key Characteristics of Main Energy Technologies Promoted for Decarbonization	385
Table 18 · Regional Breakdown of Renewable Energy Investments (in US\$ billion) and their Growth Rates, 2022–2024 .	416
Table 19 · Solar, Wind, and Nuclear: Regional Electricity Generation Metrics vs. World Average in percentage. . .	432
Table 20 · Status of Canadian Nuclear Fleet - PLEX and Expected Closures	462
Table 21 · Belgian Nuclear Fleet (as of 1 July 2025).	489
Table 22 · Status of the Spanish Nuclear Fleet (as of 1 July 2025)	505
Table 23 · Chinese Nuclear Reactors in Operation (as of 1 July 2025).	564
Table 24 · Chinese Nuclear Reactors in LTO	566
Table 25 · Fuel Supply for Soviet-designed Reactors in the E.U. and Ukraine (as of mid-2025)	567
Table 26 · Status of Nuclear Power in the World (as of 1 July 2025).	571
Table 27 · Nuclear Reactors in the World “Under Construction” (as of 1 July 2025).	572

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FOREWORD

by **Letizia Magaldi**¹

The history of nuclear power in Italy is characterized by a pioneering role in the construction of power plants, which led the country to become the third largest producer of nuclear power in the world in the 1960s, with plants in Latina, Trino, Garigliano, and Caorso. Then, within a few decades, two referendums—in 1987 in the wake of Chornobyl and in 2011 after Fukushima—drew a clear line, sanctioning a voluntary withdrawal from nuclear power, an unprecedented choice in Europe. However, while nuclear power disappeared from the political agenda, the expertise did not vanish, and several companies continued to work abroad, also collaborating on the international ITER² program.

Today, driven by an increasingly alarming climate crisis, by the European taxonomy that has recognized nuclear power as a sustainable activity provided that strict standards are met, and by the acceleration represented by the energy shock triggered by the war in Ukraine, Italy has returned to questioning the use of nuclear power. Price volatility and the fragility of a system still dependent on gas and electricity imports have highlighted how precarious our energy mix is. The electricity grid, which is unbalanced between the north and south, requires programmable sources capable of compensating for the fluctuating generation of renewables. It is in this context that in 2025 the government opened the door to a possible revival of the sector, aiming to achieve a share of between 11 percent and 22 percent of electricity production by 2050 with nuclear power, in particular with Small Modular Reactor (SMR) and Advanced Modular Reactor (AMR) plants.

The industrial world is moving forward, and the Meloni government is pushing in this direction. Studies such as those by Confindustria–ENEA and EY estimate a market worth €46–50 billion (US\$54–58 billion) by 2050, 117,000 new jobs and up to €10 billion (US\$11.6 billion) saved each year in energy bills.

In reality, as the history of recent decades in the West shows, these scenarios represent an aspiration that has little chance of being realized.

The Bank of Italy itself, in its Occasional Paper ‘L’atomo fuggente’ (The Fleeing Atom) published in June 2025, highlights how the return of nuclear power is unlikely to have a significant impact on the final price of electricity, since even modular reactors remain highly capital-intensive investments, characterized by returns spread over the long term. The main contribution is therefore not to be found in a reduction in immediate costs, but rather in the ability to stabilize the volatility of electricity prices, mitigating exposure to international markets and offering greater protection to businesses and households in the face of possible shocks. However, the study also highlights new potential critical issues related to dependence on foreign supplies of fuel and advanced components, as well as the geopolitical risks arising from global uranium chains. A further concern relates to timing: the construction times, which

¹ - President, Kyoto Club, Rome, Italy

² - ITER is the International Fusion Energy project in Cadarache, France

are inevitably long even for SMRs, appear difficult to reconcile with the urgency of reducing emissions. From this perspective, if nuclear power ever returns to the national energy mix, it will at best complement renewables in a decarbonization process that will continue to rely heavily on solar, wind, and storage systems.

The risk, if anything, is that renewables' growth will slow down, reaching levels above 80 percent by the middle of the next decade (Germany's target for 2030).

An analysis of characteristics of the emerging overall energy system indicates that photovoltaics, batteries, and power electronics are already changing the logic of the overall system in a way that makes it increasingly difficult to integrate nuclear energy. Time frames play a key role: until a nuclear power plant, decided on today, begins to produce electricity, new technologies will have radically transformed the energy system.

Interesting insights into these critical issues are contained in the chapter “Challenges of integrating nuclear energy into the energy system” of the *World Nuclear Industry Status Report 2025*. It highlights how the logic of the energy system is changing radically, with increasingly decentralized electricity production involving millions of investors and operators. Generation technologies are transforming from gigantic and customized to modular and mass-produced. Moreover, grid-forming inverters are now available that can play an important role in stabilizing the grid in critical situations. Proposing nuclear energy as part of a stable energy mix with highly fluctuating renewable sources overlooks its weaknesses. For technical and economic reasons, nuclear power plants do not provide the kind of flexible and programmable energy that can fill the gaps between solar production peaks.

In the face of hypothetical nuclear scenarios, it is therefore essential to look at the present: Italy is experiencing an unprecedented season in the field of renewables. In May 2025, renewable sources covered 55.9 percent of national electricity demand, a historic record, while photovoltaics recorded a 27-percent increase compared to the same month last year. The role of solar energy has also exploded in Europe: in June 2025, photovoltaics became the E.U.'s main source of energy for the first time, accounting for 22.1 percent of electricity production, surpassing gas, coal, and even nuclear energy. This signal is powerful and irrefutable: renewables are no longer a promise but a reality that is growing rapidly and strongly.

Terna, the transmission network operator, reminds us that fluctuating generation needs adequate storage systems as we continue to install solar and wind power. Short- and long-term capacity is needed; lithium-ion batteries do the day-to-day work, while pumping and Long-Duration Energy Storage (LDES) are building the future with pilots and commercial plants already in operation.

We cannot ignore this fact: Italy—and with it Europe—is demonstrating that a reliable energy transition can be based on renewables. When rethinking nuclear power, we need to place this reflection in the current context. SMRs could be a valuable complement if, and only if, they meet the demand for stability and do not shift it to uncertain terrain and timescales. We must embrace a coherent vision: efficiency, smart grids, storage, distributed generation, renewables, and—only where necessary—advanced nuclear power. Only in this way can we build a truly resilient, sustainable, and democratic electricity system.

Italy is now at a crossroads. As a country that has twice said “no” to nuclear power, it could choose to explore new solutions, such as SMRs, which are currently only a hypothesis with very uncertain timescales and costs. But at the same time, it is already undergoing another revolution: that of renewables and storage, which are already proving capable of covering more than half of our consumption and have taken the lead in Europe. As highlighted by IRENA³, in 2024, 91 percent of new renewable projects have been cheaper than fossil fuels, and 87 percent of new power capacity installed in the world has been renewable; in the past ten years lithium-ion batteries’ LCOS⁴ has fallen substantially by more than half. Between historical memory and the future, between atomic promises and solar certainties, the real challenge will not be to choose a single path but to compose a coherent mosaic of solutions, in which renewables are the backbone and nuclear power, if it ever really enters the picture, a complement.

For this reason, more than ever, transparency, stable rules, democratic participation and independent data are needed. *The World Nuclear Industry Status Report* remains the benchmark for distinguishing reality from illusion. It is from here that Italy will have to decide whether and how nuclear power can be part of its energy future. Only then will we be able to clearly assess whether nuclear power can be part of our real energy future, or whether it risks remaining yet another unfulfilled promise.

3 - International Renewable Energy Agency, “Renewable Power Generation Costs in 2024”, 2025.

4 - Levelized Cost of Storage

KEY INSIGHTS

Fewer Countries Operating Nuclear Power Plants

- As of mid-2025, 31 countries were operating nuclear power plants in the world, one fewer than one year earlier, as Taiwan closed its last reactor in May 2025. In total, 408 reactors were operating worldwide, excluding Long-Term Outages (LTOs), identical to one year ago and 30 below the 2002-peak.
- 33 units were in LTO, including 19 in Japan and 6 in Ukraine.

Fewer Countries Building Nuclear Power Plants

- As of mid-2025, 11 countries, 2 fewer than mid-2024, 5 fewer than mid-2023, are hosting 63 reactor construction projects, 5 more than mid-2024 but one less outside China.
- Of these, 22–26 are delayed, including 14 reporting increased delays.
- China has the most reactors under construction (32) but only one abroad. Russia dominates the international market with 27 units under construction, 20 of them in 7 other countries.
- Construction started on 9 reactors in 2024—up from 6 in 2023, down from 10 in 2022—including 7 implemented by China (one in Pakistan) and one each in Egypt and Russia.
- Chinese and Russian government-controlled companies implemented 44 of 45 reactor construction starts globally from January 2020 through mid-2025.
- Besides Russia's Rosatom and China's CNNC, only France's EDF is currently building nuclear power plants abroad (2 units in the U.K.).
- 95 percent of all ongoing construction projects (60 of 63) are carried out either in Nuclear Weapon States (NWS) or by NWS-controlled companies in other countries.

Fukushima Status Report

Onsite and offsite challenges remain overwhelming, with an initial removal of fuel debris amounting to around a billionth of the total. A focus on food-safety monitoring finds an opaque system that makes it challenging for the government to convince observers it has control over the situation.

New Global Production Record, but Significant Decline *Outside China* Since Previous Record

- Global nuclear power generation increased by 2.9 percent—following a 4.4 percent drop in 2022 and a 2.2 percent increase in 2023—reaching a new record of 2,677 TWh, just 14 TWh (a large reactor's nominal annual output) above the previous, 18-year-old record. Outside China, nuclear generation in 2024 remained 363 TWh below the 2006-level, an almost 14-percent plunge.
- In 2024, 7 new reactors started up and 4 were closed. As of end-2024, the world fleet's total electric net operating capacity reached a record 369.4 GW, before slightly declining again by mid-2025, to 368.7 GW, just 1.6 GW—a large reactor equivalent—above the previous 2006 end-of-year record.
- Nuclear energy's share of global commercial gross electricity generation declined very slightly (0.13 percentage points) to reach 9 percent in 2024, over 45 percent below the 17.5-percent peak in 1996.
- Between 2005 and 2024, there were 104 startups and 101 closures. Of these, 51 startups and none of the closures were in China. Thus, outside China, there has been a net decline by 48 units over the same period.

Some Major National Developments in 2024

- **China.** Nuclear power generation increased by 3.7 percent but its share of total electricity output slipped slightly for the third year in a row to 4.5 percent. While nuclear capacity grew by 3.5 GW, solar capacity grew by 278 GW.
- **France.** The Flamanville EPR started up in December 2024, 12 years later than planned, at a cost of US\$25.6 billion, a staggering sixfold increase over the original US\$4.3 billion estimate.
- **Japan.** For the first time, the Nuclear Regulation Authority (NRA) rejected a restart application citing non-compliance with regulatory safety standards.
- **Ukraine.** The Zaporizhzhia site, shut down and occupied by Russia's army, and the remaining nine operating reactors are a constant cause of concern due to the ongoing war.
- **United States.** The 54-year-old Palisades reactor in Michigan, officially closed in 2022, obtained regulatory approval for moving back into "operational status".

Decommissioning

Of 218 closed power reactors, only 23 have been fully decommissioned and 9 released from regulatory control as greenfield sites.

Small Modular Reactors (SMRs)

So far, there is only one Design Certification and one Standard Design Approval (both NuScale, U.S.) but no constructions in the West. Two of the largest European nuclear startups Newcleo (cash shortage) and Naarea (insolvent) are in serious financial trouble.

Potential Newcomer Countries

Many countries have made announcements but, so far, only Bangladesh, Egypt, and Türkiye are building reactors—all of them Russian.

Russia Nuclear Dependencies

Russia continues its key role as supplier of fuel services, involving uranium mining and conversion and fuel assembly manufacturing for Soviet-designed VVER pressurized water reactors. Russia is also a significant client for parts and services of Western nuclear companies. Thus, there are significant interdependencies.

Challenges of Integrating Nuclear Power into the Energy System

New energy technologies disrupt markets and systems. Photovoltaics directly produces electricity from solar radiation in harmless nanometer-thin semiconductor junctions allowing for ongoing steep cost reductions and performance increases. This is complemented by similar advances in power electronics and batteries. Together these new technologies are evolving towards a highly flexible fully electrified energy system with a decentralized control logic outcompeting traditional centralized fossil and nuclear systems. Nuclear energy increasingly has difficulties to survive in this context. 2024 has been a pivotal year as battery storage costs have dropped by 40 percent.

Solar Adds Hundreds of Gigawatts, Nuclear Remains Irrelevant in the Market

Deployment in 2024 corroborates the analysis of fundamentals. Storage has passed a trigger point, there are first signs of a revolution behind the meter and low-income countries are starting to leapfrog. In 2024, total investment in non-hydro renewable electricity capacity reached a record US\$728 billion, 21 times the reported global investment in nuclear energy. Solar and wind power capacities grew by 32 percent and 11 percent, respectively, resulting in 565 GW of combined new capacity, over 100 times the 5.4 GW of net nuclear capacity addition. Global wind and solar facilities generated 70 percent more electricity than nuclear plants.

China. Solar power generation increased by 44 percent compared to nuclear's 3.7-percent growth. Solar and wind combined produced over four times as much power as nuclear reactors. Renewables including hydro generated 33.7 percent of power, while coal declined to 57.8 percent.

European Union. The 28-percent wind plus solar contribution to total electricity production outcompeted nuclear's 23-percent share. The E.U. nuclear output increased slightly year-on-year but declined outside France.

India. Solar capacity grew by 34 percent with power generation increasing by 20 TWh. A new 0.63-GW reactor was connected to the grid in early 2024 and nuclear generation increased by 6 TWh to a total of 52 TWh. Solar plants generated 135 TWh, 2.6 times nuclear's output.

United States. By the end of 2024, Texas alone had an installed capacity of almost 10 GW of grid-connected batteries, expected to double in 2025 to 20 GW. Texas has also been building up around 40 GW of solar and wind each and retiring fossil-fueled plants. It remains uncertain how much the current Trump administration's pro-fossil fuels and pro-nuclear policies will impact state-level energy transition efforts.

Overall Conclusion

2024 has seen an unprecedented boost in solar and battery capacity expansion driven by continuous significant cost decline. As energy markets are rapidly evolving, there are no signs of vigorous nuclear construction and the slow decline of nuclear power's role in electricity generation continues.

EXECUTIVE SUMMARY AND CONCLUSIONS

The World Nuclear Industry Status Report 2025 (WNISR2025) provides a comprehensive overview of nuclear power plant data, including information on age, operation, production, construction and decommissioning of reactors. WNISR2025 includes various topical focus chapters. These include, for the first time, an in-depth assessment of the multiple **Challenges of Integrating Nuclear Power into the Energy System** as the system changes rapidly on all levels and in all geographical regions. The revamped traditional chapter **Nuclear Power vs. Renewable Energy Deployment** provides a complementary detailed overview of the astonishing expansion in the renewables sector, especially in combination with the soaring deployment of battery storage capacity on the one hand, and the stagnating nuclear sector on the other.

The **Focus Countries** chapter includes a detailed overview of developments in eight of the 31 nuclear countries including the top 5 generators (by rank)—i.e., the **United States, China, France, Russia, and South Korea**—as well as **Japan, Ukraine, and the United Kingdom**, plus **Taiwan** that closed its last reactor in May 2025. The chapter on **Potential Newcomer Countries** includes an **Africa Focus** section that assesses the status of planning in four selected countries on the continent. In addition, the chapter analyzes the status of nine other potential newcomer countries, including the only three (**Bangladesh, Egypt, Türkiye**) that are currently building their first commercial reactors. The traditional chapter on **Small Modular Reactors (SMRs)** reports many plans, particularly in potential newcomer countries, and finds increasing expenditures but still sees little progress on the ground.

Russia Nuclear Interdependencies follows up on the **Russia Nuclear Dependencies** chapter in WNISR2024 and looks into the mutual nature of dependencies between nuclear industries in the West and Russia. The **Fukushima Status Report** has been thoroughly upgraded, including a deep dive into the Japanese monitoring system intended to guarantee food safety. The **Decommissioning Status Report** now covers 218 closed reactors, almost one third of all the units ever connected to the grid over the past 70 years.

Finally, **Annex 1** presents overviews of nuclear power programs in each of the countries not covered in the Focus Countries chapter.

PRODUCTION AND ROLE OF NUCLEAR POWER

Reactor Operation and Capacity. As of 1 July 2025, a total of 408 reactors—excluding Long-Term Outages (LTOs)—were operating in 31 countries, which is the same as the number of reactors reported in WNISR2024, but operating in one less country.⁵ There were 33 units in LTO, including 19 in Japan and 6 in Ukraine. Operating units are also 10 less than in 1989—the first peak and the end of the preceding uninterrupted rise—and 30 below the historic peak of

⁵ - Balance since WNISR2024: +4 startups +4 restarts -3 new LTOs -5 closures = no change.

438 in 2002. As of the end of 2024, the world fleet had a total electric net operating capacity of a record 369.4 GW that had slightly declined by mid-2025 to 368.7 GW, which is just 1.6 GW—the equivalent of a large reactor—more than the previous end-of-year record of 367.1 GW in 2006.

IAEA versus WNISR Assessment. Between September 2022 and April 2023, the International Atomic Energy Agency (IAEA) significantly modified its statistics—including retroactively—in its online-Power Reactor Information System (PRIS). As of 1 July 2025, the IAEA-PRIS statistics show a peak of 440 reactors operating globally in 2005, whereas, as of the end of 2024, the operating capacity reached 377 GW, a new record, marginally over the previous peak of 374 GW reached in 2018, according to the new IAEA data. As of mid-2023, the IAEA had pulled, retroactively since shutdown, 23 units in Japan and four reactors in India from its list of operating reactors and added them to a new category labeled “Suspended Operation”. Following four subsequent restarts in Japan, as of mid-2025, the IAEA classified 19 reactors in Japan and four units in India as suspended.

As of 1 July 2025, WNISR classified 33 units as in LTO, of which 19 were in Japan, six in Ukraine, three in India, two each in Canada and South Korea, and one in China—the number decreased by one compared to WNISR2024.

Nuclear Electricity Generation. In 2024, the world nuclear fleet generated 2,677 net terawatt-hours (TWh or billion kilowatt-hours) of electricity. After a 4.4 percent drop in 2022, production increased by 2.2 percent in 2023 and again by 2.9 percent in 2024. It is the highest output ever, the previous record being 2,663 TWh in 2006. China, with a 3.7-percent increase (compared to 11.3 percent in 2021, 2.5 percent in 2022, and 4.1 percent in 2023), produced more nuclear electricity than France for the fifth year in a row and remains in second place—behind the U.S.—among the top nuclear power generators. Nuclear production outside China increased by 2.8 percent, similar to the level of global production in the mid-1990s prior to China’s nuclear buildout. If global nuclear generation exceeded the previous 18-year-old record by a modest 14 TWh—hardly more than a single large reactor’s nominal annual generation—outside China, nuclear generation in 2024 was 363 TWh below the 2006 level, a significant fall of nearly 14 percent.

Share in Electricity/Energy Mix. Nuclear energy’s share of global commercial gross electricity generation in 2024 was almost stable at 9 percent (–0.13 percentage points), the lowest value in four decades and more than 45 percent below the peak of 17.5 percent in 1996.

REACTOR STARTUPS AND CLOSURES⁶

Startups. In 2024, seven reactors were connected to the grid, three in China and one each in France, India, the UAE, and the U.S., leaving zero active construction projects in France, the UAE, and the U.S.

In the first half of 2025, one unit was connected to the grid in India—remarkably, not a single unit was connected in China or elsewhere.

6 - See [Focus Countries](#) and [Annex 1](#) for a country-by-country overview.

Closures.⁷ Four units were closed over the year 2024, two in Canada and one each in Russia and Taiwan. In the first half of 2025, two were closed, one each in Belgium and Taiwan.

Over the past two decades (2005–2024), there were 104 startups and 101 closures in the world. Of these, 51 startups were in China, which did not close any reactors. As a result, outside China, the net number of reactors has significantly declined by 48 units and net capacity has declined by close to 27 GW over the period.

CONSTRUCTION DATA⁸

As of 1 July 2025, 63 reactors (60 GW) were under construction, which is four more than in WNISR2024 but six fewer than in 2013; six of the 69 units listed in 2013 have subsequently been suspended or abandoned.

Eleven countries are building nuclear plants, two down from mid-2024 and five fewer than in WNISR2023. While Pakistan entered the category with the launch of a new construction at one of its existing sites, three countries dropped off the list: France completed its last construction project, Argentina abandoned a reactor that had been under construction since 2014, and Japan was taken off the list because the construction projects considered in earlier editions turned out to be inactive. Only four countries—China, India, Russia, and South Korea—have construction ongoing at more than one site. Three “Potential Newcomer Countries”—Bangladesh, Egypt, and Türkiye—are building their first nuclear power plants.

As of mid-2025, there is not a single active power reactor construction on the entire American continent, from Alaska to Cape Horn, including the U.S. that hosts the world’s largest nuclear power fleet.

Building vs. Vendor Countries

- ➔ As of mid-2025, China had by far the most reactors under construction with 32 units—five more than one year earlier and more than half of the total worldwide. In December 2024, China started work on its only active construction outside the country in Pakistan.
- ➔ Russia is by far the dominant supplier on the international market, with 27 units under construction as of mid-2025. Seven of these are domestic. The remaining 20 units are being constructed in seven countries, including four each in China, Egypt, India, and Türkiye.⁹ It remains uncertain to what extent these projects have been or will be impacted by the various rounds of sanctions imposed on Russia following its invasion of Ukraine. However, sanctions, including on the banking system, clearly have led to delays in various projects.
- ➔ Besides Russia’s Rosatom, only Électricité de France (EDF) and China National Nuclear Corporation (CNNC) are presently building abroad.

7 - WNISR accounts for closures in the respective years of last electricity generation and adjusts statistics retroactively if units have not generated power in the year in review.

8 - See Annex 5 for a detailed overview of the 59 reactors under construction in the world as of mid-2025.

9 - In addition, two units are under construction in Bangladesh and one each in Iran and Slovakia where a Czech-led consortium is completing a Russian-designed reactor (Mochovce-4).

Construction Times

- ➔ For the 63 reactors being built, on average 5.3 years have passed since construction start—down from the mid-2024 average of 5.9 years—but many remain far from completion.
- ➔ All reactors under construction in at least six of the 11 countries hosting building sites have experienced, often year-long, delays.
- ➔ Of the 22–26 reactors behind schedule, at least 14 have reported *increased* delays.
- ➔ WNISR2023 noted a total of 14 reactors scheduled for startup in 2024, but only seven made it to generating first power, while the commissioning of the other seven was delayed at least into 2025.
- ➔ Grid connection of the Mochovce-4 reactor in Slovakia has been delayed yet again, currently to late 2025, that is 40+ years after its initial construction start. Bushehr-2 in Iran originally started construction in 1976, almost 50 years ago, and resumed construction in 2019 after a 40-year-long suspension. Grid connection was delayed again by one year and is currently scheduled for 2029, 53 years after construction initially started.
- ➔ Two additional reactors have been listed as “under construction” for a decade or more: the Prototype Fast Breeder Reactor (PFBR) and Rajasthan-8, both in India.

Construction Starts

- ➔ Construction started on nine reactors in 2024 (including six in China), up from six in 2023 and down from 10 in 2022 (both including five in China). Chinese companies also started one construction in Pakistan. Russia began work on one unit at home and one more in Egypt. In other words, over the five years between January 2020 and the end of 2024, all 40 construction starts in the world were either implemented by the Chinese or the Russian nuclear industries.
- ➔ Construction of five reactors started in the first half of 2025, three of them in China and one each in Russia and South Korea.

OPERATING AGE

- ➔ The average age (from grid connection) of the 408 operating nuclear reactors has been increasing since 1984 and stands at 32.4 years as of mid-2025, up from 32 years in mid-2024.
- ➔ A total of 266 reactors, two-thirds of the world’s operating fleet, have operated for 31 or more years; of these, 141—more than one in three—have operated for at least 41 years.
- ➔ The age at closure remains remarkably low at 43.2 years on average for the 28 units closed in the five-year period from 2020 to 2024.
- ➔ The Plant Life Extension or PLEX Projection assesses how many reactors need to be built to compensate for expected closures. If all currently licensed lifetime extensions were maintained, all construction sites completed as planned, and all other units operated for a 40-year lifetime (unless an earlier or later closure date has been authorized), in the years to 2030, the net balance would be in the positive for 2026, drop into negative terrain in 2027–2029, followed by a sharp decrease in 2030. Overall, over the period 2025–2030, 44 new

reactors or 26 GW in addition to the 59 units already under construction and scheduled to start up prior to the end of 2030 would have to be built and commissioned (or units restarted) to replace expected closures.

- ➔ The PLEX-Projection would still necessitate ramping up the annual startup rate of the past decade by a factor of 2.5 from 6.9 to 17.3 units for the remaining years to 2030 (including the reactors already expected to start up by 2030 (see [Figure 21](#)) only to maintain the status quo. However, probably at least half of the 104 reactors currently projected to close between 2025 and 2030 are now seeking and likely to secure a lifetime extension beyond 2030.

FOCUS COUNTRIES

The following nine [Focus Countries](#) include six of the top 10 nuclear power generators in the world. Some key developments for 2024 and the first half of 2025¹⁰ include:

China. Nuclear power generation increased by 3.7 percent and provided 4.5 percent of total electricity generation, slightly slipping for the third year in a row. While nuclear capacity grew by 3.5 GW in 2024, solar capacity alone grew by 278 GW. Solar and wind together generated about four times more electricity than nuclear reactors. Since 2010, the output of solar increased by a factor of over 800, wind by a factor of 20, and nuclear by a factor of six.

France. Nuclear power generation increased by 13 percent, but at 362 TWh it remained significantly below the 400 TWh considered normal a decade ago. Nuclear power represented 67 percent of the country's total power generation, the highest nuclear share in the world, but less than 18 percent of final energy. While total outage-days at zero-production dropped again in 2024 to, still significant, 99 days or a quarter of the year per reactor, the declared “forced” outages at 342 days stayed at the second highest level in six years. The Flamanville EPR started up in December 2024, twelve years later than planned, at a cost of US\$25.6 billion, a staggering sixfold increase over the original cost estimate of US\$4.3 billion (both figures in real 2023-dollars). The decision on the newbuild program has been confirmed; cost estimates are to be updated by year-end, and the first scheduled startup is delayed to 2038. Currently, there is no reactor under construction in the country.

Japan. Two additional reactors were restarted since mid-2024, bringing the total operational units to 14, while 19 reactors remain in LTO. Nuclear power generation increased by 9.5 percent, and the nuclear share in total electricity rose slightly from 7.7 percent in 2023 to 8.4 percent in 2024. Other restart schedules have been delayed again, and for the first time the Nuclear Regulation Authority (NRA) rejected a restart application on the grounds of non-compliance with regulatory safety standards. The operator of Tsuruga-2 could not prove there was no active seismic fault below the site. On the policy side, the goal to “reduce dependence on nuclear energy as much as possible” has been deleted from the Seventh Strategic Energy Plan, which sets out to “maximize the use of both renewables and nuclear power.”

Russia. State-controlled Rosatom is the leading global nuclear power plant exporter and the fourth largest nuclear electricity producer, contributing 17.8 percent of national power

10 - Note: For certain indicators, WNISR switched from IAEA-PRIS to the Energy Institute's data series. This leads to some differences with the numbers reported in earlier WNISR editions.

generation (down from 20.3 percent in 2020). Nuclear output has declined for the second and nuclear share in electricity for the fourth year in a row. For the third year in a row, Rosatom maintained its proactive role in the hostile military occupation of Europe's largest nuclear power plant, Zaporizhzhia, in Ukraine.

South Korea. The country operates the fifth largest nuclear power program by capacity and production in the world. In May 2025, the South Korean nuclear industry became the first other than the Chinese and Russian (at home and abroad) to start construction since December 2019. The future of the nuclear industry remains uncertain nevertheless. Incoming President Lee Jae-myung is ambiguous about the expansion of nuclear power and favors a renewables-based strategy. This did not prevent the national nuclear utility—Korea Electric Power Corporation (KEPCO)/Korea Hydro & Nuclear Power Co. Ltd. (KHNP)—from signing a construction contract in the Czech Republic in spite of the group's consolidated massive debt that, as of year-end 2024, stood at an unparalleled US\$150 billion with revenues at US\$69 billion.

Taiwan. With the country's last reactor closing in May 2025, the country has completed its nuclear phaseout.¹¹ Five other units had been closed previously in the framework of the strategy. Natural gas, contributing 42 percent, is now the largest source of electricity generation. So far, the buildup of renewables is lagging target levels, and the country remains dependent on imports for 95 percent of its overall primary energy supplies.

Ukraine. Of 15 operating or operable reactors, six are at the Russian occupied Zaporizhzhia site and stay in the LTO category as of mid-2025. The remaining operating reactors are a constant cause of concern in a country engaged in a full-blown war. Nevertheless, at over 50 percent, Ukraine has the third highest nuclear share in total electricity generation in the world. But production is down almost 40 percent compared to pre-war levels, as consumption also significantly shrank. Westinghouse is partnering with Ukrainian companies in a project to build two AP-1000s (of potentially nine in the country) at the Khmelnytskyi site. However, three years after the signature of a framework agreement, construction is yet to begin.

United Kingdom. There are only nine reactors with a combined capacity of 5.8 GW left operating versus 36 closed units in the country. Nuclear power provided a stable 38.6 TWh contributing 14.3 percent of the total supply (down a marginal 0.4 percentage points year-on-year but down from 28 percent in 1997). On 22 July 2025, after the WNISR mid-year editorial deadline, the U.K. Government signed the Final Investment Decision for the construction of two EPRs at the Sizewell C site. Meanwhile, in 2024, wind power alone provided more than twice as much energy as nuclear plants.

United States. Nuclear output increased slightly (+0.9 percent) to 782 TWh in 2024. The nuclear share of commercial electricity generation decreased by 0.4 percentage points to 18.2 percent. As of mid-2025, the U.S. nuclear fleet is still the largest in the world with 94 units. It is also one of the oldest with a mean age of 43.7 years. There is not a single nuclear reactor under construction in the country. There are many initiatives, plans, projects, financing schemes, and even presidential orders to restart building nuclear plants, big and small, but

11 - A national referendum aimed at overturning the phaseout and allowing the restart of reactors was held on 23 August 2025. While almost three quarters of the votes were in favor of restart, the proposal was rejected, because the favorable votes did not reach the legal quorum of one quarter of the total number of voters.

little is happening on the ground. A noteworthy development is Holtec successfully obtaining regulatory approval for moving the Palisades reactor in Michigan, officially closed in 2022, back into “operational status”.

FUKUSHIMA STATUS REPORT

Fourteen years have passed since the East Japan Great Earthquake on 11 March 2011 triggered the start of the Fukushima Daiichi nuclear power plant disaster (also referred to as 3/11 throughout the report). The situation is still far from having been stabilized.

Overview of Onsite and Offsite Challenges

Onsite Challenges

Fuel Debris Removal. In November 2024 and in April 2025, two samples of fuel debris were taken from the molten core of Unit 2. The total amount was 0.9 grams. There are an estimated 880 tons of fuel debris in Units 1–3, about a billion times the amount sampled, to be eventually extracted from the reactors and safely stored somewhere. There is no concept yet for a pathway to this goal, which is scheduled to be completed by 2051.

Spent-Fuel Removal. All spent fuel from the pool of Unit 3 had been removed by February 2021. Preparatory work is still underway on Units 1 and 2, with removal to begin in FY2026 for Unit 2 and in FY2027–2028 for Unit 1. TEPCO had completed spent-fuel removal from the pool of the relatively little impacted Unit 6 by mid-April 2025 and planned to start removal from Unit 5 in July 2025. TEPCO aims to have all the spent- and fresh-fuel assemblies removed from Units 1–6 by 2031, around 20 years after the disaster began.

Contaminated Water Management. As water injection continues to cool the fuel debris, highly contaminated water continues to run out of the cracked containments, mixing with water from an underground river in the basements. Various measures have reduced the influx of water from up to 540 m³/day in 2015 to about 50 m³/day in the first quarter of 2025. Nonetheless, an equivalent amount of water is partially decontaminated and stored in 1,000-m³ tanks daily, with a new tank filling up every three weeks.

The safety authority has allowed operator TEPCO to release treated contaminated water into the ocean, and as of the end of April 2025, TEPCO had discharged a total of 94,000 m³. As of the end of March 2025, two thirds of the 1.2 million m³ of stored water needed to be treated again, and all of the water has to be diluted by a factor of 100 or more in order to meet licensed standards before being released into the ocean. The ocean discharges remain contested in Japan and overseas.

Offsite Challenges

Offsite, the future of tens of thousands of evacuees, the contamination of food, and the management of decontamination wastes, all remain major challenges.

Evacuees. Although down from a peak of nearly 165,000 in May 2012, nearly 25,000 residents of Fukushima Prefecture remained living as evacuees as of 1 February 2025. The total number of people who have returned to former evacuation zones is uncertain and varies widely between locations. About 2.2 percent of the Fukushima Prefecture surface continues to be designated as “difficult-to-return zone”.

Disposal of Contaminated Soil. The soil, leaves, timber, and other waste removed in decontamination efforts is currently stored in interim facilities. There was around 14 million cubic meters of waste as of the end of December 2024, enough to fill 5,600 Olympic swimming pools, even though much of the heavily forested prefecture remains untouched. The government plans to use, e.g. in a range of construction applications, the soil that is judged safe for reuse, with radiation levels below 8,000 Bq per kilogram. The plan has met with significant opposition where trials have been proposed. The more heavily contaminated soil shall be shipped outside Fukushima Prefecture, but the destination and processing remain unclear.

Food Contamination. The section provides an analysis of the food monitoring system’s evolution over the years. Testing for radionuclides in most food stuffs has shown vanishingly few samples that exceed legal contamination limits. There are noteworthy exceptions though. In FY2024, 29 percent of the wild boar meat from Fukushima Prefecture that was tested exceeded radiation limits, with one specimen registering a cesium level of 13,000 Bq/kg, 130 times the legal limit of 100 Bq/kg. High levels in wild game have also been identified in other prefectures. Testing guidelines are vague, leaving details such as where and how much of various products are tested to the local governments, which implement them in different ways. There is no reliable, centralized data collection of testing results either. The interpretation of the significance of testing statistics is virtually impossible. The food monitoring system remains opaque and appears disorganized, making it challenging for the government to convince international observers, and even its own citizenry, that it has control over the situation. This has not stopped most of the 55 countries and regions that initially halted imports of food from Japan from lifting those bans, with only China, Russia, South Korea, Taiwan, Hong Kong, and Macau still restricting some products as of mid-2025.

DECOMMISSIONING STATUS REPORT

As an increasing number of nuclear facilities either reach the end of their operational lifetime or close due to excessive lifetime extension costs, timely decommissioning is becoming a key challenge.¹²

- ➔ The number of closed power reactors reached 218 units by mid-2025—five more than a year earlier and about one third of all reactors connected to the grid in the past 70 years. These had a total operating capacity of 110 GW. Over 100 units were closed in the past 20 years alone.

¹² - Note that the status of radioactive waste management is not part of this analysis.

- ➔ 195 units are awaiting or are in various stages of decommissioning. Of these, 96 are in the “warm-up stage”, 33 in the “hot-zone stage”, 24 in the “ease-off” stage, and 42 in “long-term enclosure”.
- ➔ Only 23 units—about 10.5 percent of the closed reactors—have been fully decommissioned, no change from a year ago: 17 in the U.S., four in Germany, and one each in Japan and Spain. Of these, only nine, or 4 percent of all closed reactors, have been released from regulatory oversight as greenfield sites.
- ➔ The average duration of the decommissioning process is about 20 years, with a large range of 6–45 years (both extremes are for reactors with very low power ratings of 22 MW and 63 MW, respectively).
- ➔ To date, four of the early major nuclear states—Canada, France, Russia, and the U.K.—are yet to fully decommission a single reactor.

POTENTIAL NEWCOMER COUNTRIES

Potential Newcomer Countries with Active Reactor Construction

There are three potential newcomer countries with active reactor construction: Bangladesh, Egypt, and Türkiye. All the projects are implemented by the Russian nuclear industry.

Bangladesh. Two reactors of the Russian VVER design have been under construction since 2017–2018. They were scheduled to start up in 2023 and 2024. Sanctions have reportedly led to delays in the delivery of some equipment, and the commissioning of Unit 1 had been pushed back to December 2024, which also passed. In April/May 2025, employees of the local building company went on strike, followed by the dismissal of at least 18 engineers. The commissioning date of the plant is uncertain.

Egypt. Construction of the first nuclear power plant comprising four VVER-1200 reactors was launched at the El Dabaa site on 20 July 2022, even as the war in Ukraine was ongoing. Building of Units 2, 3, and 4 began in November 2022, May 2023, and January 2024, respectively. Startup of the first unit was previously planned for 2026 but has been pushed back to 2028.

Türkiye. Construction of the first of four VVERs started in April 2018, with Units 2–4 following in April 2020, March 2021, and July 2022, respectively. The first unit was to start operating in 2023 but that has been delayed several times. Current estimates are contradictory, putting commissioning at late 2025 or delayed again into 2026. There were multiple reasons for delays including technical issues on site, impacts of sanctions, and a wave of staff illnesses. In the latest development, as of mid-2025, reportedly 10,000 of 14,000 Russian employees returned home because they had not been paid.

Potential Newcomer Nuclear Countries in Africa

Only South Africa operates two aging reactors in continental Africa (see [South Africa](#) in Annex 1). China and especially Russia have been the most aggressive promoters of nuclear power on the continent. More recently the U.S. also started promoting nuclear technology on the continent, often marketing SMRs. These efforts focused on economically stronger

countries such as Ghana and Kenya, with which the U.S. concluded nuclear agreements in the past year. China in turn is also involved in the implementation of large non-nuclear projects, solar in particular, on the continent.

Ghana. The country has set up a Nuclear Regulatory Authority, the Ghana Atomic Energy Commission with a Nuclear Power Institute and the company Nuclear Power Ghana to develop the first nuclear power plant project. The U.S. considers Ghana an important ally in the region, and a U.S.-Japan initiative aims at establishing Ghana as an African leader in SMR rollouts. While Ghana's representative stated at the 2024 IAEA General Conference that "Corporation Framework Agreements" for an SMR and a large reactor had been signed, there are no official public documents and no company has communicated on the issue. Also, the country's total installed power generating capacity of around 5 GW would not allow for the integration of a large reactor.

Kenya. The country has set up an official Nuclear Power Energy Agency (NuPEA) and plans to start construction of a large reactor in 2027, which in turn has amplified opposition from local communities and non-governmental organizations as well as parliamentary opposition. In a surprise move, in early 2025 the government announced its intention to dissolve NuPEA in the framework of a major restructuring of state institutions and relocate its functions elsewhere. Nuclear projects will not go far with the allocated budget of less than US\$6 million for FY2025/2026.

Nigeria. The country signed nuclear cooperation agreements with several countries and considered the option of developing up to 4 GW of nuclear capacity. An official of the Nigerian Atomic Energy Commission presented in late 2024 a proposal to start building a nuclear plant by 2028/2029 with startup scheduled for 2034. Despite these pronounced ambitions, it is telling that the 2024 Nigeria Integrated Resource Plan, the country's official roadmap for electricity generation, has not included any nuclear power in its projections to 2045. There is indeed no indication that Nigeria has in the past year moved any closer to implementing a nuclear power program.

Uganda. The country offers a striking illustration of the disconnect between reality and plans for nuclear development: the Ugandan government in May 2025 reaffirmed its intent to build 24 GW of nuclear capacity, 12 times the country's total installed capacity as of mid-2024, and signed contracts for 26-month pre-feasibility studies with several Korean companies. How this could possibly fit with the timetable for the startup of a large reactor by 2031, as indicated by the minister in charge, remains a mystery.

Case Studies: Italy and Poland

Italy. The country was one of the first ones to start operating a nuclear power plant in 1963, Latina, which operated until November 1986. One year later, the Italian people, shocked by the Chernobyl disaster in 1986, decided in a national referendum to abandon the commercial use of nuclear energy. No reactor has generated power after the referendum, and Italy became the first of now five countries to phase out the use of an active commercial nuclear program. A second referendum was held in June 2011, only three months after the Fukushima disaster started

unfolding. Then-President Berlusconi had planned to reintroduce nuclear power and had passed legislation to allow for nuclear newbuild, but 94 percent of Italian voters rejected the law.

Fourteen years later, Giorgia Meloni's government contemplates the reintroduction of a nuclear program, while decommissioning of the facilities of the first program is still ongoing and there is no site for a final nuclear waste repository yet. The government has set up a National Platform for Sustainable Nuclear (PNNS) and its National Energy and Climate Plan (NECP) sees "great potential to develop new nuclear technologies for Italy." A "with nuclear" scenario sees nuclear power covering around 11 percent of the electricity demand in 2050. Three major energy companies established Nuclitalia to assess market opportunities with an initial focus on SMRs. A Bank of Italy assessment warns about "the uncertainty surrounding the technologies chosen, most of which are not yet available for commercialization," and calls for "a cautious approach that also prepares and promotes alternative strategies".

Poland. The country already attempted to start a nuclear program; two reactors had been under construction for two years, when the Chornobyl disaster began in April 1986, which led to the abandonment of the project. Poland is one of a number of countries that started building their first reactors but abandoned prior to completion. There were several failed attempts to restart a nuclear program. The latest Polish Nuclear Power Program released for public consultation in early 2025 targets the deployment of 6–9 GW of nuclear capacity with somewhat unclear timelines. Original construction start dates were delayed, and as of December 2024, first concrete for the first unit was scheduled for 2028 with the aim of consecutive grid connections of the first three Westinghouse AP-1000 units with up to 3.75 GW between 2036 and 2038. Westinghouse has partnered up with U.S. construction giant Bechtel and the Polish state-owned project company Polskie Elektrownie Jądrowe (PEJ). Cost estimates have doubled since 2022 to over US\$48 billion. A second large-reactor project led by Korean KHNP and various SMR designs are also being discussed but remain in earlier stages.

Other Examples

An increasing number of countries are declaring plans to introduce nuclear power programs. Many of these claims either lack credibility or imply timeframes that are at this point irrelevant for an annual report on the industry. Early potential newcomers include Ecuador, Estonia, Indonesia, Jordan, Kazakhstan, Saudi Arabia, and Uzbekistan that are briefly analyzed hereunder.

Ecuador. In the fall of 2024, a senior member of government had unveiled an "ambitious roadmap" to deploy a 300-MW reactor by 2029, with a 1-GW reactor to follow in the longer term. No official document is available. The country has no regulatory framework and no institutions like a nuclear regulator or a nuclear waste management agency, and it is very uncertain whether the national grid could deal with a nuclear plant of any size.

Estonia. In 2023, an interministerial Nuclear Energy Working Group (NEWG) concluded that the introduction of nuclear energy in Estonia was feasible and that SMRs with a capacity of less than 400 MW would be suitable for the country. While a resolution supporting the adoption of nuclear energy allowing for the drafting of appropriate legislation was adopted in parliament

in June 2024, it saw 27 of 68 MPs voting against (25) or abstaining (2). This was an unexpected political signal in the very early stages of the potential introduction of a nuclear program.

Indonesia. Indonesian government representatives have long been talking about nuclear power plans. More recently, a senior official told the media that Indonesia was planning to operate 10 GW of nuclear capacity by 2040 and that companies from various countries “have shown interest”. The country is looking for IAEA assistance to develop a comprehensive roadmap towards a nuclear program but seems a long way from actually building reactors.

Jordan. Set up in 2008, the Jordan Atomic Energy Commission developed various plans for the construction of large nuclear reactors in what is one of the water poorest countries in the world. Ten years later, these plans were abandoned, and the focus has since been redirected to SMRs. Jordan has so far not selected a design, vendor, site, or completed a financing package, let alone started building any nuclear power plant, small or large.

Kazakhstan. The country is one of five to have discontinued the use of nuclear power in the past. It has been the world’s leading uranium producer for more than a decade. The restart of a commercial nuclear power program has been contemplated for the past two decades. In a national referendum held in October 2024 about 71 percent of the votes expressed support for a nuclear program. In the months before, civil society movements staged various forms of protest against the plan. In March 2025, the President created the national Atomic Energy Agency by decree. In June 2025, the agency announced Rosatom as the supplier of the first new Kazakhstani nuclear plant and a forthcoming agreement with China for a second plant.

Saudi Arabia. The King Abdullah City for Atomic and Renewable Energy (KA-CARE) was established in 2010. In September 2024, a government representative stated that “the Kingdom is moving towards utilizing nuclear energy.” But not much progress has been made over the 15 years since the establishment of KA-CARE. In the meantime, over the past decade alone renewable energy capacity has grown by a factor of 200, from 24 MW to 4.7 GW in 2024 (90 percent solar), yet it still represents only 2.2 percent of power generation.

Uzbekistan. In May 2022, officials announced that a site for the construction of two Russian-designed VVER-1200 reactors had been chosen. Subsequently, the plan was apparently abandoned in favor of an SMR project. Reportedly, in May 2024 the government signed an agreement with Russia’s Rosatom to build six 55-MW Small Modular Reactors (SMRs) in the eastern Jizzakh region. In April 2025, Rosatom announced that onsite work had begun to set up production facilities, administrative buildings, and warehouses for the SMR cluster. By June 2025, the project had circled back to include large units.

RUSSIA NUCLEAR INTERDEPENDENCIES

Russia is a major global supplier of nuclear fuel services, including uranium mining, conversion, enrichment, and fuel assembly fabrication for Soviet-designed VVER pressurized water reactors, of which there are 19 in the E.U. and 15 in Ukraine. Since Russia’s full-scale invasion of Ukraine in February 2022, E.U. members and others in the region have discussed and taken measures to deprive Russia of the considerable revenue streams provided by such businesses and reduce the inherent risk of the region’s dependence on Russia. While the U.S.

banned the import of uranium products from Russia in May 2024—to which Russia responded in November 2024 with a tit-for-tat restriction on enriched uranium exports—the E.U. has not established any sanctions in the nuclear sector, a strong indicator of its dependency on Russia. However, the dependency is multifaceted; Russia is also dependent on the West for European companies' cutting-edge technology used in its reactors, and business interests of these same companies have certainly contributed to the prevention or delays of sanctions.

In 2024, U.S. imports of enriched uranium from Russia dropped by about half compared to 2023, while imports from China grew to the sixth largest in 2023–2024 after zero imports in 2020–2022. In the E.U., Rosatom's share decreased in 2024 after a spike in 2023 in the three categories natural uranium, uranium conversion, and uranium enrichment, but it still provided 16–24 percent of the respective services in 2024 compared to a 23.5–38 percent share in 2023. Imports of fuel assemblies for 17 Soviet-designed VVERs in four E.U. countries—Czechia, Finland, Hungary, and Slovakia (Bulgaria with its two units is not included)—have also declined in 2024 to 438 tons from a peak of 573 tons in 2023, though they still exceed the 314 tons in 2022. Four of the five countries, except Hungary, have signed supply contracts with Westinghouse, the only operational alternative, so far, to Rosatom subsidiary TVEL for VVER fuel. In addition, four of the five, excluding Finland, have signed contracts with EDF subsidiary Framatome for VVER fuel. However, Framatome does not yet have any operational manufacturing plant. A Lyon-based Russian-French joint venture chose Framatome's Lingen site in Germany for a VVER-dedicated fuel-assembly production-line project that ran into political problems with the German authorities and significant public opposition that, one year later, still remain to be resolved.

The long-standing business relations between Framatome, its partner Siemens Energy, and Rosatom create a mutual dependency, including significant Russian dependence on the West which may get increasingly relevant when further sanctions are considered. For at least a decade Russia has received from Framatome and Siemens Energy Instrumentation & Control (I&C) technology not only for the initial construction but also modernization and servicing of existing reactors which last long into the future. The most recent reported case involves a Framatome I&C system, due to be fully installed at the newbuild Kursk II nuclear power plant (two units under construction) by the end of 2025.

With the exception of one Chinese project in Pakistan and one “first concrete” in South Korea, Rosatom implemented all 16 nuclear power reactor construction sites started outside China over the past five years and a half, and providers of parts, e.g., France's Arabelle turbines, do not have any other foreign customer besides Rosatom.

SMALL MODULAR REACTORS (SMRs)

The first time WNISR published a [chapter dedicated to SMRs](#) it read: “One reaction to the decline of nuclear power from the nuclear industry and other proponents has been to advocate what it terms ‘advanced reactors’. (...) In the last decade, the overwhelming focus of this effort has been on what are called Small Modular Reactors (SMRs).” That was in 2015, a decade ago. The conclusion then was: “For decades, small modular reactors have been held out as holding great promise for expanding nuclear power into various new markets. Remarkably similar

claims have been made by the nuclear industry in multiple countries. Nowhere have these claims come true.” Today, the conclusion is very similar, except that the gap between hype and industrial reality has never stopped growing.

A significant development is that multiple governments are now spending large amounts on SMRs, and international organizations and financial institutions are starting to make financing available. Some startups are also raising increasing amounts of private money, even if generally only complementing generous public matching grants. The OECD’s Nuclear Energy Agency (NEA) has estimated the total public/private funding made available worldwide for SMRs at US\$15.4 billion. The NEA included 74 SMR designs in its SMR dashboard of a total of 127 it has counted, which means the amount would be thinly spread, unless a large number of designs are abandoned. Just one company, NuScale, has already invested around US\$2 billion and has still not started any construction anywhere.

Country-by-Country Status Overview

Argentina. The CAREM-25 project had been under construction since 2014. Construction was halted in spring 2024 due to budget cuts. By September 2024, 470 workers had been laid off, and in December 2024, the president of the National Atomic Energy Commission (CNEA) declared the end of the project as “this reactor is not economically competitive.” Another SMR design also under development in Argentina called ACR-300 is now the focus of attention. A former CNEA president commented that “this kind of announcement of the Argentine government is to say something for people [to] cheer” because the ACR-300 “has no engineering detail of any kind.”

Canada. In April 2025, the Canadian Nuclear Safety Commission (CNSC) approved a license request by Ontario Power Generation (OPG) for the construction of a BWRX-300 reactor designed by GE-Hitachi at the Darlington site. This is significant as it represents the first SMR construction license in the Western world for a design that has not yet been built anywhere. Grid connection is scheduled for 2030. In May 2025, the Ontario Government approved OPG’s plan to spend US\$5.6 billion on stage one of the project that shall ultimately include the construction of three more BWRX-300 units with a total investment of US\$15.2 billion. Various other SMR projects in early stages are also under consideration in other provinces.

China. The country is operating or building two kinds of SMRs, a high-temperature gas-cooled reactor design called the HTR-PM and an integral pressurized water reactor design, the ACP100 (or Linglong One). There is little to no information available as to the operational experiences with the two HTR-PM modules. The nominal capacity has been reduced by one quarter from combined 200 MW to 150 MW for unknown reasons. No reliable information is available on its performance. The second design, called ACP100, has been under construction since July 2021 with scheduled startup by May 2026.

France. In mid-2024, EDF announced that it had suspended and reoriented the development of its project called Nuward towards “a design based on proven technological building blocks.” Soon after the announcement, TechniAtome, France’s nuclear submarine reactor maker, pulled out of the project consortium. In January 2025, the EDF subsidiary Nuward revealed that the new design would be a 400-MW reactor and offer an option for cogeneration (up to about

100 MWt). The power rating would exceed the limit of 300 MW usually attributed to the SMR definition, and the concept is in its very early pre-basic-design phase.¹³

India. The Indian government in February 2025 announced that there would be “at least five indigenously developed SMRs” in operation by 2033. There have also been announcements about imported SMRs. Whether small or large reactors, India’s plans to build or import nuclear technology have mostly not materialized. In addition, the many challenges confronting SMRs, especially their lack of economic viability, render the ambitious construction plans quite unrealistic.

Russia. Russia is building both light water and fast neutron SMRs, with a special focus on barge-mounted reactors for coastal locations. Two 30-MW “floating reactors”, the Akademik Lomonosov, were started up in December 2019 and have been underperforming since. At least two more barge-mounted projects are underway. Construction on a different, land-based SMR project, a lead-cooled fast reactor design called BREST-300, started in June 2021. The projected startup date has been delayed to 2028.

South Korea. In 2012, the System-Integrated Modular Advanced Reactor (SMART), a PWR design, received the safety authority’s approval, but did not find any buyers. Another design called the i-SMR is in early stages of development. The regulator has yet to receive an application for standard design approval, currently not expected before 2028, with plans to start construction delayed to 2031.

United Kingdom. Since 2014, Rolls-Royce has been developing the “UK SMR”, a (now) 470-MW reactor (exceeding the size-limit of 300 MW for the generally adopted SMR definition). The regulator is currently carrying out a Generic Design Assessment (GDA) that is scheduled to be completed by December 2026. Two other SMR designs are under GDA: Holtec’s SMR-160 and GE-Hitachi’s BWRX-300. Westinghouse and EDF had withdrawn from the competition. The U.K. Government has pledged a significant US\$3.4 billion for the overall SMR program aiming at the commissioning of three units in the mid-2030s.

United States. The Department of Energy (DOE) is the largest funder of SMR development in the U.S. and awarded a combined US\$2.8 billion in matching grants to X-energy, TerraPower, and Kairos Power. In November 2024, Kairos Power received a permit to build a facility with two 35-MWt test reactors called Hermes-2. While this permit is explicitly for a non-power facility (and thus excluded from WNISR statistics), theoretically the reactors could later be transformed into a power plant, upon approval of necessary license amendments. In May 2025, the Tennessee Valley Authority (TVA) submitted a permit application to the regulator to build a GE-Hitachi BWRX-300 SMR. In March 2024, TerraPower had submitted its application to build a 345-MW fast reactor called Natrium—exceeding the size-limit of the SMR-definition—in Wyoming. However, only one design, NuScale, has received a Standard Design Approval from the regulator but is not yet under construction anywhere in the country.

¹³ - In late August, early September 2025, the French economic press reported that Newcleo, the largest nuclear startup in Europe, was running out of cash and that a second SMR-focused startup, Naarea, has already declared insolvency.

CHALLENGES OF INTEGRATING NUCLEAR POWER INTO THE ENERGY SYSTEM

This topical focus chapter examines the systemic implications of the fundamental differences between nuclear fission and renewable energy technologies and their respective roles within the overall energy supply and consumption systems.

New Energy Technologies Disrupt Markets and Systems

The declines in unsubsidized costs observed in photovoltaics, batteries, and power electronics over the past decade are unparalleled in the history of energy technologies. This has led to a spectacular acceleration of deployment. However, the new energy technologies are not merely replacing the old ones, they are fundamentally changing the logic of the system. As electricity becomes the central energy carrier, its generation becomes increasingly decentralized, and fluctuating wind and solar require the development of new flexibility options.

Nuclear Power Plants Need to Be Large

Due to several physical laws, thermal and mechanical devices are intrinsically more efficient, e.g., for power generation, when they are larger. These basic characteristics as well as the constant search for economies of scale have led to ever increasing average sizes of nuclear power plants. They also make the search for an economical small reactor rather illusory. The idea of replacing economies of scale by economies of series production cannot compete with the advantages of mass production in the renewable energy sector. Over the past 20 years, an average of five reactors per year started up. If it was possible to increase the construction frequency by a factor of 10 or even 100, the series would remain very small in terms of industrial mass production. For comparison, a modern solar factory can produce two *billion* photovoltaic cells per year.

Photovoltaics—Essentially Electronic and Extremely Scalable

The real price of solar modules declined by 99.6 percent between 1976 and 2019. The conversion efficiency from solar radiation to electricity is currently around 20 percent, and next mass-market technologies already reach up to 35 percent in the lab. Gains in efficiency caused by advances in nanoscience-based material research are the main driver of solar electricity cost reductions. While production costs per module area may not further decrease substantially, efficiency is expected to continue to improve considerably. Solar cells have around 5–6 Watts each and can be assembled to modules of various sizes (medium size about 1.8 m² and 400–700 Watts) and any number of modules can make electricity generating facilities of any size.

Underestimated Power Electronics

Wind turbines, electric cars, photovoltaic devices, and efficient electric motors would not be possible or would have a hard time competing against traditional systems without modern,

semiconductor-based power electronics. Thanks to an improving understanding of the processes involved at the nanoscale and the development of new materials, the power density of power electronics devices has increased by a factor of 1,000 over the past 25 years. Power electronics are at the core of the upcoming digitally controlled network that allows for highly efficient power flows in all directions, flexibly adapting to the demands and offers of millions of power producers and consumers.

Wind Power's Breakthrough with Power Electronics

Since the late 1990s, advancements in power electronics have enabled the complete decoupling of generator speed from the frequency of the power delivered to the grid. Furthermore, digital controls facilitate the continuous optimization of the blade pitch, thereby ensuring maximum rotor efficiency in variable wind conditions.

Renewable Power Generation—Unbeatably Cheap

Two recent authoritative, comparative assessments of the Levelized Costs of Energy (LCOE), i.e., the costs per kilowatt-hour over the lifetime of a facility, show a clear advantage of solar and wind power generation over traditional competitors. In a detailed study for Germany, the Fraunhofer Institute concluded that in 2024, utility-scale PV plants in southern Germany could produce at US\$4.5/kWh, whereas small rooftop installations, delivering at the retail level, at US\$6.8/kWh. Compared at the retail level, PV rooftop electricity costs were lower than the costs of PV utility scale if distribution costs were added. Onshore wind power came in at US\$4.7/kWh for good locations. The lowest estimates for natural gas were US\$9.6/kWh, for lignite US\$16.4/kWh, for hard coal US\$18.8/kWh, and for nuclear US\$14.8–53/kWh. In the U.S., according to Lazard, LCOEs for onshore wind are at US\$3.7/kWh, for PV utility US\$3.8/kWh, for offshore wind US\$7/kWh, and for PV residential and commercial US\$8.1/kWh, while the lower end for U.S. nuclear was at US\$14.1/kWh (3.7 times as much as utility solar) and for gas peakers US\$14.9/kWh. With US\$3.4/kWh, purely operational costs for nuclear power plants are in the range of onshore wind and utility PV.

Battery Costs Reach a Tipping Point for the System

Retail prices for ready-to-use home storage kits now start at US\$200/kWh. Assuming levelized costs of storage between US\$3.4/kWh and US\$8.9/kWh (based on actual offers on the market) and that 100 percent of the electricity generated by rooftop PV is being stored to be delivered at any time during the following 24 hours, taking Fraunhofer's lower values for rooftop PV in southern Germany quoted earlier and applying the two indicated levelized cost estimates leads to an overall cost for solar power delivered around the clock of US\$9.7–15.2/kWh—the latter corresponding to about half of the present utility power retail price in southern Germany. In reality, the storage need is of course much lower than 100 percent, which makes the option even more compelling. In China, a December-2024 auction reaching a price level of US\$66/kWh of storage capacity has demonstrated what this means on the large scale: storing one kWh for about one cent.

The price decline has led to a surge of stationary storage capacity, growing with a compounded annual growth rate of 58 percent in Europe between 2022 and 2024. However, the vast majority of batteries, about 85 percent, are being used in cars. As most cars are sitting idle for over 90 percent of the time, the electric vehicle fleet has an extraordinary potential if bidirectional charging becomes the norm. If all cars in Germany were electrified, their batteries could power the country for two days of current consumption.

Nuclear Power and the Imperatives of the Energy System

Nuclear Power and the Climate Emergency. Nuclear power's much longer lead times and far higher costs per MWh, compared to modern renewables, mean new nuclear plants will save less emissions per dollar as well as per year (see [Climate Change and Nuclear Power in WNISR2019](#)).

Lifetime Extensions. Upgrading and uprating existing reactors is possible but expensive and limited in scope. The output of a nuclear reactor can be increased by little more than 20 percent while repowering of wind turbines frequently doubles or triples their output. Repowering solar plants to double output is becoming attractive as well.

New Nuclear Reactor Designs. New concepts cannot eliminate the basic cost drivers: safety and security issues linked to the elementary nuclear forces involved and the inherent drive for size in thermal power plants, whatever primary energy they operate on.

Nuclear as a Dispatchable Power Source. For technical and economic reasons, nuclear plants do not provide the type of flexible, dispatchable power that can fill the gaps between solar and wind power peaks. They also need flexibility from other sources to bridge considerable planned and unplanned outages and for buffering services between changing demand and their inflexible full-load operation.

Nuclear Power and Data Centers. Building new nuclear plants for data centers appears incoherent. Time horizons do not match: while data centers need power in the short term, nuclear power plants need many years to develop, plan, and build; competing solar power plants can be set up within months (see also [Nuclear Power vs. Renewable Energy Deployment](#)).

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

A mix of contradictory trends has marked the year 2024. On the one hand, in most regions, inflation, rising interest rates, growing political uncertainties, regulatory stagnation, and declining investor confidence provided a more difficult environment for the energy transition. On the other hand, declining prices and advancements in key technologies have been encouraging and have opened new perspectives. In the first months of 2025, these trends became even more pronounced. For example, in April 2025, global solar electricity generation exceeded monthly nuclear power generation for the first time and kept doing so in May and June 2025.

Investment. For two decades, global investments in renewable power generation have exceeded those in nuclear energy—which hardly changed over the past decade—and are now 21 times higher. In 2024, solar PV saw the strongest growth at 22 percent compared to 2023. Wind power investments have shown lesser resistance to an accumulation of issues, including interest rate increases, inflation, supply chain pressures, as well as regulatory and political uncertainties, and have declined by 16 percent over the same year. Total investment in non-hydro renewable electricity capacity in 2024 was estimated at US\$728 billion, up eight percent compared to the previous year. Most remarkable, however, is the 2024-surge in minor markets: Asia-Pacific, excluding China and India, +81 percent; Central and Southern Africa plus Europe, excluding the E.U. and U.K., +85 percent; and the Americas, excluding the U.S. and Brazil, +167 percent.

Installed Capacity. Solar and wind capacity grew by 452 or 32 percent and 113 GW or 11 percent, respectively, with grid scale battery capacity jumping 113 percent to 126 GW, according to the Energy Institute. These numbers compare with a net addition of 5.4 GW nuclear capacity between new startups and closures.

Electricity Generation. In 2021, the combined output of solar and wind plants surpassed nuclear power generation for the first time. In 2024, wind and solar facilities generated over 70 percent more electricity than nuclear plants. The evolution of the global electricity supply system since 2000 shows that coal's part peaked in 2007 at 41 percent and declined to 34 percent in 2024, while renewables' share (including hydro) increased from 19.4 percent to 31.6 percent between 2010 and 2024 alone. Over the same period, nuclear contribution fell from almost 13 percent to 9 percent.

In 2024, wind power generation grew by 8 percent or 188 TWh to 2,486 TWh—getting close to nuclear's new record generation of 2,677 TWh—and solar output grew by 28 percent or 461 TWh to 2,091 TWh net. Total non-hydro renewable power generation increased by 670 TWh, which—and that is the bad news—covered only 52 percent of the global increase in electricity production of close to 1,300 TWh.

Nuclear power generation grew by 3 percent or 80 TWh. The new global record is marginally above the previous 18-year-old record (see above) but remains almost 14 percent below the 2006-generation level outside China, a significant decline.

Negative Power Prices and Batteries. The rapidly increasing deployment of stationary Battery Energy Storage Systems (BESS) might be a gamechanger for the increasing lack of flexibility in the grid systems. Negative power prices indicate temporary overproduction and illustrate the system's difficulties in coping with fluctuating renewables. The number of negative hours across all power markets in continental Europe shot up by a factor of 10 between 2022 and 2024.

The acceleration of grid-scale BESS installations is impressive. Over 80 percent of the overall BESS capacity has been added in the past three years. The average annual global growth rate jumped to 115 percent between 2021 and 2024, with large geographical variations, achieving a total BESS capacity of 360 GWh. The grid integration of 350 GWh “batteries-on-wheels” in the U.S. alone would almost double global capacity and illustrates their huge potential.

Boom Behind the Meter. Decentralized PV installations represent significant shares of solar installations. On the global average, 42 percent of total solar capacity added in 2024 were rooftop systems. China, which had pushed the rooftop market share to 58 percent in 2022, scaled back to 44 percent in 2024. With the dramatic decline in costs of batteries, an increasing number of stakeholders—households, businesses, services, farmers—decide to add storage to their solar system. Many, especially in some Asian and African countries, are not connected to the grid. This has created some statistical uncertainty about the real scope of the ongoing transformation.

China. In 2024, China alone accounted for 40 percent of the global solar electricity generation, and the same is true for wind. But solar grew by 44 percent, more than three times as fast as wind which increased 13 percent. In contrast, China's nuclear output accounted for 16 percent of global nuclear electricity production and grew only by 3.7 percent. As other sources have been growing so much faster, the nuclear share in power generation dropped slightly for the third year in a row to 4.5 percent in 2024, when solar and wind alone generated over four times more power than nuclear. Renewables, including hydro, increased from 18.7 percent in 2010 to 33.7 percent in 2024, while coal peaked in 2007 at 81 percent and declined to 57.8 percent in 2024.

European Union. In 2024, wind contributed 485 TWh or 17 percent to the overall electricity generation, while solar contributed 300 TWh or 11 percent. Fossil fuel generation has dropped to 793 TWh, hardly more than wind and solar combined. The wind plus solar contribution of 28 percent to the total electricity production, not only outcompetes nuclear's 23-percent share in the E.U., but is also much higher than in China (18 percent) or the U.S. (17 percent) and nearly twice the global average (15 percent). The E.U. nuclear output increased slightly year-on-year (+28.5 TWh) due to the partial recovery of the French nuclear fleet (+41.3 TWh). In other words, outside France nuclear power generation declined by 13 TWh.

India. Solar capacity grew by 24 GW (33 percent) and wind by 3 GW, while solar power generation increased by 20 TWh and wind generation stagnated. A new reactor with 0.63 GW was connected to the grid early in the year, and nuclear generation increased by 6 TWh to a total of 52 TWh. Solar generated 135 TWh, 2.6 times the nuclear output, and wind produced 81 TWh, which is 56 percent more than the nuclear fleet.

United States. Wind and solar in 2024 have grown, respectively, by 3.5 percent and 28 percent in capacity and by close to 8 percent and 27 percent in electricity generation. Combined, wind with 453 TWh and solar with 303 TWh, are approaching nuclear power's rather stable output of 782 TWh, the same level as already achieved in 2005. In recent years, Texas, a conservative, Republican-run oil state, has become the epicenter of stationary battery growth. By the end of 2024, Texas had an installed capacity of almost 10 GW of grid-connected batteries, expected to double in 2025 to 20 GW. Only three years earlier, in 2022, battery capacity stood at 2.8 GW. At the same time, Texas has been building up around 40 GW of solar and wind each and retiring fossil-fueled plants; notably, 7.3 GW of coal and gas closed between 2018 and 2023. It remains uncertain to what extent the current Trump administration's pro-fossil fuels and pro-nuclear policies will impact the energy transition efforts on state level.

INTRODUCTION

The World Nuclear Industry Status Report 2025 (WNISR2025), more than ever, documents the widening and deepening gap between public perception and reality of the status and trends of the nuclear industry. The number of operating reactors is identical to a year ago as described in WNISR2024. Following the completed nuclear phaseout in Taiwan, there are less countries operating nuclear power plants. With France completing its last reactor under construction (third largest fleet in the world), Argentina abandoning a construction project it started in 2014, and Pakistan being the only additional country starting construction, there are fewer countries in total building power reactors. The average age of the world's fleet keeps increasing.

Several governments announced major policy changes, financial commitments, and legal or regulatory changes in favor of operational lifetime extensions and nuclear newbuild. In some cases, public matching funds now attract significant private capital into design development. Remarkably, in some countries, there are initiatives to restart reactors that had been formally closed. The first case where operational status of a closed unit has been reinstated by a national regulator (in July 2025) was the Palisades reactor in Michigan, United States. Similar restart-from-closure initiatives in the U.S. involve Three Mile Island-1—the twin reactor of TMI-2 that experienced a partial meltdown in 1979—and Duane Arnold-1.

None of these initiatives, so far, have translated into trend changes. The only end-of-year 2024 or mid-2025 indicators that went up are entirely due to the 'China effect'. The total number of reactors under construction slightly increased due to new projects getting under way in China. The operating capacity and with it the nuclear power generation reached a new record high of 2,677 TWh in 2024, a marginal 14 TWh (0.5 percent) above the previous record in 2006. In fact, compared to 2006, nuclear power generation outside China in 2024 was lower by 363 TWh (14 percent)—the equivalent of the combined 2024 output of the 21 smallest of the then-32 nuclear countries. Even in China, nuclear newbuild is dwarfed by the phenomenal expansion of renewables, solar in particular. Reportedly, China installed about 100 solar panels every second to add 93 GW of solar capacity in the single month of May 2025.¹⁴ Over the entire year 2024, China started up just three new nuclear reactors with a combined capacity of 3.5 GW; solar panels generated almost twice as much electricity as the country's nuclear fleet, the second largest in the world.

The revamped traditional chapter **Nuclear Power vs. Renewable Energy Deployment** provides a detailed overview of the astonishing dynamic in the renewables sector, especially in combination with the soaring deployment of battery storage capacity and in comparison with the stagnating nuclear sector.

Eleven years ago, WNISR launched a first, modest attempt to look at system issues linked to the different characteristics of various power generating technologies (see **Paying to Produce** in WNISR2014). The analysis looked in particular at the issue of baseload power versus

14 - Noah Bennett, "China Shatters Global Energy Records: Historic Surge in Solar and Wind Power Redefines the Future of Clean Electricity", *Sustainability Times*, 1 July 2025, see <https://www.sustainability-times.com/energy/china-shatters-global-energy-records-historic-surge-in-solar-and-wind-power-redefines-the-future-of-clean-electricity/>, accessed 17 August 2025.

increasingly fluctuating production and economic implications of this. Ever since, the WNISR coordinator tried to design, and find a qualified author for, an in-depth assessment of the multi-layered, complex, increasing challenges of integrating nuclear power into a rapidly, drastically changing power system environment. The WNISR2025 offers just that, a 52-page assessment of the multiple *Challenges of Integrating Nuclear Power into the Energy System* as it emerges locally, regionally, nationally, globally. This chapter explains why renewables have turned into the undisputed drivers of the ongoing energy revolution. It has to do with physics, timescales, and economics. As Josephine Steppat, energy analyst at Montel Analytics, recently stated in a column on *Montel News*:

What is less understood is this is not just a policy debate but a clash of system logic. This makes nuclear power and renewables fundamentally incompatible as sources of energy in a modern grid. (...) Pursuing both new nuclear baseload and volatile renewables is not a coherent strategy – it is a conflict. The results: overcapacity, price collapses during renewables peaks, rising electric grid costs and inefficient investment on both sides.¹⁵

Updated and expanded country focus chapters on *China, Japan, Russia, South Korea, Ukraine* and the *United States* look into some of the major developments over the year. The chapter *Russia Nuclear Interdependencies* follows up on the *Russia Nuclear Dependencies* chapter in *WNISR2024*. The slight modification of the title is not a coincidence. The chapter documents why the dependency of Western nuclear companies on Russia as a client is (at least) as significant as their dependency on Russia as a supplier of materials and services. After all, the international market for nuclear reactors is a niche seller's market entirely dominated by Russia: all 13 construction starts outside China and Pakistan (where Chinese companies started building a reactor in late 2024) in the five years between 2020 and end of 2024 were implemented by Rosatom and its subsidiaries. If Russia was not buying the Western industries' equipment and components, who would?

The traditional chapter on *Small Modular Reactors (SMRs)*, in spite of overwhelming attention by policy makers and the media as well as a flurry of non-binding agreements, has little concrete progress to report. And while one construction *permit* has been issued in Canada, there is still not a single SMR under construction in the Western world (outside China and Russia). In fact, one SMR construction, in Argentina, has been abandoned in 2024, 10 years into the works. This makes the entire American continent, from Alaska to Cape Horn, currently nuclear construction free.

Many countries have signed nuclear cooperation agreements and have announced intentions to start national nuclear power programs. A selection of these initiatives can be found in the *Potential Newcomer Countries* chapter. Only three potential newcomers are in the course of building reactors (*Bangladesh, Egypt, Türkiye*); many plans fail the industrial and economic credibility test.

The *Fukushima Status Report* has been thoroughly upgraded, including a deep dive into the Japanese system that is supposed to guarantee food safety. The outcome is a description of a rather surprisingly disorganized system that makes it difficult or impossible to gain full

¹⁵ - Josephine Steppat, "Load vs Logic – Why Nuclear and Renewables Aren't a Match", *Montel*, 20 August 2025, see <https://montelnews.com/news/1ea628ee-ffaf-499f-ac4e-fc0538ecf4fi/load-vs-logic-why-nuclear-and-renewables-arent-a-match>, accessed 20 August 2025.

independent understanding of the pertinence of statistics and their analysis made available by the Japanese government and other stakeholders.

The *Decommissioning Status Report* now covers 218 closed reactors, almost one third of all the units ever connected to the grid over the past 70 years. From mid-2024 to mid-2025, five reactors closed and four started up. As of end of August 2025, two reactors had closed (Belgium and Taiwan), but only one reactor had started up since the beginning of the year (India). Only one in ten closed reactors (23) have been technically fully decommissioned, while just nine, or one in 24, of the sites have been returned to “greenfield” status, free for any use.

Editor’s notes: The WNISR’s general editorial deadline is mid-year. In some cases, when authors or editors catch information that is post-1 July 2025 but considered essential or contradicting other information in the text and time permitting, it has been added to the body of the text or a footnote with the update has been inserted.

Throughout the report, to the best of our ability, amounts in foreign currencies that were allocated, estimated or spent during the ongoing year are translated into US\$2025 by applying the monthly exchange rate as of June 2025—unless the amount is explicitly based on the value of a different year, in which case the yearly exchange rate of the corresponding year is applied.

Amounts in foreign currencies that were allocated, estimated or spent in past years are converted to the corresponding value by applying the yearly average exchange rate.

GENERAL OVERVIEW

WORLDWIDE

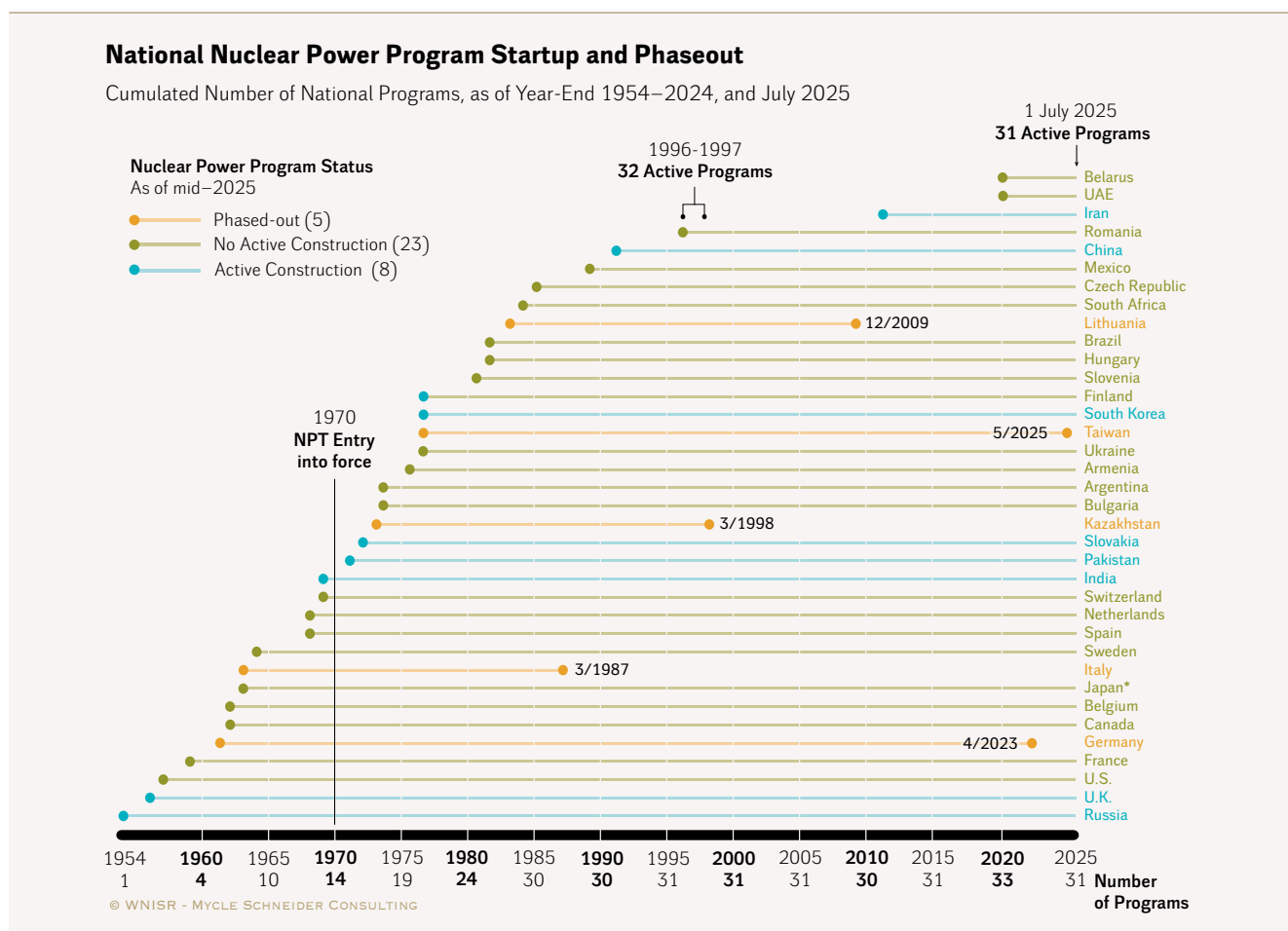
ROLE OF NUCLEAR POWER

The role of nuclear power in the global energy landscape is shrinking. As of mid-2025, there are fewer countries operating nuclear power reactors and fewer countries building reactors than one year earlier.

As of mid-2025, 31 countries operated nuclear power programs in the world. [Figure 1](#) illustrates how the spread of nuclear power throughout the world took place at a significantly slower pace and smaller scope than anticipated in the early 1970s:

- ➔ Fourteen countries had operating nuclear power reactors (grid connected) when the Treaty on the Non-Proliferation of Nuclear Weapons (commonly known as the nuclear Non-Proliferation Treaty, or NPT) entered into force in 1970.
- ➔ Sixteen additional countries were operating power plants by 1985, the year when reactor startups peaked.
- ➔ Five countries (China, Romania, Iran, United Arab Emirates, and Belarus) started up power reactors for the first time over the past 30 years, of which two in 2020.
- ➔ The number of countries operating power reactors in 1996–1997 reached 32. It took another 23 years to reach a new peak at 33 countries.
- ➔ Five countries (Germany, Italy, Kazakhstan, Lithuania, and Taiwan) abandoned their nuclear programs between 1987 and 2025, one more than in mid-2024.
- ➔ Eight of the 31 nuclear countries have active reactor construction programs, two fewer than as of mid-2024.
- ➔ Twenty-three nuclear countries—three quarters—are not constructing any reactors currently (or construction is suspended); of these, two have either nuclear phaseout or no-newbuild legislation (still) in place (Spain and Switzerland). Some of these program-limitation policies, such as in Belgium, the Netherlands, and Sweden, have been revised only recently. However, while policy changes in some countries reopen or open the door for nuclear newbuild, actual work on the ground remains many years away.

Figure 1 · National Nuclear Power Programs Development, 1954–2025



Sources: Various, compiled by WNISR with IAEA-PRIS, 2025

In 2024, the world nuclear fleet generated 2,677 net terawatt-hours (TWh or billion kilowatt-hours) of electricity¹⁶, (see Figure 2). After a decline in 2020, nuclear production increased by 4.2 percent in 2021, dropped by 4.4 percent in 2022, increased by 2.2 percent in 2023 and again by 2.9 percent in 2024. It is the highest production ever, the previous record being 2,663 TWh in 2006. China, with a 3.7-percent increase (compared to 11.3 percent in 2021, 2.5 percent in 2022 and 4.1 percent in 2023), produced more nuclear electricity than France for the fifth year in a row, and remains in second place—behind the U.S.—of the top nuclear power generators. Nuclear production outside China increased by 2.8 percent, to break even with the level of global production already reached in the mid-1990s prior to China’s nuclear buildout.

If global nuclear generation exceeded the previous record by modest 14 TWh, hardly more than what a single of the largest reactors can nominally generate annually, outside China, nuclear generation in 2024 was by 363 TWh below the 2006 level, a whooping 13.6-percent plunge.

16 - If not otherwise noted, all nuclear capacity figures throughout the report are based on International Atomic Energy Agency (IAEA) Power Reactor Information System (PRIS) online database, see <https://prisweb.iaea.org/Home/Pris.asp>, and production figures are net from Energy Institute, “Statistical Review of World Energy 2025–Data”, 2025, and “Statistical Review of World Energy 2025–Consolidated Dataset”, June 2025, see https://www.energyinst.org/_data/assets/excel_doc/0006/1656348/Statistical-Review-of-World-Energy-Data.xlsx. Faced with numerous inconsistencies over the years, WNISR moved from IAEA-PRIS to Energy Institute statistics for nuclear production data.

Nuclear energy's share of global commercial gross electricity generation in 2024 was almost stable at 9 percent (−0.13 percentage points)—the lowest value in four decades—and remained over 45 percent below the peak of 17.5 percent in 1996.

Nuclear's main competitors, non-hydro renewables, grew their gross output by 14.1 percent and their share in global gross power generation increased by 1.5 percentage points to 17.3 percent.

Non-hydro renewables, including mainly solar, wind and biofuels, continued their growth, with a 12.5 percent increase, to reach a share of 8.9 percent in primary energy. While the share of non-hydro renewables is now more than two times larger than the nuclear share of 4 percent, both figures illustrate how modest the current contribution of both technologies remains in the global context.

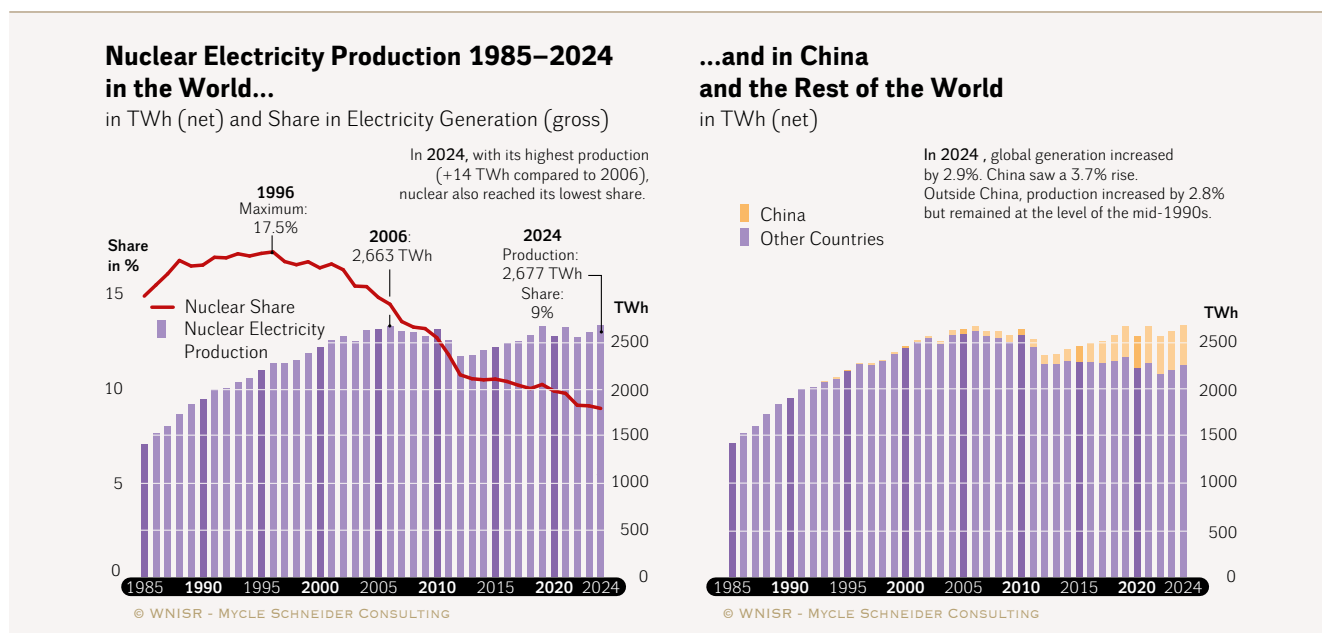
In 2024, there were five countries—compared to nine in 2023—that increased the nuclear share in their respective electricity mix, including two “newcomer countries”, the United Arab Emirates (UAE) and Belarus, which generated nuclear power for the first time in 2020, while five decreased the share, and 22 remained at a constant level (change of less than 1 percentage point). Besides the UAE and Belarus, six countries (Argentina, China, India, Iran, South Korea, Pakistan) achieved their largest ever nuclear production. China and India started up new reactors during the year, and South Korea connected one unit to the grid in December 2023, which only impacted production in 2024.

The following noteworthy developments for the year 2024 illustrate the continued volatile operational situation of the individual national reactor fleets (see country-specific sections for details):

- ➔ **Argentina's** nuclear production increased again by 16.5 percent following a 20-percent jump in the previous year and reached the level of 2021 preceding major maintenance outages in 2022.
- ➔ **Belarus** has seen another increase of 34 percent, after the 150-percent increase in nuclear generation in 2023, due to the startup of Belarusian-2 and improved operation of Unit 1.
- ➔ **Belgium's nuclear generation**, following a 25-percent decline in 2023, partially due to the closure of one unit early in the year, dropped again by more than 5 percent, and will continue to decrease significantly with the scheduled closure of three more reactors.
- ➔ **China** started up three units like in each 2022 and 2021 but only one in 2023, with nuclear generation increasing 3.7 percent, the third year in a row around 4 percent, following an 11.2-percent surge in 2021.
- ➔ **Finland** saw a 5-percent drop following a 35 percent increase in nuclear generation in 2023 due to the beginning of the commercial operation of the largest nuclear reactor in the country, Olkiluoto-3. The country's flagship reactor had a disappointing annual load factor of 70 percent.
- ➔ **France's** nuclear generation increased again by close to 13 percent after starting recovery in 2023 (+15 percent) following the “annus horribilis” 2022 that had seen drop below 300 TWh for the first time since 1990—production however remained below 400 TWh, for the ninth year in a row.
- ➔ **India's** nuclear output grew by 13.5 percent due to the startup of a new reactor early in the year.

- **Iran** managed with its only operating reactor to achieve an annual load factor of 80 percent for the first time and increased production by over 11 percent to a new record.
- **Japan's nuclear output** increased by another 9.6 percent following the restart in the second half of 2023 of two units and further two units in 2024—14 reactors are now operational. As these latest restarts took place towards the end of the year, further production improvement is to be expected in 2025. However, nuclear represented only about 8.5 percent of total power generation in the country.
- **The Netherlands'** only over 50-year-old reactor produced about 10.5 percent less power than in the previous year as the load factor dropped just below 80 percent for the first time since 2018.
- **Taiwan's** nuclear output went down by more than 31.5 percent with one of two remaining reactors closing in July. Taiwan completed its nuclear phaseout and closed its last reactor in May 2025.
- **The UAE** connected its last reactor under construction to the grid in the first quarter and increased nuclear power generation by another 18 percent to a new record. The share of nuclear in national electricity generation reached almost 23 percent.

Figure 2 · Nuclear Electricity Generation in the World... and China

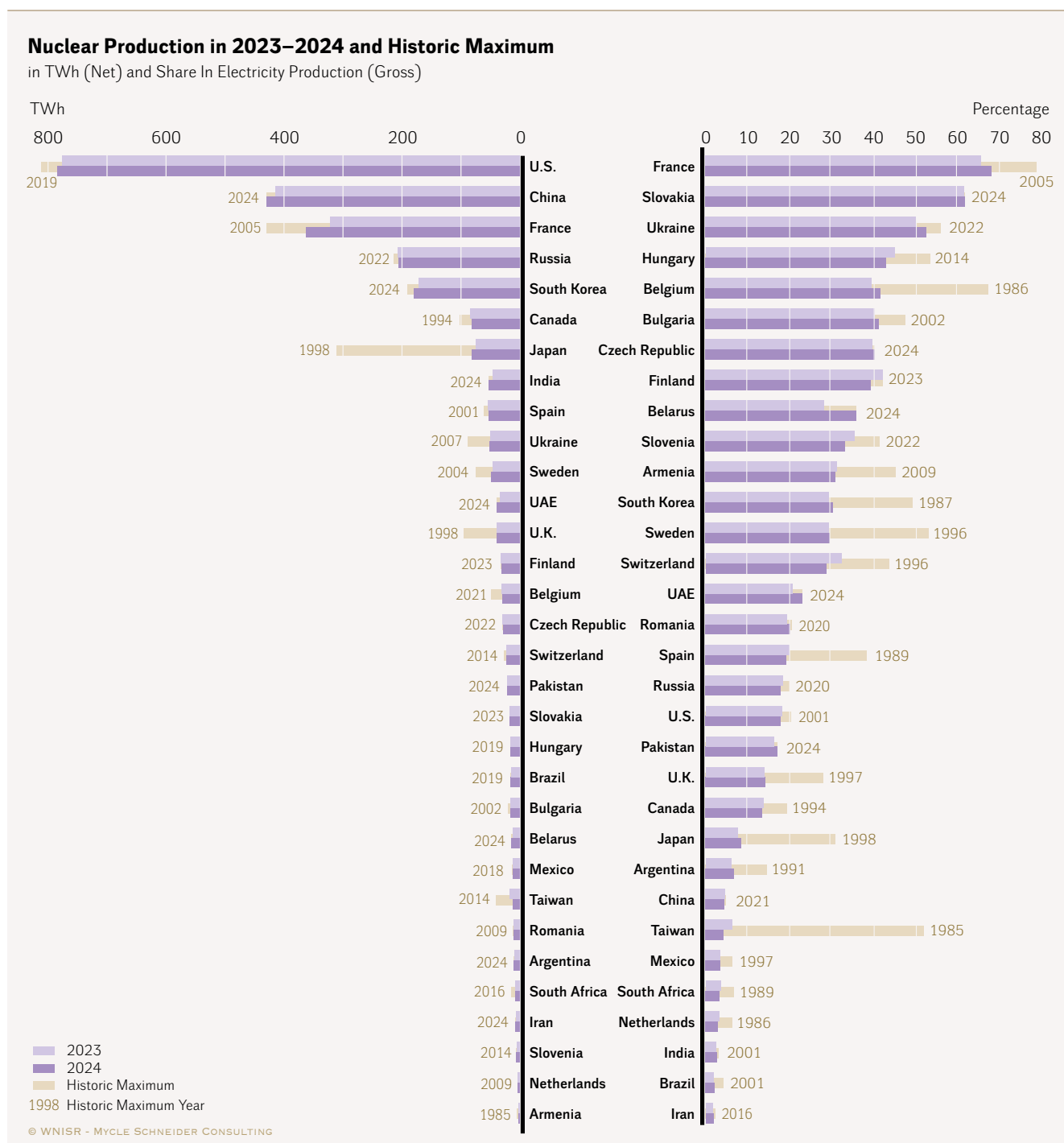


Sources: WNISR with Energy Institute, 2025

Similar to previous years, in 2024, the “big five” nuclear generating countries—the U.S., China, France, Russia, and South Korea, in that order—generated 73 percent of all nuclear electricity in the world (see Figure 3, left side).

In 2002, China was 15th in terms of global production levels; in 2007, it was tenth, and it reached third place in 2016. In 2020, China became the second largest nuclear generator in the world, a position that France held since the early 1980s. That has not changed since.

Figure 3 · Nuclear Electricity Generation and Share in National Power Generation



Sources: compiled by WNISR with Energy Institute, 2025

Notes: For comparison reasons, data used in this graphic are Energy Institute data¹⁷, and may differ from data used in the country sections.
Production: in TWh net; Share: calculated from gross data (nuclear and total generation), except for Armenia (IAEA-PRIS).

In 2024, the top three countries, the U.S., China, and France, remained at around 59 percent of global nuclear output, underscoring the concentration of nuclear power generation in a very small number of countries.

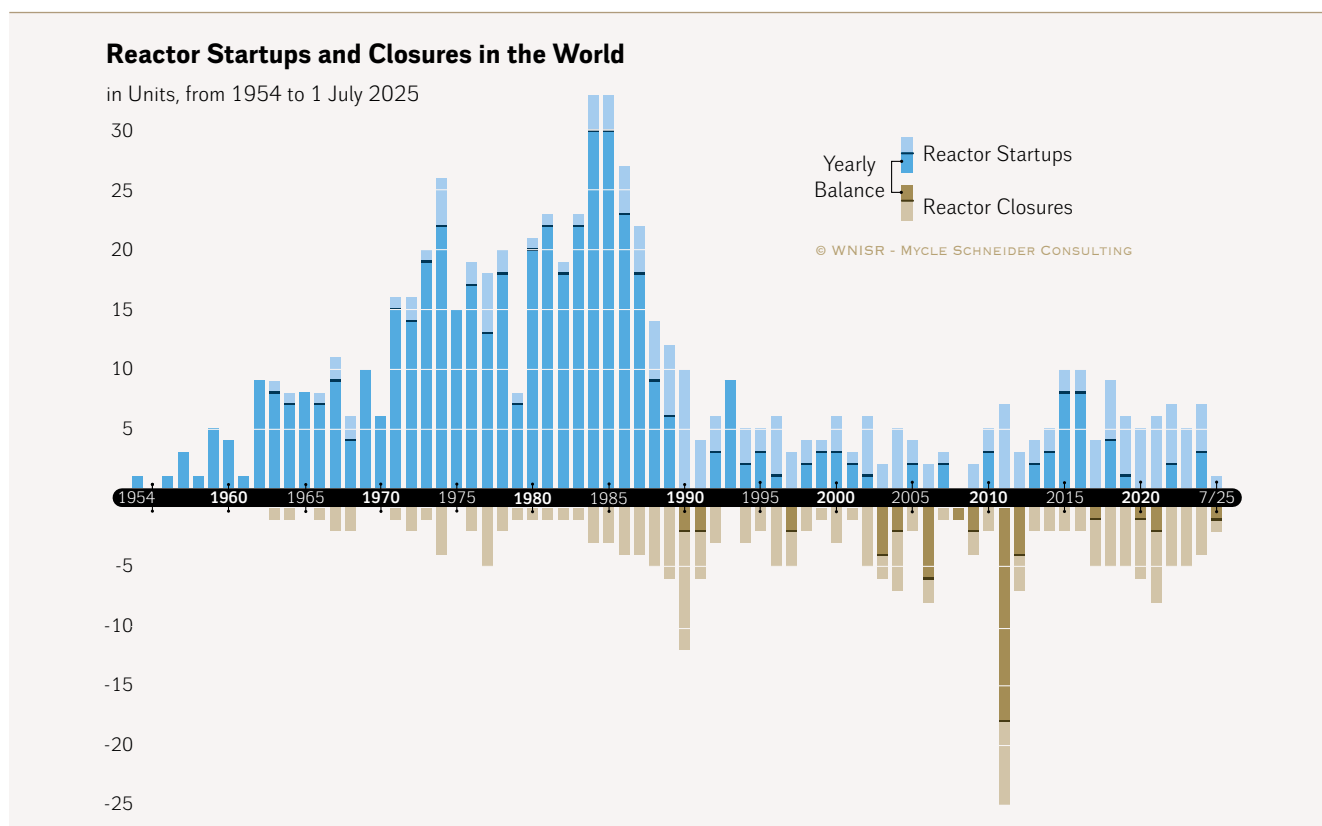
17 - Energy Institute, “Statistical Review of World Energy 2025–Consolidated Dataset”, 2025, op. cit.

In many cases, even where nuclear power generation increased, the addition is not keeping pace with overall increases in electricity production, leading to a nuclear share below the respective historic maximum (see Figure 3, right side). Six of the 32 countries that operated nuclear reactors in 2024 achieved their historically largest nuclear shares in the 1980s, seven in the 1990s, six in the 2000s, two in the 2010s, eleven in the short 2020s with five for the single year of 2024.

OPERATION, POWER GENERATION, AGE DISTRIBUTION

Since the first nuclear power reactor was connected to the Soviet power grid at Obninsk in 1954, there have been two major waves of startups. The first peaked in 1974, with 26 grid connections. The second reached a historic maximum in 1984 and 1985, just before the Chernobyl accident in 1986, reaching 33 grid connections in each year. By the end of the 1980s, the uninterrupted net increase of operating units had ceased, and in 1990 for the first time the number of reactor closures¹⁸ outweighed the number of startups.

Figure 4 · Nuclear Power Reactor Grid Connections and Closures in the World



Sources: WNISR with IAEA-PRIS, 2025

Note: WNISR considers reactors closed as of the date of their last electricity production, and not as of their closure announcement (which can be made years after the reactor ceased production).

¹⁸ - WNISR considers closure from the moment of grid disconnection—and not from the moment of the industrial, political, or economic decision—and as the units have not generated power for several years, in WNISR statistics, they are closed in the year of their last power generation.

The 1995–2004 decade globally saw slightly more startups than closures (44/37), while in the decade 2005–2014, startups compensated only for two thirds of the closures (35/54) (see Figure 4).

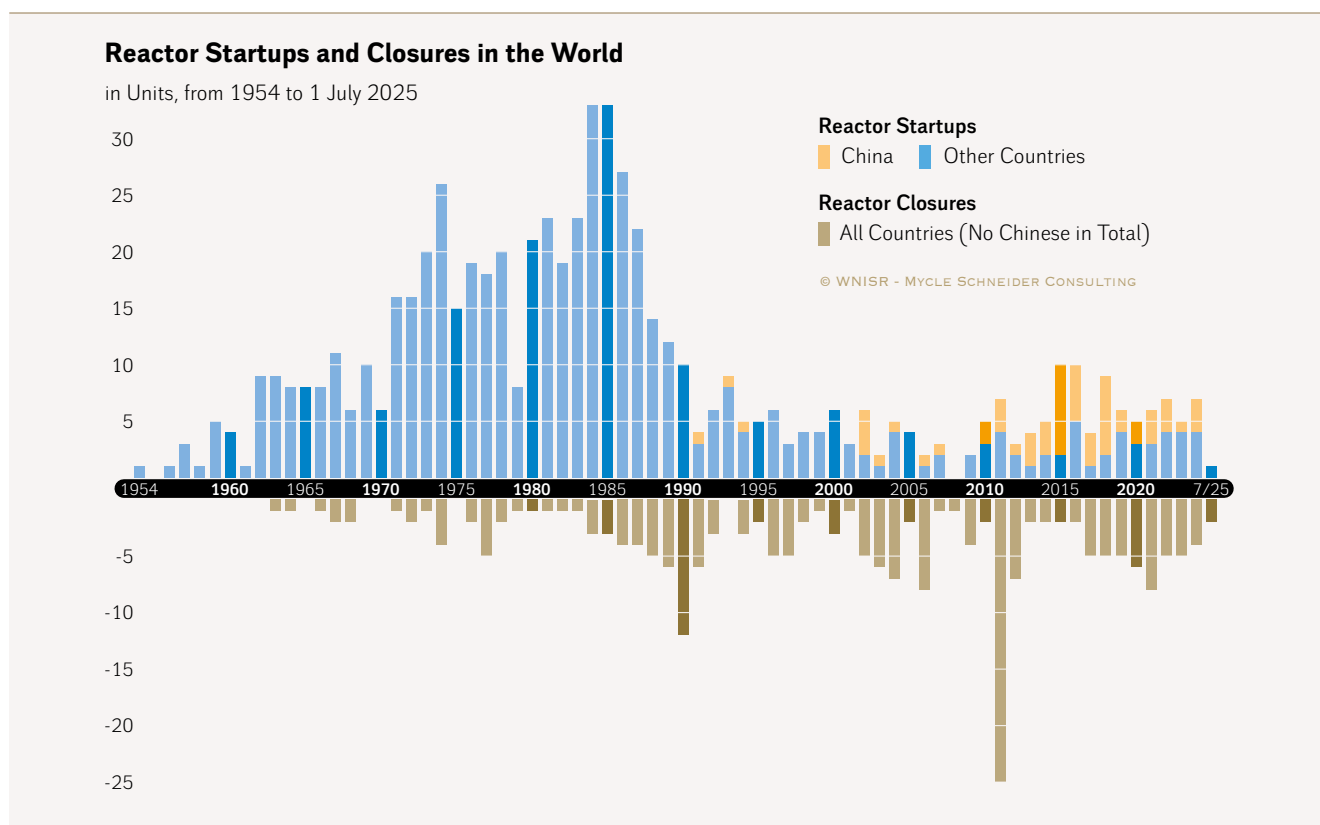
In the decade 2015–2024, startups (69) doubled compared to the previous decade—of which over half (37) in China—but closures reached 47 none of which in China. In other words, a net decline of 15 units outside China.

Over the past two decades 2005–2024, there were 104 startups and 101 closures. Of these, 51 startups were in China which did not close any reactors. As a result, outside China, there has been a drastic net decline by 48 units over the same period (see Figure 5). As larger units were started up (totaling 97.2 GW) than closed (totaling 74 GW) the net nuclear capacity added worldwide over the 20-year period was 23.2 GW. However, since China alone added over half of the capacity (49.8 GW), the net capacity outside China declined by almost 26.6 GW.

In 2024, seven reactors were connected to the grid, three in China, and one each in France, India, the UAE and the U.S.—leaving zero active construction projects in France, the UAE, and the U.S.—and four units were closed, two in Canada and one each in Russia and Taiwan.

In the first half of 2025, one unit was connected to the grid in India—remarkably, not a single unit in China or indeed elsewhere—while two were closed, one each in Belgium and Taiwan. (See Figure 5).

Figure 5 · Nuclear Power Reactor Grid Connections and Closures World/China

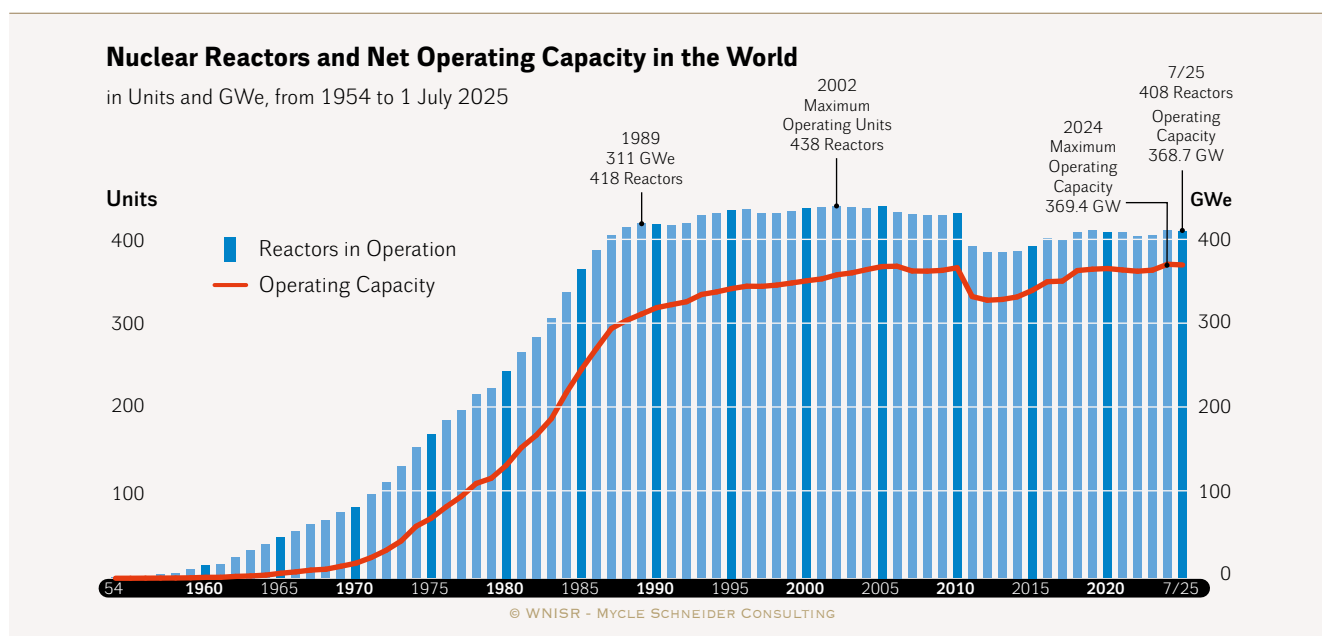


Sources: WNISR, with IAEA-PRIS, 2025

As of 1 July 2025, a total of 408 nuclear reactors—same number as reported for mid-2024—were operating in 31 countries—one less than in mid-2024.¹⁹ As of mid-2025, the world fleet has a total electric net operating capacity of 368.7 GW, while there were 33 units (28.6 GW) in Long-Term Outage (LTO): 19 in Japan, six in Ukraine, three in India, two each in Canada and South Korea, and one in China. As the annual statistics always reflect the status at year-end, the situation might change again by the end of 2025. As of the end of 2024, the operating capacity had reached a record 369.4 GW. The annual differences are within the one-digit GW range, to be compared with hundreds of GW range for renewable energy competitors.

The number of operating reactors remains by ten below the fleet size already reached in 1989 and by 30 below the 2002-peak (see Figure 6).

Figure 6 · World Nuclear Reactor Fleet, 1954–mid-2025



Sources: WNISR with IAEA-PRIS, 2025

For many years, the capacity increased more than the number of reactors as a result of the combined effects of larger units replacing smaller ones and “uprating”. In 1989, the average size of an operational nuclear reactor was about 740 MW, in 2024 it was around 900 MW. Technical alterations raised capacity at existing plants resulting in larger electricity output, a process known as uprating.²⁰ In the U.S. alone, the Nuclear Regulatory Commission (U.S. NRC) has approved 172 uprates since 1977. The cumulative approved uprates in the U.S. total 8 GW, the equivalent of eight large reactors. These include seven minor uprates (<2 percent of reactor capacity) approved since mid-2020, of which only one since mid-2021.²¹ So this is a program that is pretty much completed on most of the U.S. fleet.

¹⁹ - Balance since WNISR2024: +4 startups +4 restarts –3 new LTOs –5 closures = no change

²⁰ - Increasing the capacity of nuclear reactors by equipment upgrades, e.g., more powerful steam generators or turbines.

²¹ - U.S. NRC, “Approved Applications for Power Uprates”, United States Nuclear Regulatory Commission, Updated 20 May 2025, see <http://www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html>, accessed 23 August 2025.

A similar trend of uprates and major overhauls in view of lifetime extensions of existing reactors has been seen in Europe. The main incentive for lifetime extensions is economical, but this argument is being increasingly challenged as refurbishment costs soar and alternatives become cheaper.

The IAEA's Operating Reactors Data Revisions

Until September 2022, the IAEA's online Power Reactor Information System (PRIS) database counted 33 reactors as operational/operating in Japan, whereas 20 of these had not produced power since 2010–2012, and an additional three units had been shut down even since the Niigata Earthquake in 2007.

For almost a decade WNISR had been calling for an appropriate reflection in world nuclear statistics of the unique situation in Japan. The approach taken by the IAEA, the Japanese government, utilities, industry, and many research bodies as well as other governments and organizations to continue classifying the entire stranded reactor fleet in the country as “in operation” or “operational” was clearly misleading.

Faced with this dilemma, the WNISR team in 2014 decided to create a new category with a simple definition, based on empirical fact, without room for speculation: “Long-Term Outage” or LTO. Its definition:

A nuclear reactor is considered in Long-Term Outage or LTO if it has not generated any electricity in the previous calendar year and in the first half of the current calendar year. It is withdrawn from operational status retroactively from the day it has been disconnected from the grid.

When subsequently the decision is taken to close a reactor, the closure status starts with the day of the last electricity generation, and the WNISR statistics are retroactively modified accordingly.

The IAEA's Category of “Suspended Operation”

On 16 January 2013, the IAEA moved 47 reactors in Japan, most of them shut down in the aftermath of the Fukushima events in 2011, from the category “In Operation” into “Long-term Shutdown”²² that existed in the IAEA statistical system until October 2022. Only two days later, the move was labelled a “clerical error” and the action was reversed at the request of the Japanese government.²³

It is only in September 2022, that in the IAEA-PRIS database, twelve Japanese reactors²⁴ were gradually withdrawn from the list of “Operating” or “Operational” reactors, and their status changed to “Long-term Shutdown” (LTS). By mid-October 2022, the category title was

22 - WNISR, “Historic Move: IAEA Shifts 47 Japanese Reactors Into “Long-Term Shutdown” Category”, 16 January 2013, see <https://www.worldnuclearreport.org/Historic-Move-IAEA-Shifts-47.html>, accessed 14 November 2023.

23 - WNISR, “IAEA-Japan Reactor Status Incident: “Clerical Error” Explanation Not Credible”, 20 January 2023, see <https://www.worldnuclearreport.org/IAEA-Japan-Reactor-Status-Incident.html>, accessed 14 November 2023.

24 - Kashiwazaki Kariwa 1–5, then Tomari 1–3, then Hamaoka 3–5, followed by Tsuruga-2.

changed to “Suspended Operation” on the PRIS website²⁵, and in November 2022, four more Japanese units²⁶ joined the new category as well as one Indian reactor (Rajasthan-1) that has not generated any power since 2004 and is considered closed by WNISR.

As of the end of 2022, the PRIS database still counted 17 Japanese reactors as “In Operation”. Whereas ten have effectively restarted since the beginning of the Fukushima disaster (also referred to as 3/11), the remaining seven have not produced any electricity since 2010–2012. Then, in April 2023, those seven units also joined the “Suspended Operation” category, followed in May 2023 by three additional Indian reactors, that have not produced power since 2018 (Madras-1) and 2020 (Tarapur-1 & -2).

The definition of the new IAEA category is as follows:

A reactor is considered in the suspended operations status, if it has been shut down for an extended period (usually more than one year) and there is the intention to re-start the unit but:

1. restart is not being aggressively pursued (there is no vigorous onsite activity to restart the unit) or
2. no firm restart date or recovery schedule has been established when unit was shutdown [shut down].

Suspended operations may be due to [due to] technical, economical, strategic or political reasons. This status does not apply to long-term maintenance outages, including unit refurbishment, if the outage schedule is consistently followed, or to long-term outages due to regulatory restrictions (licence suspension), if restart (licence recovery) term and conditions have been established. Such units are still considered “operational” (in a long-term outage). If an intention not to restart the shutdown unit has been officially announced by the owner, the unit is considered “permanently shutdown [shut down]”.²⁷

It is important to understand that the application of this new rule modifies retroactively *all* of the IAEA’s statistics on operating reactors—in most cases as of day of last production—back to 2007. This dramatically modifies the IAEA’s representation of the Japanese nuclear reactor fleet’s evolution. The changes obviously also impact the IAEA’s representation of the long-term evolution of the entire global nuclear power-reactor fleet (see a [detailed discussion in WNISR2023](#)).

The differences with WNISR statistics are greatly reduced, and the remaining ones mostly relate to official closure dates, as WNISR statistics consider the end of electricity production as reference for dating closures, and not the “announcement” or “political decision” to permanently withdraw a reactor from the grid. Currently, a significant difference is that the IAEA considers the six Zaporizhzhia reactors as operational although they have not produced any power in years (see hereunder and [Ukraine Focus](#)).

25 - In fact, this category was already mentioned in the IAEA’s “Nuclear Power in the World” booklet in July 2015, but never used in the Agency’s online resources. It said: under “Long term shutdown (suspended operation)”: “A unit is considered to be in long term shutdown if it has been shut down for an extended period (usually several years) initially without any firm recovery schedule, but with the intention to restart the unit eventually. Suspended operation is a new term for this status.

26 - Higashi Dori-1, Onagawa-3 and Shika-1 & -2.

27 - IAEA-PRIS, “Glossary of Terms in PRIS Reports”, Power Reactor Information System, International Atomic Energy Agency, 2023, see <https://pris.iaea.org/PRIS/Glossary.aspx>, accessed 23 August 2025. It is remarkable that the typos in this section have never been corrected since the definition was first uploaded to the Glossary.

IAEA vs. WNISR Assessment

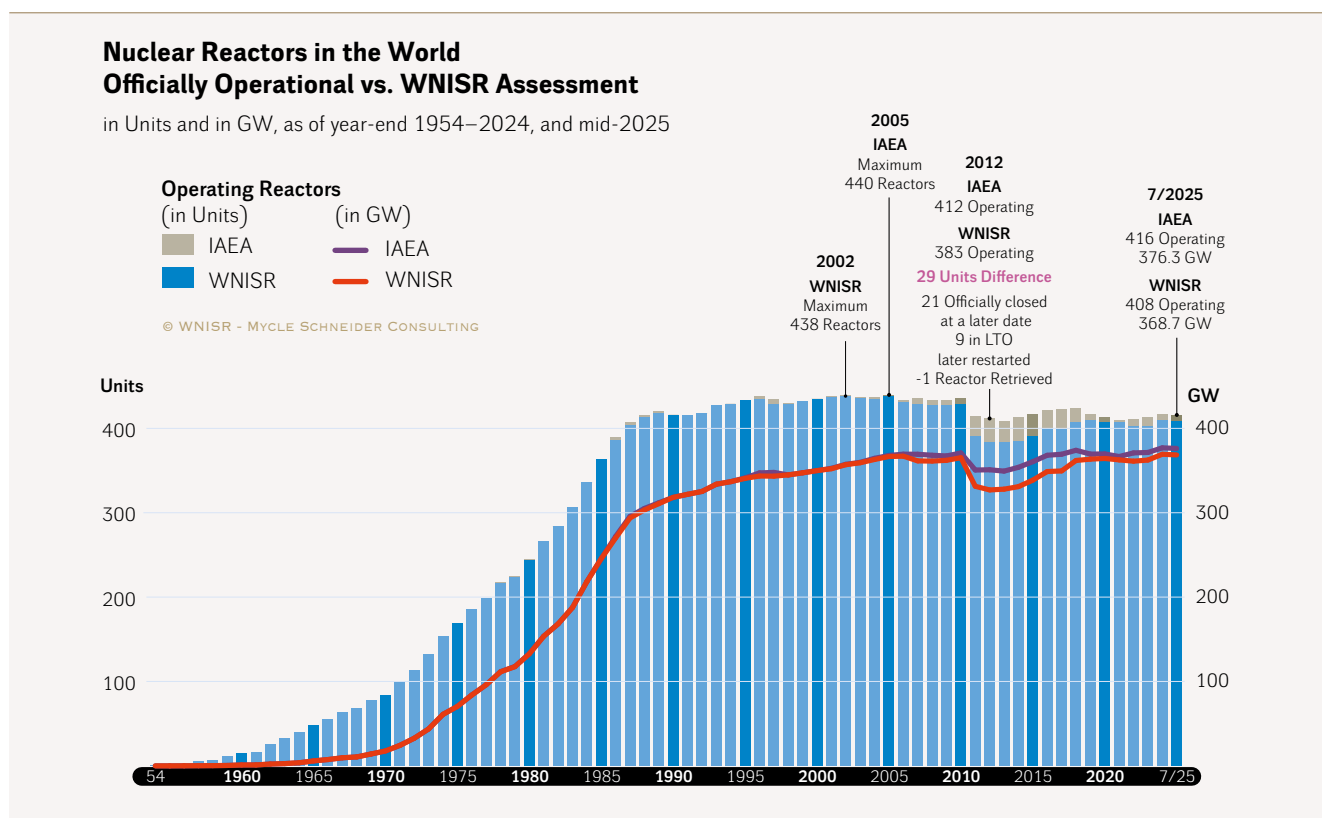
WNISR's assessment of “operating” reactors has shown significant differences with IAEA statistics since the beginning of the Fukushima disaster in 2011. However, after major changes in the PRIS statistics (see above), those differences were reduced to minor disparities during the period September 2022 to May 2023.

The following section provides a detailed explanation and justification of the differences.

Figure 7 presents the evolution of the number and capacity of the world reactor fleet “in operation” as reported by the IAEA vs. WNISR.

As of 1 July 2025, the evolution of the world nuclear fleet in the IAEA-PRIS statistics shows a peak of 440 reactors operating in 2005, whereas, as of the end of 2024, the operating capacity reached 377 GW, a new record, marginally over the previous peak of 374 GW reached in 2018, according to the new IAEA data.

Figure 7 · World Nuclear Reactor Fleet – IAEA vs WNISR, 1954–July 2025



Sources: IAEA-PRIS and WNISR, 2025

Notes: The IAEA data used for this graph includes at least three reactors that have been later withdrawn from the PRIS statistics for operating reactors (Niederachbach, VAK-Kahl and HDR Großwelzheim, in Germany, now only appearing as “Decommissioning Completed”). On the other hand, the Swiss research reactor in Lucens is not included. Reactors classified as in “Suspended Operation” by the IAEA are not represented here. Although the total number of reactors in operation according to WNISR statistics has always remained, albeit slightly, inferior to IAEA-PRIS data, it contains several Chinese reactors not accounted for in PRIS (see below).

In the WNISR statistics, which consider reactors closed from the day they stop producing electricity and systematically apply the LTO status to reactors not operating for a certain period, a maximum number of 438 *operating reactors* was reached as soon as 2002, and again in

2005. At the end of 2024, with a balance of plus 5.3 GW between closed and newly started-up reactors during the year plus a balance of three fewer reactors in LTO, the *operating capacity* reached a new maximum of 369.4 GW.

Although not the only case, the Japanese fleet still provides the main and more visible differences between the two datasets, especially over the decade 2011–2020. This applies both to reactors that did not produce electricity for many years before they returned to service (designated as “LTO later restarted” or “Restarted from LTO”), or which were declared permanently closed years after they stopped producing electricity (“Closed at a later date”).

Applying this definition to the world nuclear reactor fleet, as of 1 July 2025, leads to classifying ten units considered “in operation” by the IAEA as LTO:

- ➔ **Bruce-3 and Darlington-4** in Canada under refurbishment since March and July 2023 respectively (see section on [Canada](#)).
- ➔ **Kori-2 and Kori-3** in South Korea, shut down in April 2023 and September 2024 respectively, after 40 years of operation and the expiration of their operating license. Currently, they are expected to be restarted at an unknown date, pending inspection results and potential upgrading; therefore they are considered in LTO (see [South Korea Focus](#)).²⁸
- ➔ **The six reactors at Zaporizhzhia** in Ukraine that did not produce any electricity in 2023 and 2024 and are considered in LTO as of the end of 2022.

As of mid-2025, the IAEA classified 19 reactors in Japan and four in India as suspended. With the exception of one reactor in India (Rajasthan-1) considered closed since the end of 2004, WNISR classifies all of them in LTO.

On the other hand, WNISR statistics do include additional reactors in China:

- ➔ **Shidao-Bay-1:** The IAEA considers the two 100-MW modules as one reactor as they drive a single 200-MW turbine. WNISR considers that each module is a separate reactor.
- ➔ **Shidaowan Guohe One-1:** This is the first of two CAP1400 at Shidao Bay that started operating in 2024, a second unit is still under construction. For unknown reasons, the two units are not listed in the IAEA database.
- ➔ **China Experimental Fast Reactor (CEFR):** The IAEA has simply deleted the file for the reactor without any indication of reasons. Chinese sources have argued it should have never been in the IAEA’s PRIS database in the first place as it is to be considered an experimental reactor. However, as this is a grid-connected nuclear power reactor, it is considered as such by WNISR. Its current operational status is uncertain. In the absence of operational data, WNISR considers it in LTO as of May 2023 (but still operating as of December 2022).²⁹

The biggest difference between IAEA-PRIS and WNISR is found as of the end of 2012, with 29 units less operating according to WNISR criteria: the IAEA-PRIS counts 30 reactors

28 - Kori-4 was also shut down on 7 August 2025 because its operating license expired; see *NEI Magazine*, “Kori 4 Shuts Down”, *Nuclear Engineering International*, 7 August 2025, see <https://www.neimagazine.com/news/kori-4-shuts-down/>, accessed 24 August 2025.

29 - CEFR was considered in LTO in WNISR statistics from 2017 to 2020, until it was reconnected to the grid in February 2021; see WNN, “Chinese Fast Reactor Begins High-Power Operation”, 19 February 2021, see <https://www.world-nuclear-news.org/Articles/Chinese-fast-reactor-begins-high-power-operation>, accessed 8 November 2023.

(detailed in Table 1) that are not considered operating according to WNISR, but on the other hand has retrieved the Chinese CEFR it previously considered operational at that date.

Table 1 · WNISR Rationale for the Classification of 30 Reactors as Non-Operational as of end 2012

Countries	Officially Closed at a Later Date 21 Reactors		Restarted from LTO 9 Reactors
	Reactors that last produced electricity in (or prior to) 2012, officially closed after 2012 (either considered closed by WNISR as early as 2012, or after a certain period in LTO). Most of those reactors were considered “in operation” for many years before their official closure date.		
	Reactors considered closed in 2012	Reactors in LTO prior to closure	Reactors in LTO as of December 2012 Restarted prior to 1 July 2023
Japan	6 Reactors Fukushima Daiichi 5–6 Fukushima Daini 1–4 Officially Closed in 2013 and 2019	11 Reactors Last production in 2010–2012 Officially closed 2015–2019	8 Reactors Restarted 2015–2021
South Korea			1 Reactor Wolsong-1, Restarted in 2015
Spain	1 Reactor Santa Maria de Garoña Last production in 2012 Officially Closed in 2017*		
U.S.	3 Reactors San Onofre-2 & -3 Last production in 2012 Officially closed in 2013 Crystal River-3 Last production in 2009 Officially closed in 2013		

Sources: IAEA-PRIS and WNISR, 2024

Note: *Garoña was subsequently considered in “Suspended Operation” during 2013–2016 by the IAEA until its official closure.

The differences between the IAEA and WNISR are not limited to the effects of the Fukushima disaster. Even prior to 3/11, WNISR and IAEA-PRIS data had differences, reaching up to 10 units at the end of some years. These differences were mainly due to the definition of the closure date that the IAEA either sets at last production or as closure-decision date while WNISR systematically applies the day of last electricity generation (when available). Other reasons for differences lie in the IAEA’s delays to classify reactors in “suspended operation” and that WNISR considers reactors undergoing refurbishment in LTO as soon as they meet the LTO criteria, or as soon as they are shut down (with expected restart) in case their license has expired (as it is the case in South Korea for example).

OVERVIEW OF CURRENT NEWBUILD

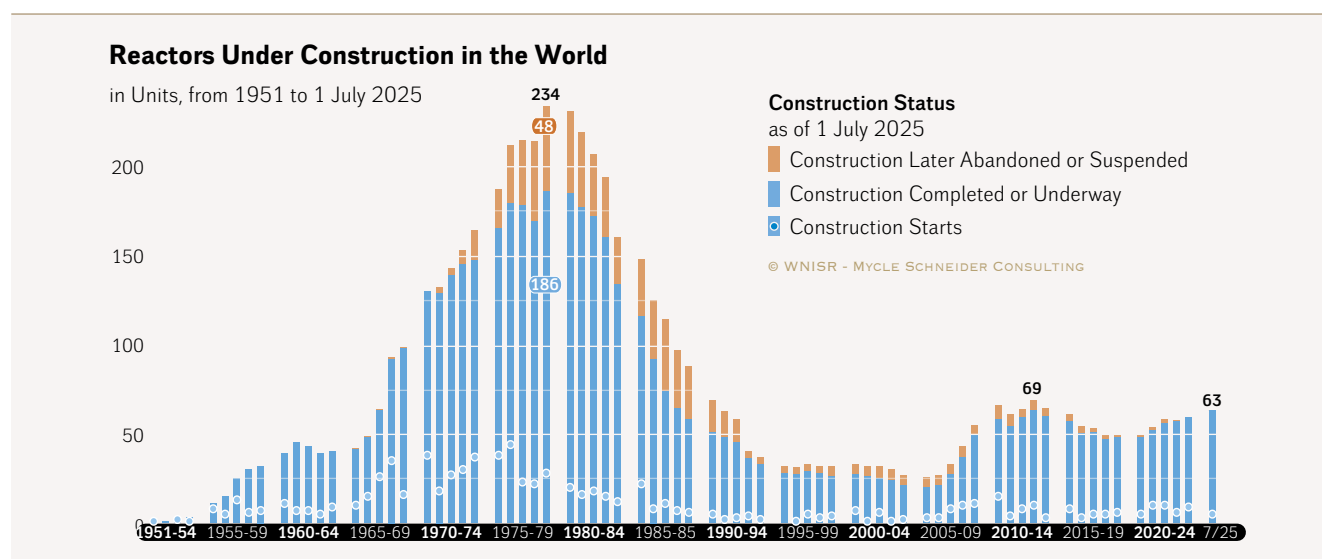
As of 1 July 2025, 63 reactors were considered as under construction³⁰—including 32 units in China—four more than the WNISR reported a year ago and six fewer than in 2013 (see [Figure 8](#) and [Figure 9](#)). Of the 69 reactors listed at the end of 2013, six projects were subsequently abandoned or suspended.

Nine in ten of all reactors are being built in Asia or Eastern Europe (see [Building vs. Vendor Countries](#)). Eleven countries are building nuclear plants, down from 16 in as of mid-2023 and 13 as of mid-2024. While Pakistan entered the category with the launch of a new construction at one of its existing sites, three countries dropped off the list: France, where the latest and last reactor under construction was connected to the grid; Argentina, where the CAREM reactor construction has been abandoned, and Japan where no active construction is underway at both construction sites that had been previously listed at some point in time.

Only four countries—China, India, Russia and South Korea—have construction ongoing at more than one site, and three countries only have a single reactor under construction (see [Table 2](#) and [Annex 5](#) for details). Between mid-2024 and mid-2025, construction of ten units was launched worldwide, seven in China and one each in Pakistan, Russia, and South Korea.

The 63 reactors listed as under construction represent just over one quarter of the 234 units—totaling more than 200 GW—listed in 1979. However, 48 of those projects listed at the time were never finished (see [Figure 8](#)). The year 2005, with 26 units listed as under construction, was the lowest since the early nuclear age in the 1950s.

Figure 8 · Nuclear Reactors “Under Construction” in the World



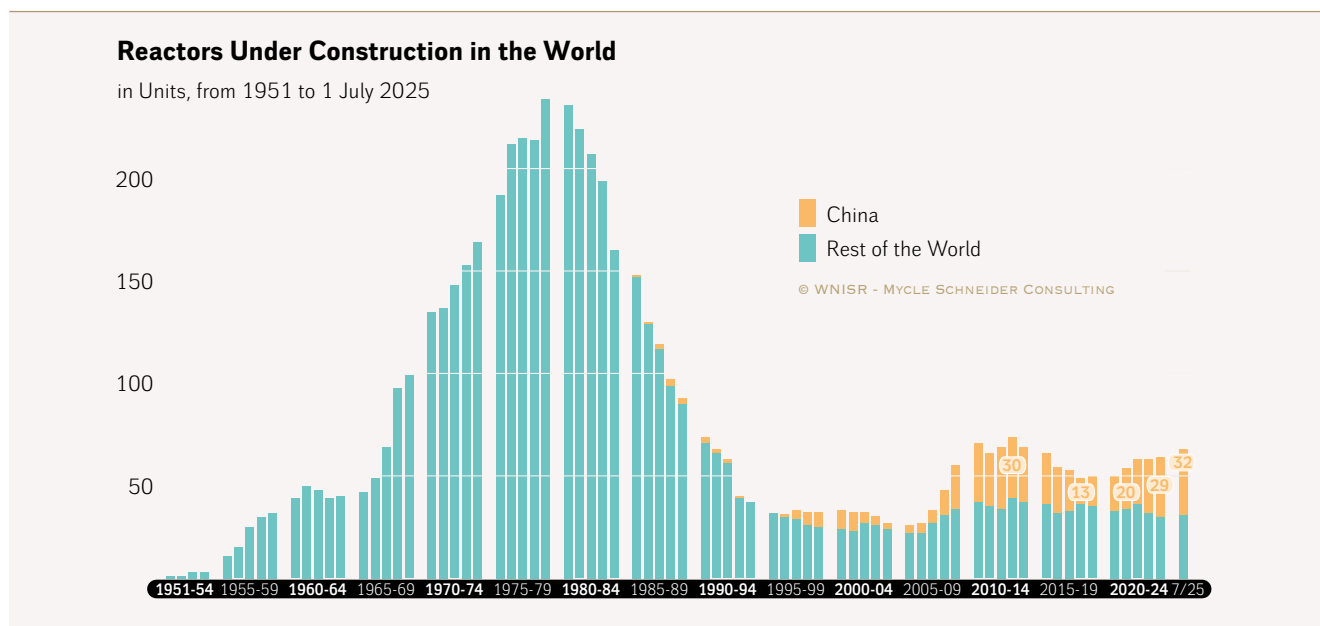
Sources: WNISR, with IAEA-PRIS, 2025

Notes: This figure includes construction of two CAP1400 reactors at Rongcheng/Shidaowan, although their construction has not been communicated by the IAEA, one of which has been connected to the grid in October 2024 (see [China Focus](#)).

30 - Generally, a reactor is considered under construction with the beginning of the concreting of the base slab of the reactor building. Site preparation work, excavation and other infrastructure developments are not included.

Compared to mid-2024, the number of units under construction in the world increased from 58³¹ to 63 in mid-2025 with the combined capacity increased by 6.7 GW net to 65.2 GW, with an average size of 1 GW.

Figure 9 · Nuclear Reactors “Under Construction” – China and the World



Sources: WNISR with IAEA-PRIS, 2025

BUILDING VS. VENDOR COUNTRIES

As of mid-2025, China hosts 32 or more than half of all reactors under construction in the world (63). So far, Chinese companies have only exported to Pakistan, where they started building another reactor in December 2024.

It is remarkable that, as of mid-2025, there is not a single active construction on the entire American continent, from Alaska to Cape Horn, including the United States, that hosts the world's largest nuclear power fleet (see Figure 10).

Russia is in fact largely dominating the international market as a technology supplier with 27 units under construction in the world, as of mid-2025, of which seven at home and 20 in seven different countries, including four each in China, Egypt, India, and Türkiye, and two in Bangladesh. It remains uncertain to what extent these projects are impacted by the various layers of sanctions imposed on Russia following its invasion of Ukraine.

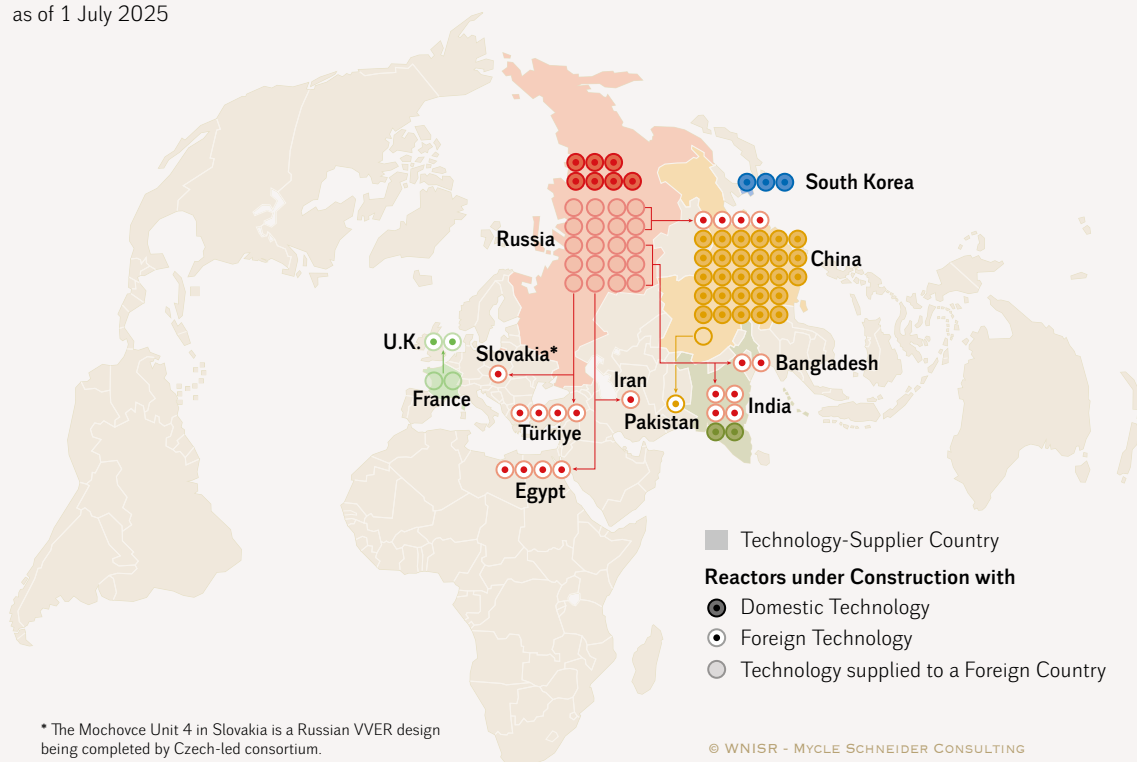
Besides Russia's Rosatom, there is only France's EDF (Électricité de France) and China's CNNC (China National Nuclear Corporation) presently building abroad (see Table 2).

31 - Corrected from 59 in WNISR2024, due to the retroactive retrieval of Japan's Shimane-3 from the list, as of 2011.

Figure 10 · Nuclear Reactors “Under Construction” by Technology-Supplier Country

Nuclear Power Reactors Under Construction in the World

Units by Technology-Supplier Country and Construction Country
as of 1 July 2025



Sources: WNISR with IAEA-PRIS, 2025

Table 2 · Nuclear Reactors “Under Construction” (as of 1 July 2025)³²

Country	Units (Domestic Design)	Other Vendor	Capacity (MW net)	Construction Start	Grid Connection	Units Behind Schedule
China	32 (28)	Russia: 4	34 512	2017 – 2025	2025 – 2030	1 (2?)
Russia	7 (7)	–	5 110	2018 – 2025	2025 – 2032	3 (5?)
India	6 (2)	Russia: 4	4 768	2004 – 2021	2026 – 2028	6
Türkiye	4 (–)	Russia: 4	4 456	2018 – 2022	2026 – 2029	4
Egypt	4 (–)	Russia: 4	4 400	2022 – 2024	2028 – 2031	–
South Korea	3 (3)	–	4 020	2017 – 2025	2026 – 2032	2
Bangladesh	2 (–)	Russia: 2	2 160	2017 – 2018	2025 – 2027	2
U.K.	2 (–)	France: 2	3 260	2018 – 2019	2030 – 2031	2
Slovakia	1 (–)	Russia: 1 ^(a)	440	1985	2025	1
Iran	1 (–)	Russia: 1	974	1976	2029	1
Pakistan	1 (–)	China: 1	1 117	2024	2030	–
Total	63		65 217	1976 – 2025	2025 – 2032	22 (26?)
Total per Vendor Country: Russia: 27 – China: 29 – South Korea: 3 – France: 2 – India: 2						

Sources: Various, compiled by WNISR, 2025

(a) - Mochovce -4 is a Russian VVER design being completed by a Czech-led consortium.

This table does not contain suspended or abandoned constructions. It does include construction of one CAP1400 reactor at Rongcheng/Shidaowan, although that has not been communicated by the IAEA (see [China Focus](#)) as well as two floating reactors of Russian design to be deployed in Russia—thus counted under Country-Russia, but with the barges built in China, which are likely also delayed.

32 - For further details, see Annex 5.

CONSTRUCTION TIMES

Construction Times of Reactors Currently Under Construction

A closer look at projects listed as “under construction” as of 1 July 2025 illustrates the level of uncertainty and problems associated with many of these projects, especially given that most builders still claim a five-year construction period in their project proposals:

- ➔ For the 63 reactors being built, an average of 5.3 years has passed since construction start—slightly lower than the mid-2024 average of 5.9 years of the fleet under construction then—and many remain far from completion.
- ➔ All reactors under construction in at least six of the 11 building countries have experienced often year-long delays. Over one third (23) of the building projects are documented to be delayed. Most of the units—26 of 40—which are nominally being built on-time (yet) were begun within the past three years (July 2022–July 2025) and 30 of the 40 are in China, making it difficult to assess whether they are on schedule. Significant uncertainty remains over construction in China because of lack of systematic access to information.
- ➔ It remains also unclear what will happen with Russian designed and/or implemented projects in six other countries, as sanctions have or will likely have an impact on supply chains. Russian projects in five of the seven countries are already documented to be delayed (Bangladesh, India, Iran, Slovakia, Türkiye), some of them due to sanctions’ impacts.
- ➔ Of the 22–26 constructions behind schedule, at least fourteen—in Bangladesh, India, Iran, Russia, Slovakia, South Korea and Türkiye—have reported *increased* delays, three have confirmed delay indications, and one delay has been identified for the first time over the past year.
- ➔ WNISR2023 noted a total of 14 reactors scheduled for startup in 2024. At the beginning of 2024, 14 were still planned to be connected to the grid (including three pushed back from 2023 to 2024), but only half made it to generate first power, while the commissioning of the other seven was delayed at least into 2025.
- ➔ The initial construction start of the Mochovce-4 reactor in Slovakia dates back 40 years and its grid connection has—again—been further delayed, currently to later in 2025. Bushehr-2 in Iran originally started construction in 1976, almost 50 years ago, and resumed construction in 2019 after a 40-year-long suspension. Grid connection is currently scheduled for 2029.
- ➔ Two additional reactors have been listed as “under construction” for a decade or more: the Prototype Fast Breeder Reactor (PFBR) and Rajasthan-8 in India.

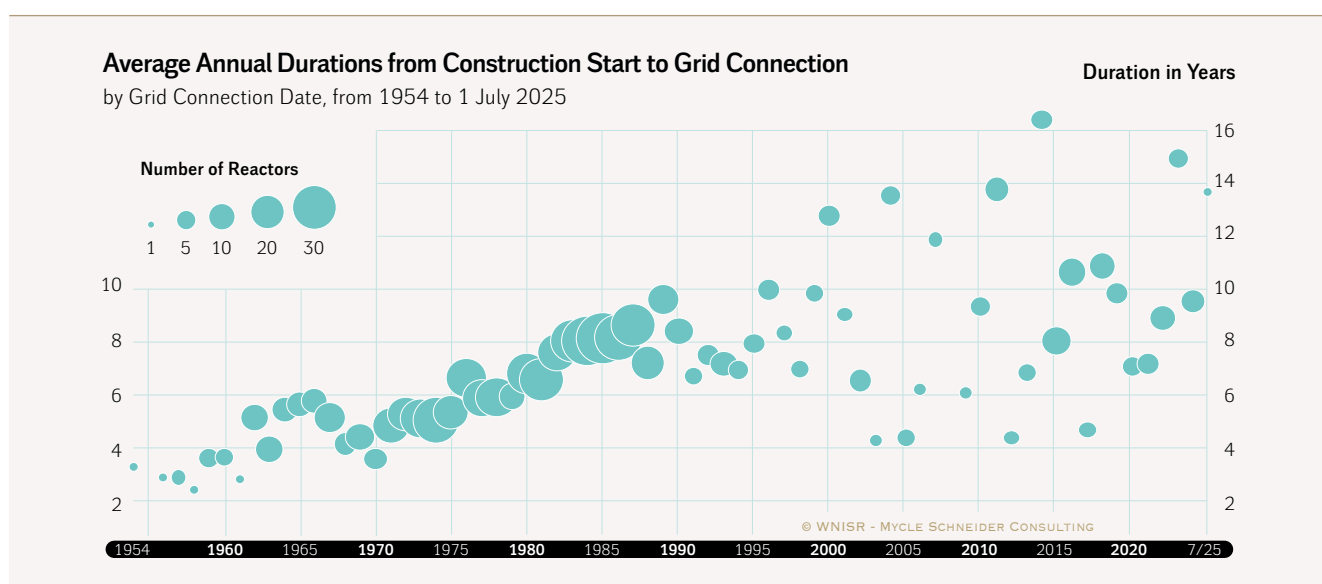
The actual lead time for nuclear plant projects includes not only the construction itself but, in most countries, also lengthy political and legal processes, licensing procedures, complex financing negotiations, site preparation, and other infrastructure development.

Construction Times of Past and Currently Operating Reactors

Since the beginning of the nuclear power age, there has been a clear global trend towards increasing construction times. National building programs were faster in the early years of nuclear power, when units were smaller, and safety and environmental regulations were less stringent.

As Figure 11 illustrates, average times between construction start and grid connection of reactors completed in the 1970s and 1980s were quite homogeneous, while in the past two decades they have varied widely.

Figure 11 · Average Annual Construction Times in the World



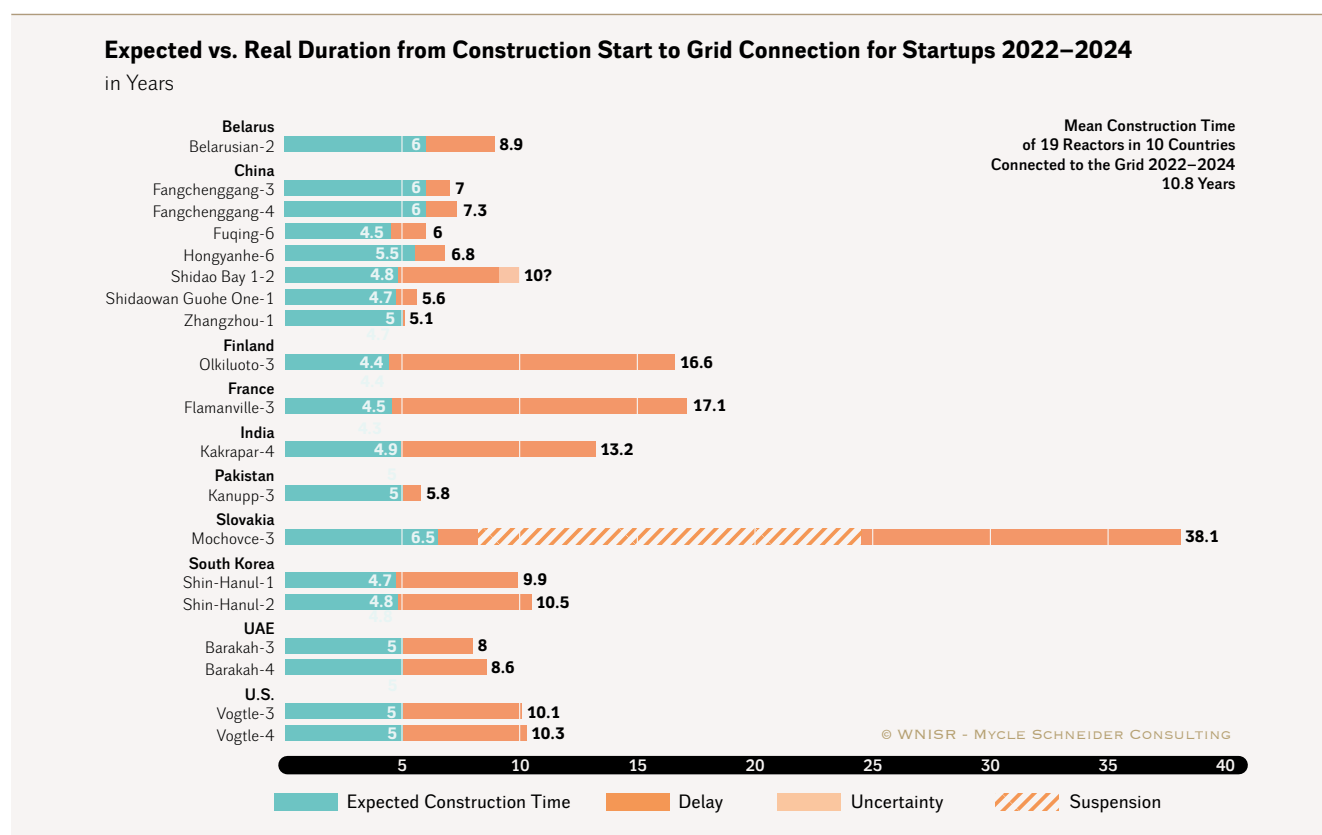
Sources: WNISR with IAEA-PRIS, 2025

In the three years 2022–2024, there were 19 startups in 10 countries after an average 10.8-year construction time. None of them was on-time, delays varied from a few weeks to many years (see Figure 12). The longest construction time was seen for Mochovce-3 at 38 years in total or at 22 years net, taking into account the 16-year-long construction suspension, followed by the French Flamanville-3 European Pressurized Water Reactor (EPR) at 17.1 years, and the Olkiluoto-3 EPR at 16.6 years. The longest construction time experienced in China, overall a significantly better performer than its foreign competitors, was seen for the second of the High-Temperature Reactor Pebble-bed Modules (HTR-PM) at Shidao Bay at 9–10 years. The seven units completed in 2022–2024 in China took on average 6.8 years to build.

The seven units that started up in the world in 2024 were completed after an average construction time of 9.6 years. The mean time from construction start to grid connection for the five reactors started up in 2023 was 14.9 years, almost six years more on average than the nine years for the units started up in 2022. This was mainly due to Mochovce-3 in Slovakia.

Only one unit began power generation in the first half of 2025, Rajasthan-7 in India, after 13.7 years of construction.

Figure 12 · Delays for Units Started Up, 2022–2024



Sources: Various, compiled by WNISR, 2025

Notes: Expected construction time is based on grid connection data provided at construction start when available; alternatively, best estimates are used, based on commercial operation, completion, or commissioning targets.

At Shidao Bay, the HTR plant, where construction started in 2012, has two reactor modules onsite and is therefore counted as two units as of WNISR2020. Grid connection of the first unit of the twin reactors officially took place on 20 December 2021. No date was provided for startup of the second reactor, which WNISR considers operating by the end of 2022 with total construction time set at 10 years.

The longer-term perspective confirms that short construction times remain the exceptions. Eleven countries completed 69 reactors over the decade 2015–2024—of which 37 in China alone—with an average construction time of 9.4 years (see Table 3), less than the 9.9 years of mean construction time in the decade 2014–2023, but equal to the decade 2013–2022. The construction durations from the beginning of concreting of the foundations of the reactor building to first grid connection have had better and worse years but over a decade they have averaged out around 10 years for over a decade, with a broad range between countries and between projects inside individual countries.

Table 3 · Duration from Construction Start to Grid Connection, 2015–2024

Construction Times of 69 Units Started Up 2015–2024				
Country	Units	Construction Time (in Years)		
		Mean Time	Minimum	Maximum
China	37	6.3	4.1	10
Russia	8	16.2	8.1	35.1
South Korea	5	8.7	6.4	10.5
Pakistan	4	5.6	5.5	5.8
UAE	4	8.3	8.0	8.6
India	3	12.5	10.1	14.2
U.S.	3	21.5	10.1	42.8
Belarus	2	8.0	7.0	8.9
Finland	1	16.6	16.6	
France	1	17.1	17.1	
Slovakia	1	38.1	38.1	
World	69	9.4	4.1	42.8

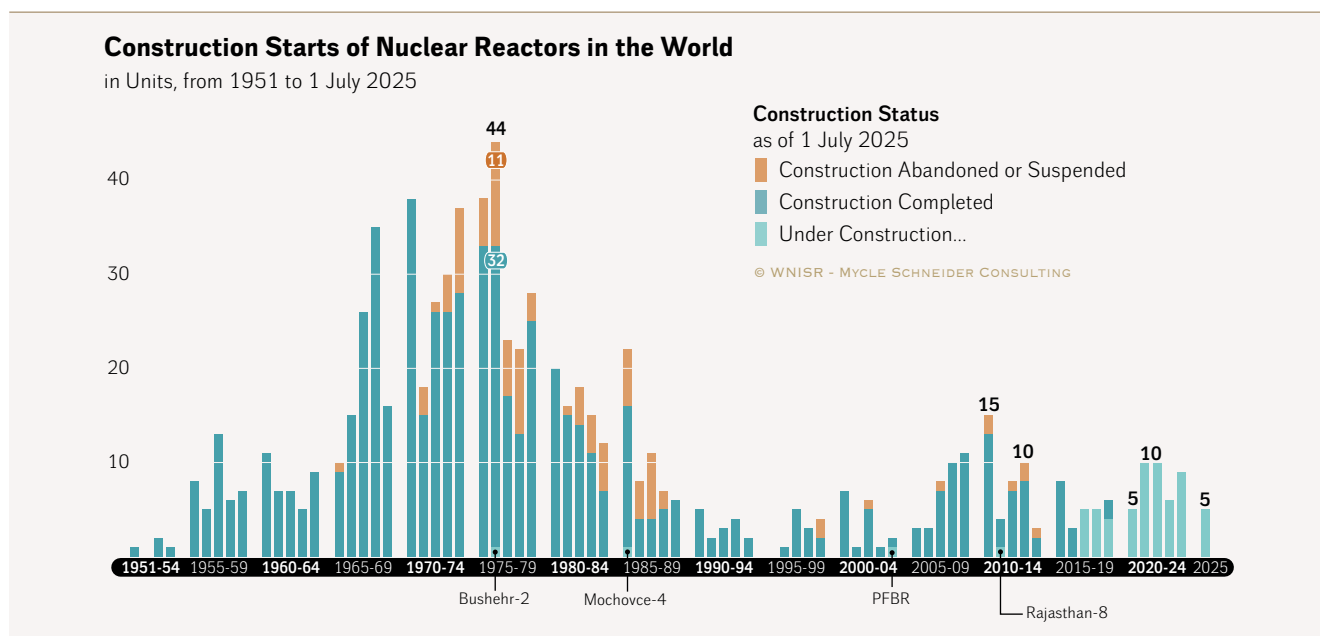
Sources: Various, compiled by WNISR, 2025

CONSTRUCTION STARTS AND CANCELLATIONS

The number of annual construction starts in the world peaked in 1976 at 44, of which 11 projects were later abandoned. In 2010, there were 15 construction starts—including 10 in China—the highest level since 1985 (see [Figure 13](#) and [Figure 14](#)). That number dropped to five in 2020 (including four in China), while building started on ten units in 2021 (including six in China), as well as in 2022 (including five in China). Six constructions started in 2023, of which five in China and one in Egypt implemented by the Russian nuclear industry. Nine constructions started in 2024, of which six in China, one in Russia, one in Pakistan implemented by Chinese companies, and one in Egypt implemented mainly by Russian companies. In other words, over the five years between January 2020 and the end of 2024, all of the 40 construction starts in the world were either implemented by the Chinese or the Russian nuclear industries.

Five reactors got underway in the world in the first half of 2025, three of them in China, one in Russia, and one in South Korea. So, Chinese and Russian government-owned or -controlled companies launched all 44 of the 45 reactor constructions in the world over the 66-month period from the beginning of 2020 to mid-2025.

Figure 13 · Construction Starts in the World



Sources: WNISR with IAEA-PRIS, 2025

Over the decade 2015–2024, construction began on 67 reactors in the world, of which way over half (39) in China. As of mid-2025, 13 of those units had started up, while 54 remain under construction.

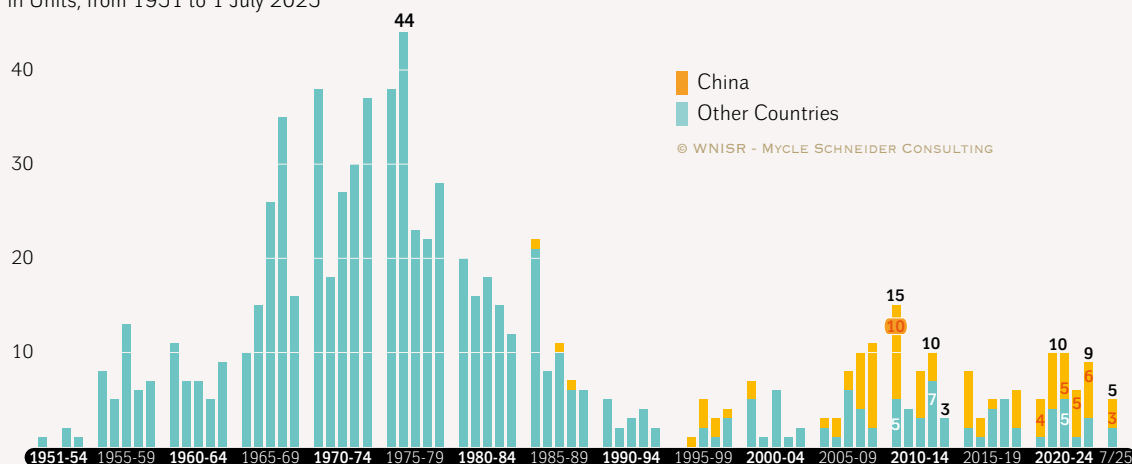
Seriously affected by the Fukushima events, China did not start any construction in 2011 and 2014 and began work on “only” seven units in total in 2012 and 2013. While Chinese utilities started building six more units in 2015, the number shrank to two in 2016, only a demonstration fast reactor in 2017, none in 2018, but four each in 2019 and 2020, six in 2021, five each in 2022 and 2023, six in 2024 and three in the first half of 2025 (see Figure 14). While this increase represents a sign of the restart of large-scale reactor building in China, the level continues to remain far below expectations. The five-year plan 2016–2020 had fixed a target of 58 GW operating and 30 GW under construction by 2020. As of the end of 2020, China had 49 units with 51 GW (47.5 GW net) operating, one reactor in LTO (CEFR), and 17 units (17.5 GW gross / 16 GW net) under construction, much lower than the original target.

With an operating capacity of around 61 GW as of mid-2025, the 14th Five-Year Plan (2021–2025) target of 70 GW operational capacity is also out of reach. At the end of 2024, 59 reactors with a total capacity of 56.7 GW were operating and 29 units (31 GW) were under construction. According to plans, 4.5 GW are scheduled to come online in 2025, but no new reactor started up in the first half of the year (for details and references, see China Focus).

Figure 14 · Construction Starts in the World/China

Construction Starts of Nuclear Reactors in the World

in Units, from 1951 to 1 July 2025



Sources: WNISR with IAEA-PRIS, 2025

Experience shows that having an order for a reactor or even having a nuclear plant at an advanced stage of construction, is no guarantee of ultimate grid connection and power production. The two V.C. Summer units, abandoned in July 2017 after four years of construction and following multi-billion-dollar investment, are only one example in a long list of failed significantly advanced nuclear power plant projects. Another recent example is the Small Modular Reactor (SMR) CAREM-25, an Argentinian domestic design, that was abandoned in 2024 after ten years of construction.

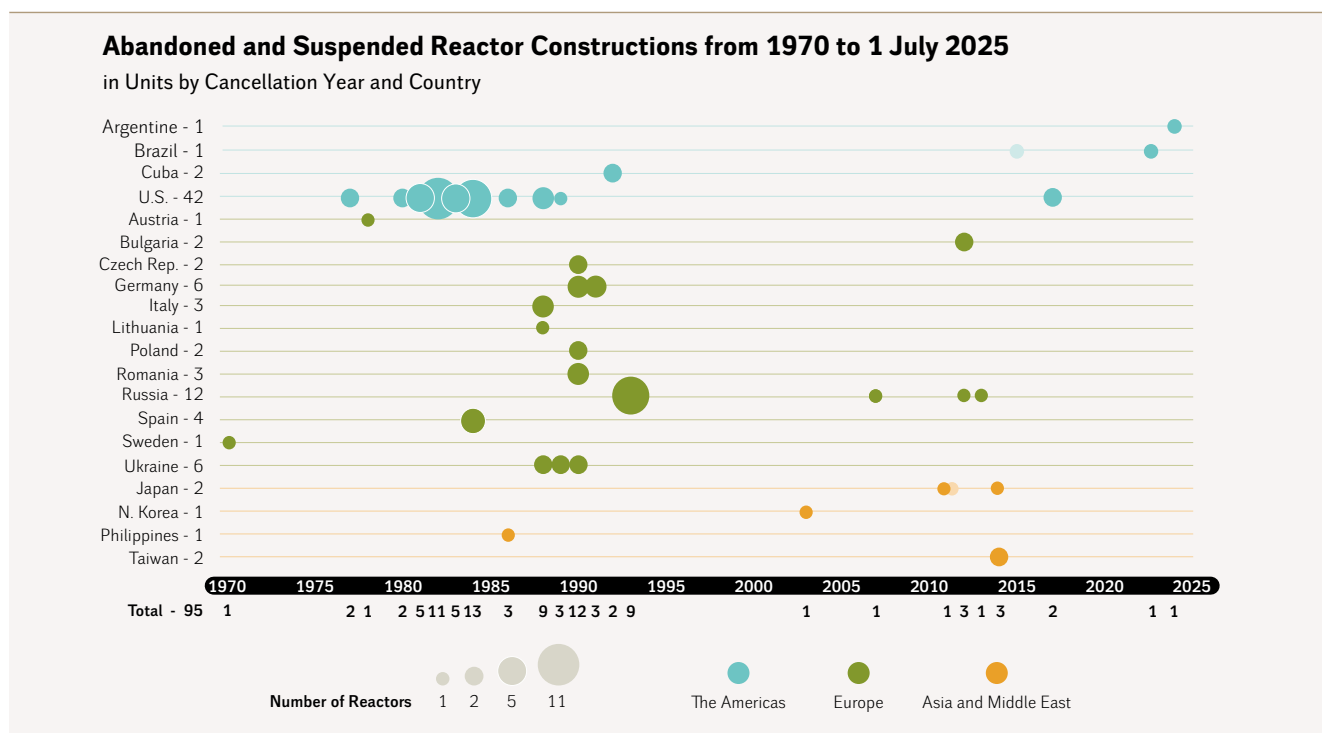
French Alternative Energies and Atomic Energy Commission (CEA) statistics through 2002 indicate 253 “cancelled orders” in 31 countries, many of them at an advanced construction stage (see also Figure 15). The United States alone accounted for 138 of these order cancellations.³³ Unfortunately, the data series does not distinguish between “orders” and “constructions” and it has been discontinued.

Of the 817 reactor constructions launched since 1951, at least 95 units in 20 countries had been abandoned or suspended, as of 1 July 2025. This means that 11.5 percent—or one in nine—of nuclear constructions have been abandoned.

Close to three-quarters (66 units) of all cancelled projects were in four countries alone—the U.S. (42), Russia (12), Germany and Ukraine (six each). Some units were 100-percent completed—including Kalkar in Germany and Zwentendorf in Austria—before it was decided not to operate them.

33 - CEA, “Elecnucl—Nuclear Power Plants in the World”, Commissariat à l’énergie atomique et aux énergies alternatives/French Alternatives Energies and Atomic Energy Commission, 2002. The section “cancelled orders” has disappeared after the 2002 edition.

Figure 15 · Cancelled or Suspended Reactor Constructions



Sources: Various, compiled by WNISR, 2025

Notes: The shaded colors indicate the first suspension in the case of reactors where construction was suspended several times (Brazil and Japan).

This figure only includes constructions that had officially started with the concreting of the base slab of the reactor building. Many more projects have been cancelled at earlier stages of construction/site preparation and equipment manufacturing.

OPERATING AGE

In the absence of significant, successful newbuild over many years, the average age (from grid connection) of operating nuclear power plants has been increasing for 40 years, since 1984, and as of mid-2025 stands at 32.4 years, up from 32 years in mid-2024 (see Figure 16).³⁴

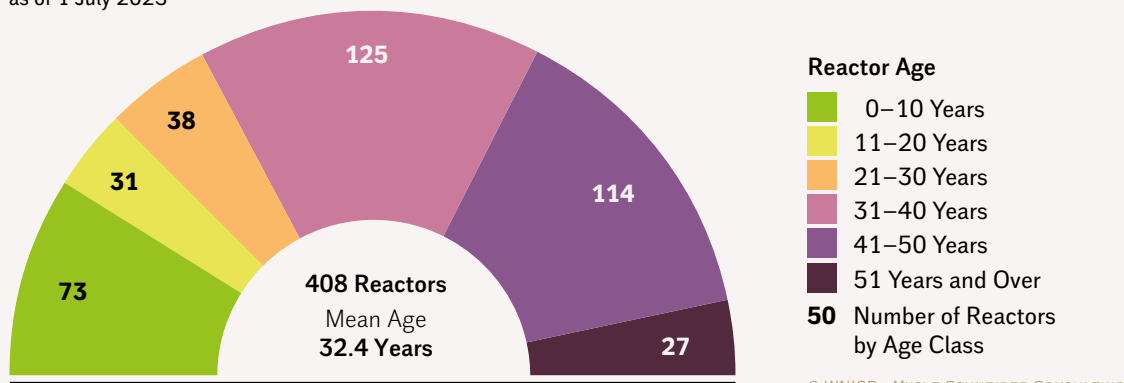
A total of 266 reactors, two-thirds of the world's operating fleet, have operated for 31 or more years, including 141—more than one in three—for at least 41 years.

³⁴ - WNISR calculates reactor age from grid connection to final disconnection from the grid. In WNISR statistics, “startup” is synonymous with grid connection and “closure” with withdrawal from the grid. In order to have a better image of the fleet and ease calculations, the age of a reactor is considered to be 1 between the first and second grid connection anniversaries. For some calculations, we also use operating years: the reactor is in its first operating year until the first grid connection anniversary, when it enters the second operating year.

Figure 16 · Age Distribution of Operating Reactors in the World

Age of World Nuclear Fleet

as of 1 July 2025



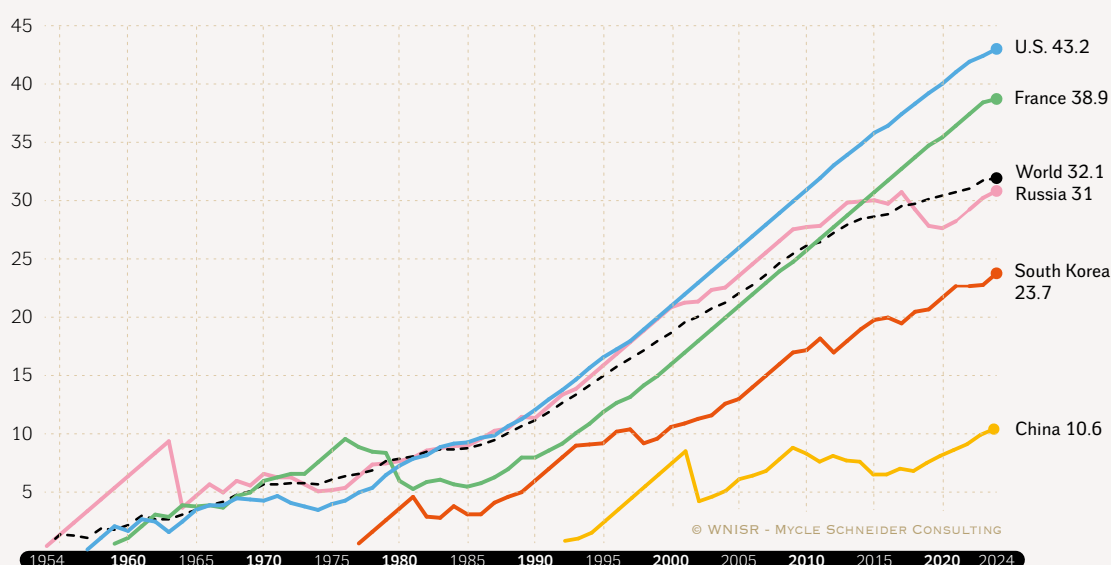
Sources: WNISR, with IAEA-PRIS, 2025

In 1990, the average age of the operating reactors in the world was 11.3 years; in 2000, it was 18.8 years, and it stood at 26.3 years in 2010. The leading nuclear nation also has the oldest reactor fleet of the top-five nuclear generators. The average age of reactors in the U.S. passed 40-years in 2020 and reached 43.2 years as of the end of 2024. France's fleet reached almost 39 years. Russia's fleet age peaked in 2017 and declined for a few years before increasing again starting in 2020, and its average fleet age of 31 years, as of the end of 2024, caught up with that of 2017. South Korea's reactors reached 23.7 years (including two reactors in LTO); the operating fleet, with an average age of 22.3 years remained almost half as old as the U.S. fleet. And China, the outrunner, had an average fleet age of only 10.6 years. (See Figure 17).

Figure 17 · Reactor-Fleet Age of Top 5 Nuclear Generators

Evolution of Mean Age of Top 5 Reactor Fleets in the World

in Years, as of year-end 1954–2024

Mean Age
in Years, as of 31 December 2024

Sources: WNISR with IAEA-PRIS, 2025

Many nuclear utilities envisage average reactor lifetimes of beyond 40 years up to 60 and even 80 years. In the U.S., reactors are initially licensed to operate for 40 years, but nuclear operators can request a license renewal from the Nuclear Regulatory Commission (NRC) for an additional 20 years. An initiative to allow for 40-year license extensions in one step was terminated in June 2021 after NRC staff recommended that the Commission “discontinue the activity to consider regulatory and other changes to enable license renewal for 40 years.”³⁵

As of mid-2025, 86 of the 94 operating U.S. units had received a first 20-year license extension, applications for four further reactors were under NRC review, including the Initial License Renewal application for the Diablo Canyon units, that was slated for closure and is now planned to be restarted.³⁶

As of 1 July 2025, the NRC had granted Subsequent Renewed Operating Licenses to thirteen reactors, which permit operation from 60 to 80 years. A further twelve reactors have their applications still under review, and owners have notified of their intentions to submit applications for a further 29 reactors between 2025 and 2034, including three currently retired reactors See [Extended Reactor Licenses in United States Focus](#) for details and references.

Only nine of the 41 units that have been closed in the U.S. had reached 40 years on the grid. All nine had obtained licenses to operate up to 60 years but were closed long before, mainly for economic reasons. In other words, almost one quarter of the 135 reactors connected to the grid in the U.S. never reached their initial design lifetime of 40 years. Only one of those already closed had just reached 50 years of operation (Palisades, closed after 50.4 years, and currently undergoing a potential restart process). The mean age at closure of those 41 units was 22.8 years.

On the other hand, of the 94 currently operating plants, 57 units have already operated for 41 years or more, of which 20 have been on the grid for 51 years or more; thus, two thirds of the units with license renewals have entered the lifetime extension period, and that share is growing rapidly with the mid-2025 mean age of the U.S. operational fleet exceeding 43.7 years (see [Figure 46](#)).

Many countries have no specific time limits on operating licenses. In France, for example, reactors must undergo in-depth inspection and testing every decade against reinforced safety requirements. The French reactors have operated for over 39 years on average, as of mid-2025.

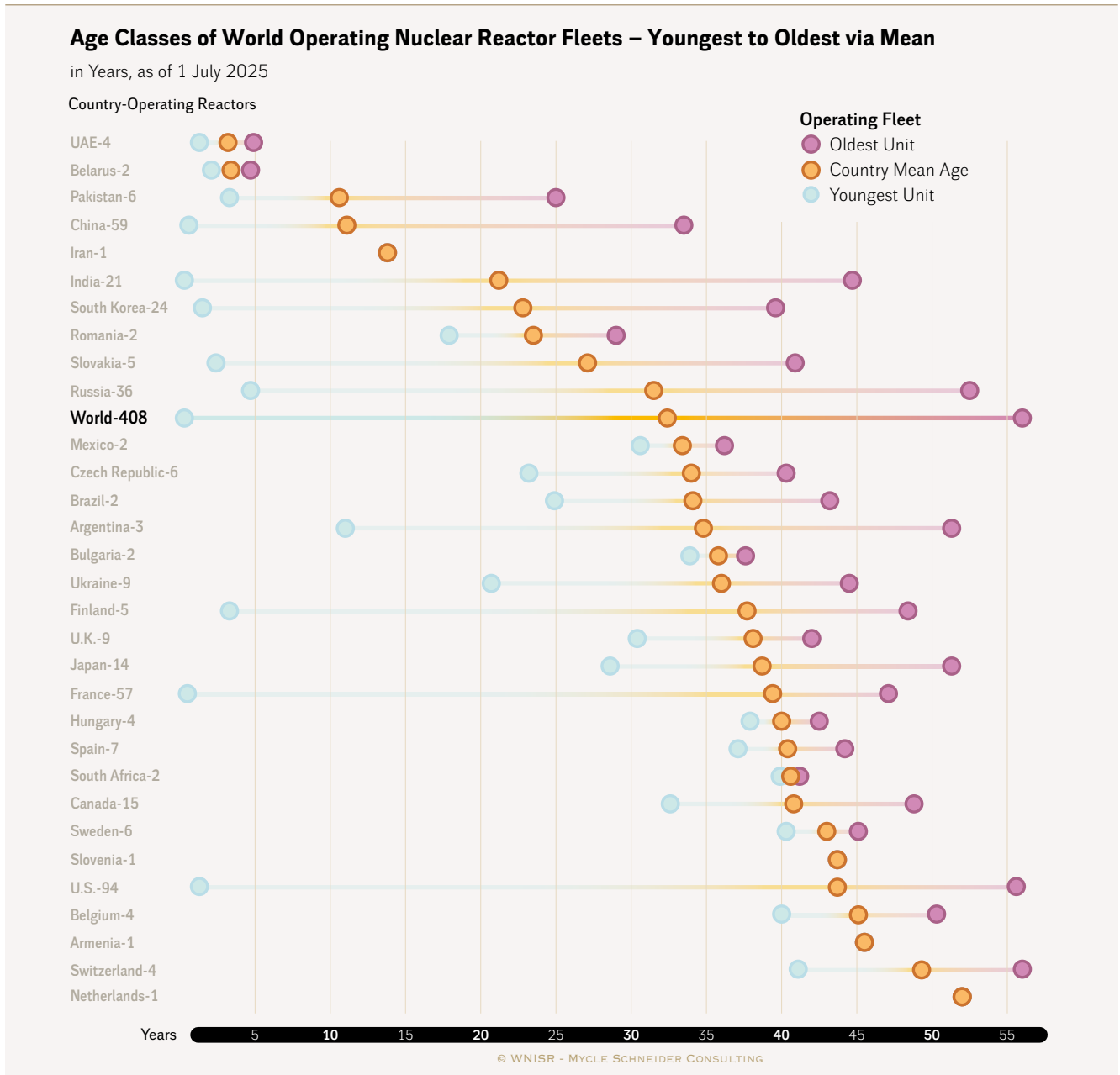
EDF’s approach to lifetime extension has been reviewed by the Nuclear Safety Authority (ASN) and its Technical Support Organization. In February 2021, ASN granted a conditional generic agreement to lifetime extensions of the 32 reactors of the 900 MW series. Lifetime extensions beyond 40 years require reactor-specific licensing procedures involving public inquiries in France and transborder consultations. For an assessment of the status of fourth decennial inspections see [Decennial Inspections – Lifetime Extensions in France Focus](#).

35 - Division of New and Renewed Licenses, “Closure of Activity to Consider License Renewal for 40 Years of Additional Nuclear Power Plant Operation”, Office of Nuclear Reactor Regulation, United States Nuclear Regulatory Commission, 22 June 2021, see <https://www.nrc.gov/docs/ML2111/ML21117A007.pdf>, accessed 11 August 2021.

36 - U.S. NRC, “Status of License Renewal Applications and Industry Activities”, United States Nuclear Regulatory Commission, Updated March 2025, see <http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html>, last accessed 15 August 2025.

Recently commissioned reactors and units under construction, e.g., in South Korea and the U.K. do or will seek a 60-year operating license from the start.

Figure 18 · Age of World Nuclear Fleets



Sources: WNISR with IAEA-PRIS, 2025

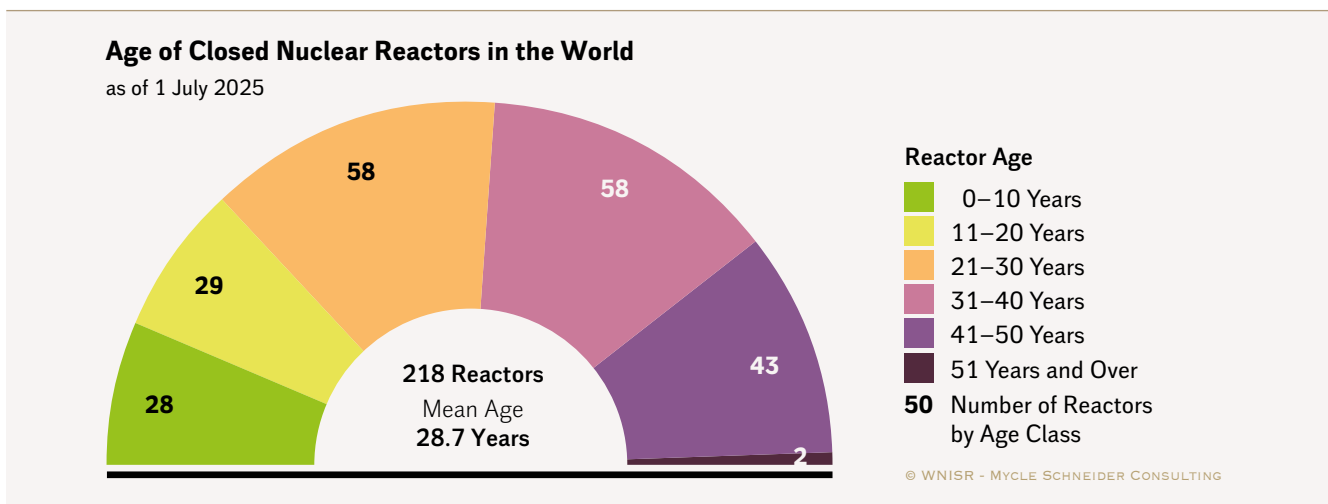
Note: This figure only takes into account reactors operating as of 1 July 2025, thus excluding reactors in LTO, in particular Tarapur-1 & -2 in India, that have passed 50 years.

Figure 18 shows that the average fleet age in 22 of the 31 countries that operate nuclear reactors as of mid-2025 is over 30 years, and in ten countries over 40. Two in three, that is 22 of the countries have been operating one or more reactors for more than 40 years, but only seven countries operate reactors that are over 50 years.

In assessing the likelihood of reactor fleets being able to operate for 50 or 60 years, it is useful to compare the age distribution of reactors that are currently operating with the 218 units that have already closed (see Figure 16 and Figure 19). In total, 103 of these units operated for 31 years or more, of which 45 reactors operated for 41 years or more. Many units of the first-generation designs only operated for a few years. The mean age of the closed units is about 29 years.

At the same time, for the first time, in 2024 reactors closed that have been operating for 51 years and more (Pickering-1 and -2 in Canada). Only few units have been closed exceeding 50 years of operational lifetime, e.g. Doel-1 in Belgium at 50.5 years and Palisades in the U.S.

Figure 19 · Age Distribution of Closed Nuclear Power Reactors

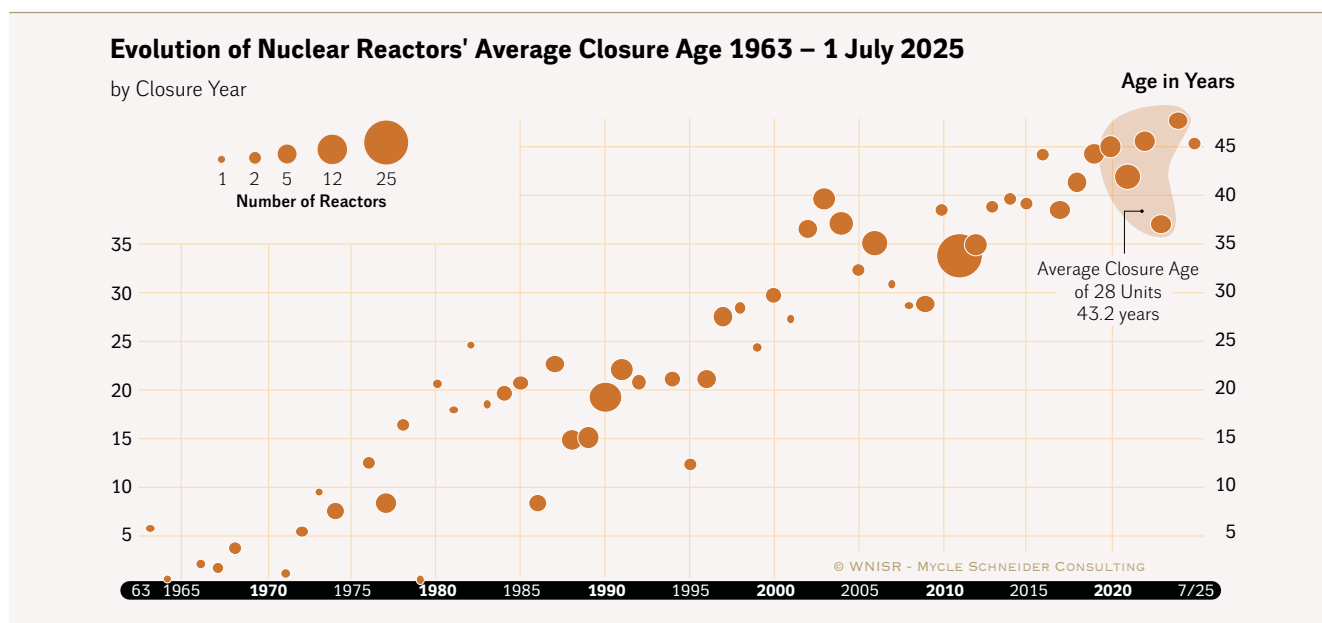


Sources: WNISR with IAEA-PRIS, 2025

While the operating time prior to closure has clearly increased continuously, the mean age at closure of the 28 units taken off the grids in the five-year period between 2020 and 2024 was just 43.2 years (see Figure 20).

As a result of the Fukushima nuclear disaster (also referred to as 3/11), many analysts have questioned the wisdom of operating older reactors. The Fukushima Daiichi units (1 to 4) were connected to the grid between 1971 and 1974. The license for Unit 1 had been extended for another 10 years in February 2011, just one month before the catastrophe started unfolding. Four days after the initial events in Japan, the German government ordered the closure of eight reactors that had started up before 1981, two of which were already closed at the time and never restarted. The sole selection criterion was operational age—30 years or more. Other countries did not adopt the same approach, but clearly the 3/11 events in Japan had an impact—at least temporarily—on previously assumed extended lifetimes in other countries. Some of the main nuclear countries closed their oldest units, at the time, before or long before age 50, including Germany at age 37, South Korea at 40, Sweden at 46. France closed its two oldest units in Spring 2020 at age 43. The U.S. closed its oldest unit, Palisades, at age 50 in 2022 and is now considering reopening it.

Figure 20 · Nuclear Reactor Closure Age



Sources: WNISR with IAEA-PRIS, 2025

LIFETIME PROJECTIONS

Nuclear operators in many countries continue to implement or prepare for lifetime extensions. In previous years, WNISR had modeled two lifetime projections. A first scenario assuming a general lifetime of 40 years for worldwide operating reactors as that, explicitly or implicitly, corresponds to the design lifetimes of most operating reactors; and a second scenario, the Plant Life Extension or PLEX Projection (see [Figure 21](#)), which takes into account all *already-authorized* lifetime extensions as of mid-year and assumes that the respective reactors will operate until the expiration of their license—a conservative assumption considering empirical evidence from the past.

As operational lifetime extensions or license renewals beyond 40 years have increasingly become the norm, as of this edition WNISR drops the 40-year scenario.

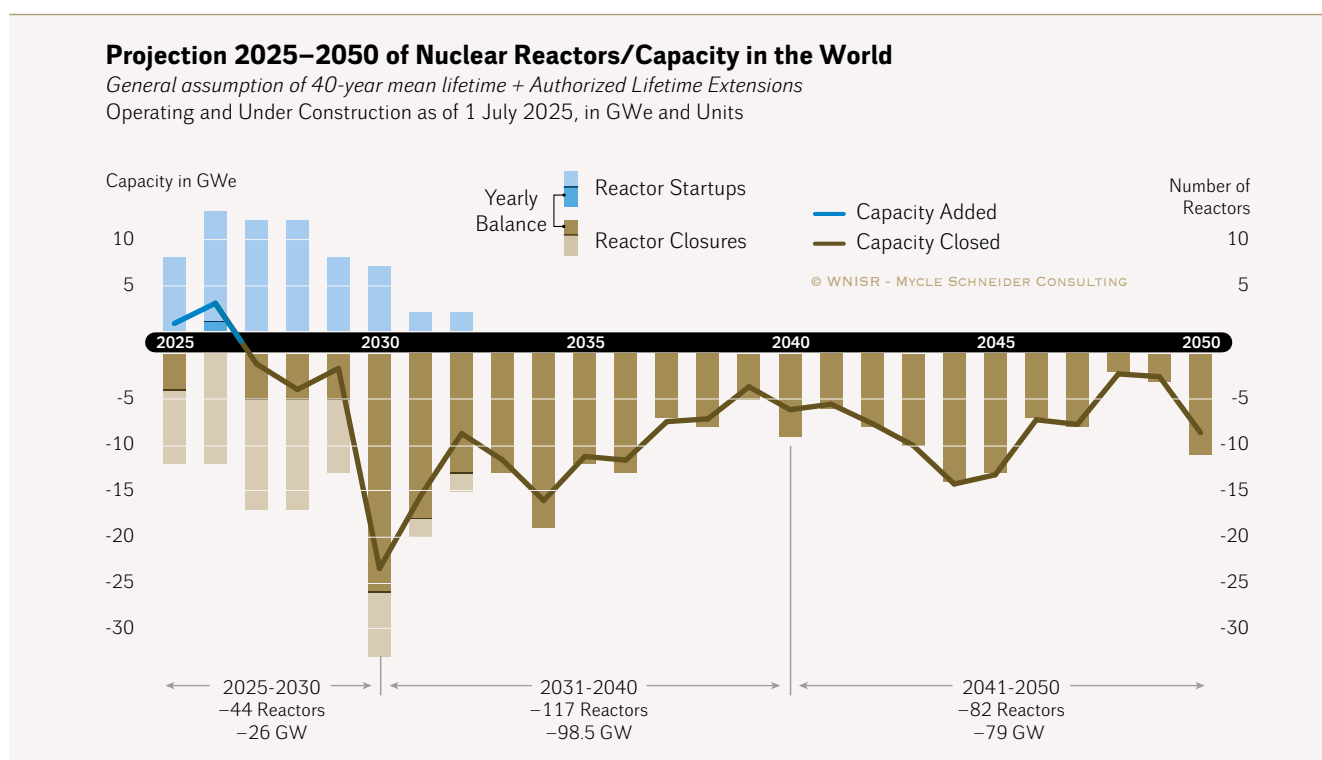
Generalized lifetime extensions—far beyond 40 years—are clearly the objective of the international nuclear power industry, and, especially in the U.S., there are numerous, increasingly successful attempts to obtain subsidies for uneconomic nuclear plants in order to keep them on the grid, or even restart units that have been closed (see [Subsidies and Financing for Nuclear Power in United States Focus](#)). Expensive operational lifetime extensions are now also planned in Europe, e.g., for two reactors for ten years in Belgium.

The extension of the operation of the current nuclear fleet is essential to maintaining at least the status quo as not enough reactors are coming on line to compensate for closures. Developments in Asia, including in China, do not fundamentally change the global picture. Reported ambitions for China's targets for installed nuclear capacity have fluctuated in the

past. While construction starts have picked up speed again since 2021, Chinese medium-term ambitions appear significantly lower than anticipated in the pre-3/11 era.³⁷

The lifetime projection allows for an evaluation of the number of reactors and respective power generating capacity that would have to come online over the next decades to offset closures and simply maintain the same number of operating plants and level of capacity, if all units were closed after their present licensed lifetime extension.

Figure 21 · The PLEX Projection (not including LTOs)



Sources: Various sources, compiled by WNISR, 2025

Notes

Restarts or closures amongst the 33 reactors in LTO as of 1 July 2025 are not represented; however, at least some are expected to be restarted (and later closed, after 2050 in some cases).

In the case of reactors that have reached 40 years of operation prior to 2025, the projection uses the end of their licensed lifetime, including 80 years for 13 reactors in the U.S, where the Subsequent License Renewal Applications have been approved for a further 20 years of operation.

In the case of the French 900 MW-fleet the projection uses the scheduled date of their 4th periodic safety review. In case this deadline is or will be passed by the end of 2025, we apply a "de facto" 10-year extension (operation to 50 years) or the deadline for the fifth review when available.

In the PLEX Projection, all currently licensed lifetime extensions and license renewals are implemented in full, and all construction sites are completed. For all other units, a 40-year lifetime projection is maintained, unless a firm later closure date has been authorized. By the end of 2025, the net number of operating reactors would slightly decline, and the operating capacity would marginally increase (-4 units / +0.8 GW).

In the remaining years to 2030, the net balance would be just in the positive for the year 2026, then drop into negative terrain in the years 2027–2029 with a sharp decrease in 2030; overall, over the period 2025–2030, 44 new reactors or 26 GW *in addition* to the 63 units already under

37 - As of late August 2025, four construction starts had taken place in China since the beginning of the year. Worldwide only two more reactor buildings started (in Russia and in South Korea) in the first eight months of the year.

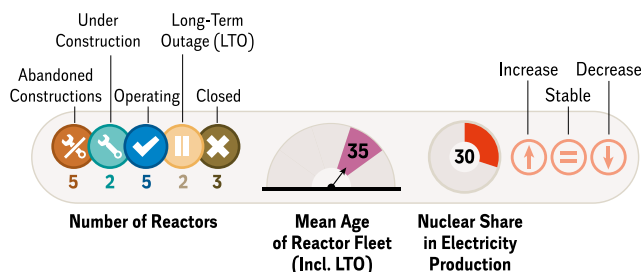
construction and scheduled to start up prior to 2030 would have to be built and commissioned (or units in LTO restarted) to replace expected closures.

Taking into account the already licensed lifetime extensions, the PLEX-Projection would mean for the remaining years to 2030, the need to ramp up the annual startup rate of the past decade by a factor of 2.5 from 6.9 to 17.3 units—including the reactors already expected to start up by 2030 (see [Figure 21](#))—only to maintain the status quo. However, probably at least half of the 104 reactors now projected to close between 2025 and 2030 are seeking and likely to secure a lifetime extension beyond 2030.

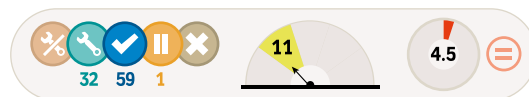
As documented in detail above, construction starts have not been picking up over the past decade. Between the beginning of 2020 and mid-2025, a total of 45 constructions were launched around the world, of which 30 implemented by Chinese companies (including one in Pakistan) and 14 by the Russian industry in various countries, plus one in South Korea, thus an average of 8.2 units per year were launched. Based on empirical evidence, it is unlikely if not impossible that any substantial number of reactors will come online by 2030 that are not under construction as of mid-2025. In other words, newbuild will not be sufficient, only further operational lifetime extensions will allow for the world nuclear fleet not to decline significantly by 2030 and thereafter.

FOCUS COUNTRIES

These “quick view” indicators will be used in the country sections throughout the report.



CHINA FOCUS



Overview

As of mid-2025, China operated 59 nuclear reactors with a combined capacity of 56.7 GW. This count exceeds the IAEA’s tally of 57 because the WNISR records the Shidao Bay project’s twin High-Temperature Reactor Pebble-bed Modules (HTR-PM) as two separate reactors and includes the CAP1400 Shidaowan Guohe One-1.³⁸ (see Table 23 and Table 24 in Annex 2).

In 2024, nuclear plants generated a record 418.4 TWh net electricity, a 2.9 percent increase from 2023.³⁹ Two 1.2-GW Hualong One reactors started up over the year, Fangchenggang-4 in Guangxi Province and Zhangzhou-1 in Fujian Province, in addition to the CAP1400 at Shidao Bay.

According to the China Nuclear Energy Association, despite higher output, nuclear’s share of China’s total electricity production slightly slipped from 4.9 percent in 2023 to 4.7 percent in 2024, (Energy Institute data indicate a 3.7-percent increase in net production and a drop from 4.7 percent to 4.5 percent of the nuclear share).⁴⁰ The remarkable share decline occurred because China’s electricity consumption grew by 6.8 percent or 627 TWh—significantly larger than Germany’s total annual demand—to a total of over 9,850 TWh, and the country added a combined 357 GW of solar and wind capacity (278 GW and 79 GW, respectively) in the same year compared to just 3.5 GW of new nuclear.⁴¹

38 - This reactor, located at Shidao Bay, previously appeared as “Shidao Bay 2-1” in WNISR.

39 - China Nuclear Energy Association, “全国核电运行情况 (2024年1-12月)”, as published by the National Nuclear Safety Administration, 6 February 2025, see https://nnsa.mee.gov.cn/ywdt/hyzt/202502/t20250206_1101794.html, accessed 27 May 2025.

40 - Ibidem; and China Nuclear Energy Association, “全国核电运行情况 (2023年1-12月)”, 31 January 2025, see <https://www.china-nea.cn/site/content/44467.html>, accessed 23 June 2025.

41 - NEA, “2024年全社会用电量同比增长6.8%”, National Energy Administration, Government of China, 20 January 2025, see <https://www.nea.gov.cn/20250120/4f7f249bac714e7693adecac996d742f/c.html>, accessed 2 May 2025; and NEA, “国家能源局发布2023年全国电力工业统计数据”, 26 January 2024, see https://www.nea.gov.cn/2024-01/26/c_1310762246.htm; and NEA, “国家能源局发布2024年全国电力工业统计数据”, 23 January 2025, see https://www.qdn.gov.cn/zwgk_5871642/zdlyxxgk/nyzy_5872082/202501/t20250123_86671673.html; both accessed 5 August 2025.

Some reactors significantly underperformed in 2024:

- ➔ The twin HTR-PM reactors were operational for only about one fifth of the time, partially due to ongoing testing.⁴² It is unclear what other factors have contributed to the low performance.
- ➔ Fuqing-4 was offline for more than one third of the year due to repairs after an incident involving metal debris from a scratched spent fuel assembly support structure in the cooling pool.⁴³
- ➔ Daya Bay-1, a Framatome designed 900-MW reactor, was the first reactor in China subject to a major 200-day overhaul after three decades of operation. It was originally connected to the grid in August 1993. The comprehensive upgrading involved 200 upgrades including the digitalization of the instrumentation and control system.⁴⁴
- ➔ Taishan-2, an EPR, had a load factor of only 69.1 percent, but no official explanation was provided for this. The twin unit Taishan-1 had a better year by comparison—offline between August 2021 and August 2022 and again for almost all of 2023 mainly for fuel assembly repairs—rebounded in 2024 and likely accounts for the lion's share of the overall production increase.⁴⁵ The two 1660-MW EPRs are the largest units in the Chinese fleet.

Construction began on six new reactors in 2024:

- ➔ Lianjiang-2 in Guangdong Province (CAP1000, 1224 MW),
- ➔ Ningde-5 in Fujian Province (Hualong One, 1200 MW),
- ➔ Shidaowan-1 in Shandong Province (Hualong One, 1134 MW),
- ➔ Xudapu-2 in Liaoning Province (CAP1000, 1000 MW), and
- ➔ Zhangzhou-3 and Zhangzhou-4 in Fujian Province (both Hualong One, 1129 MW each).

Another three construction starts took place in the first half of 2025:

- ➔ Lufeng-1 in Guangdong Province (CAP1000, 1000 MW),
- ➔ Shidaowan-2 in Shandong Province (Hualong One, 1134 MW), and
- ➔ Taipingling-3 in Guangdong Province (Hualong One, 1209 MW).

China also advanced with its only active international nuclear project. On 30 December 2024, it poured first concrete for an 1100-MW Hualong One reactor, Unit 6 at Pakistan's Chashma

42 - Zuoyi Zhang, Yujie Dong et al., "Loss-of-Cooling Tests to Verify Inherent Safety Feature in the World's First HTR-PM Nuclear Power Plant", Institute of Nuclear and New Energy Technology, Key Laboratory of Advanced Reactor Engineering and Safety, Ministry of Education, Tsinghua University, *Joule*, Vol 8, Issue 7, 17 July 2024, see <https://www.sciencedirect.com/science/article/pii/S2542435124002903>, accessed 12 April 2025.

For example, on 13 August and 1 September 2023, the Institute of Nuclear and New Energy Technology of Tsinghua University successfully simulated a complete loss of power, shutting off all cooling systems to see if the reactor could safely cool itself without human intervention or backup systems.

43 - NNSA, "福建福清核电站4号机组下部堆内构件与构件池存放架异常接触运行事件", National Nuclear Safety Administration, 21 June 2024, see https://nnsa.mee.gov.cn/ywdh/fyd/202406/t20240621_1076370.html; and 中国核电网, "中国核电2024年全年发电量完成情况 & 2025年发电计划公告", 8 January 2025, see <https://www.cnnpn.cn/article/45889.html>; both accessed 12 April 2025.

44 - 深圳特区报/Shenzhen Special Zone Daily, "大亚湾核电站30年大修圆满完成", as published by Government of Shenzhen, 17 July 2024, see https://www.sz.gov.cn/cn/xxgk/zfxgj/zwdt/content/post_11439987.html, accessed 12 April 2025.

45 - China Nuclear Energy Association, "全国核电运行情况 (2024年1-12月)", February 2025, op. cit.

nuclear power complex⁴⁶—the third unit of the 1200-MW class China has exported to its neighbor. Previously, between 1993 and 2017, China had delivered four units of the 300-MW class to Pakistan, which remains the sole country hosting Chinese-built reactors.

Domestically, construction approvals have ramped up and stabilized with six reactors approved in 2019, four in 2020, five in 2021, and ten each in 2022 and 2023.⁴⁷

In 2024–2025, the Chinese State Council approved two major batches of new projects. On 19 August 2024, it greenlit five projects totaling 16 reactors—including six SMR modules—at a reported cost of CNY₂₀₂₄ 220 billion (US\$₂₀₂₄ 30.6 billion):⁴⁸

- ➔ Xuwei Phase I in Jiangsu Province (two Hualong Ones and a 660-MW high-temperature gas-cooled reactor plant with six modules),⁴⁹
- ➔ Lufeng Phase I in Guangdong Province (two CAP1400s),⁵⁰
- ➔ Zhaoyuan Phase I in Shandong Province (two Hualong Ones),⁵¹
- ➔ San’ao Phase II in Zhejiang Province (two Hualong Ones), and
- ➔ Bailong Phase I in Guangxi Province (two CAP1000s).⁵²

On 27 April 2025, a second batch of approvals included five projects (10 reactors) costing a reported estimated total of over CNY200 billion (US\$27.8 billion):⁵³

- ➔ Fangchenggang Phase III in Guangxi Province (two Hualong Ones),
- ➔ Taishan Phase II in Guangdong Province (two Hualong Ones),
- ➔ Sanmen Phase III in Zhejiang Province (two Hualong Ones),
- ➔ Haiyang Phase II in Shandong Province (two CAP1000s), and

46 - Ghulam Abbas, “Construction begins on 1200 MW Chashma Nuclear Power Project Unit-5”, *Pakistan Today*, 31 December 2024, see <https://profit.pakistantoday.com.pk/2024/12/30/construction-begins-on-1200-mw-chashma-nuclear-power-project-unit-5/>, accessed 4 April 2025; and Government of Pakistan, “PAEC Starts Construction on C-5 Chashma Nuclear Power Plant”, *Radio Pakistan*, 31 December 2024, see <https://www.radio.gov.pk/31-12-2024/paec-commences-construction-work-on-chashma-nuclear-power-plant-c-5>, accessed 17 June 2025.

47 - 朱学蕊, “国常会核准! 5个核电项目, 合计11台机组”, 中国能源报, as published by China Nuclear Energy Agency, 20 August 2024, see <https://www.china-nea.cn/site/content/46849.html>, accessed 24 June 2025.

48 - 戴晶晶, “史无前例, 国常会一口气核准了11台核电机组”, *Shenzhen Securities Times*, 20 August 2024, see <https://www.stcn.com/article/detail/1291744.html>, accessed 2 May 2025.

49 - CNNPN, “国务院常务会议核准江苏徐圩710亿元核电项目一期工程 中核集团总经理申彦锋: 建议加快“华龙一号”批量化建设”, 20 August 2024, see <https://www.cnnpn.cn/article/43081.html>, accessed 7 April 2025; and Zhe Dong, Zuoyi Zhang et al., “Testing the Feasibility of Multi-Modular Design in an HTR-PM Nuclear Plant”, Institute of Nuclear and New Energy Technology, Key laboratory of Advanced Reactor Engineering and Safety of Ministry of Education, Tsinghua University, *Nature Communications*, Vol. 16, Issue 1, 21 March 2025.

50 - 周雪琴 and 蔡泽韩, “进度条刷新! 陆丰核电项目1号机组主体工程开工”, Press Release, Lufeng Municipal Government Office, see http://www.lufengshi.gov.cn/gkmlpt/content/1/1126/post_1126433.html#3904, accessed 7 April 2025.

51 - CGN Power, “Approval of the Construction of Nuclear Power Generating Units”, 19 August 2024, see <https://www1.hkexnews.hk/listedco/listconews/sehk/2024/0819/2024081901394.pdf>, accessed 31 August 2025; and CGN Power, “Environmental, Social and Governance Report 2024”, March 2025.

52 - Guangxi Nuclear Power Company Ltd, “广西白龙核电一期工程1号核岛负挖启动”, State Power Investment Corporation, 31 December 2024, see https://www.spicgnp.com/kxw/gsxw/content_1136, accessed 7 April 2025.

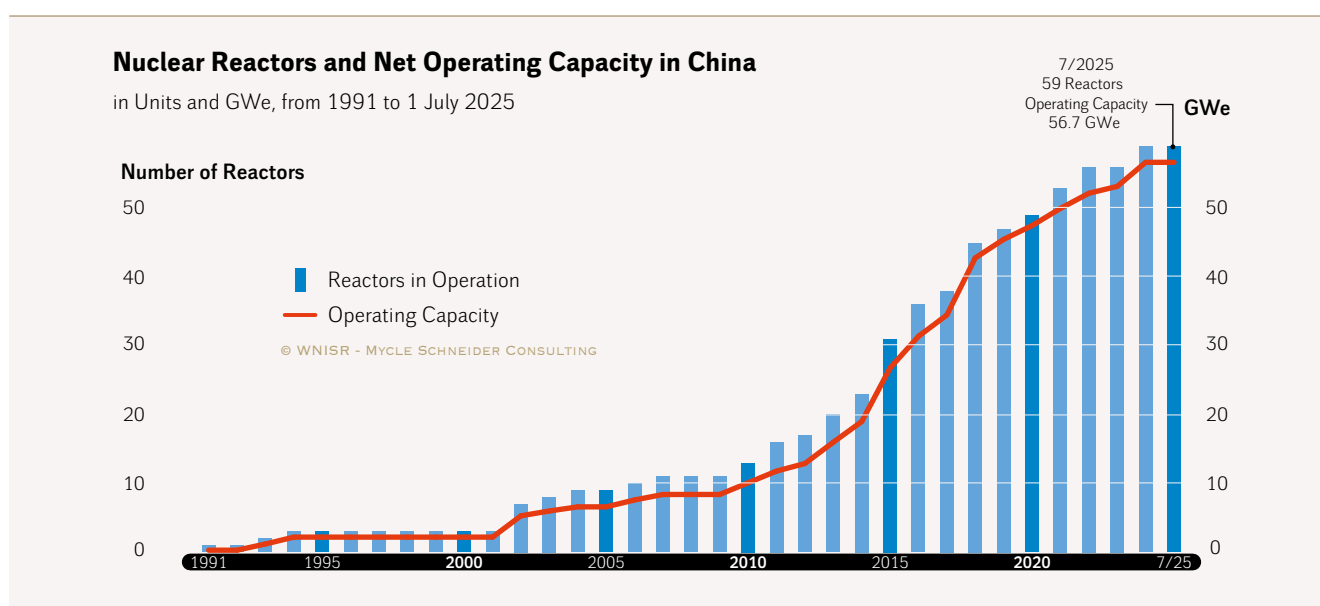
53 - 朱学蕊, “国常会再核准! 5大核电项目10台机组”, 中国能源网/CNEEnergyNews.cn, 27 April 2025, see https://www.cnenergynews.cn/hangye/2025/04/27/detail_news_20250427210962.html, accessed 29 April 2025; and 杨潇, “核电开闸! 国常会核准10台新机组, 拉动超2000亿投资, 新项目花落谁家?”, 澎湃新闻/The Paper, 27 April 2025, see https://m.thepaper.cn/newsDetail_forward_30730887, accessed 2 May 2025.

- ➔ Xiapu PWR Phase I in Fujian Province (two Hualong Ones, co-located with two 600-MW sodium-cooled fast reactors with uncertain status, see hereunder).

Sanmen Phase I and II in Zhejiang Province used the AP-1000 design or its Chinese adaptation—the CAP1000—in the case of the two latest units, while Taishan Phase 1 in Guangdong Province employed the EPR; both sites will now switch to Hualong One for future units.

In the decade 2015–2024, China expanded the number of operating reactors from 31 to 59 while more than doubling the operating capacity of its fleet from 26.8 GW to 56.7 GW (see Figure 22).

Figure 22 · The Expansion of the Chinese Nuclear Fleet, 1991–2025



Sources: WNISR with IAEA-PRIS and NNSA, 2025

With the startup of four AP-1000 reactors in 2018, China began operating its first so-called Generation III reactors.⁵⁴ The first Hualong One, China's domestic Generation III (Gen III) design, was connected to the grid in 2020, followed by one each in 2022 and 2023 and two in 2024.

China's Nuclear Sector and Ecosystem

Since the launch of major economic reforms in 1978, China has gradually expanded its civilian nuclear use, actively pursuing international partnerships to acquire advanced technology.⁵⁵

⁵⁴ - Westinghouse, "Four Additional Westinghouse AP1000® Reactors to be Built in China", Press Release, 26 April 2022, see <https://info.westinghousenuclear.com/news/four-westinghouse-ap1000-reactors-in-china>, accessed 29 May 2025.

⁵⁵ - For an overview of the history of Chinese nuclear development in English, see Yi-chong Xu, "The Politics of Nuclear Energy in China", Griffith University, Palgrave Macmillan, 2010, see <https://link.springer.com/book/10.1057/9780230290532>, accessed 5 May 2025; and Mark Hibbs, "The Future of Nuclear Power in China", Carnegie Endowment for International Peace, 2018, see https://carnegieendowment.org/files/Hibbs_ChinaNuclear_Final.pdf, accessed 20 July 2018; also Philip Andrews-Speed, "Nuclear Power in China: Its Role in National Energy Policy", The Oxford Institute for Energy Studies, January 2023, see <https://www.oxfordenergy.org/wpcms/wp-content/uploads/2023/01/Nuclear-Power-In-China-CE3.pdf>, accessed 6 May 2025.

In 1985, construction began on China's domestically designed 300-MW class Qinshan-I reactor. In 1986, under Deng Xiaoping, China purchased two French 900-MW reactors for the Daya Bay project, marking its first major step into commercial civilian nuclear power. A year later, construction began on the Daya Bay site,⁵⁶ in spite of the largest opposition movement to a nuclear power project in history to that date collecting over one million signatures within a few months.⁵⁷

While China possesses abundant coal, it has limited oil and gas reserves. Despite heavy reliance on coal for electricity generation, the country became a net importer of oil in 1993 and of natural gas in 2009.⁵⁸ In the early 2000s, as economic growth surged, China faced worsening power shortages, logistical bottlenecks, and environmental degradation. Behind the scenes, nuclear energy has been touted as a cleaner, more stable alternative. Under Premier Wen Jiabao (2003–2013), the country began accelerating the expansion of its nuclear fleet.

At the same time, China remained committed to achieving technological self-sufficiency. To facilitate quicker knowledge transfer, it widely opened its nuclear market to foreign companies in the mid-1990s. Simultaneously, Chinese vendors began developing their own domestic Generation III PWRs, building on imported designs from France and the United States. In the early 2010s, Beijing merged CNNC's and CGN's competing reactor designs into a unified national model: the Hualong One.

China has not limited itself to PWRs. It has actively pursued alternative technologies, including high-temperature gas-cooled pebble-bed reactors, sodium-cooled fast reactors, and thorium-based molten salt reactors. These efforts often revive earlier Western designs abandoned elsewhere but seen in China as promising for its long-term energy strategy.

State-Owned Giants: China National Nuclear Corporation (CNNC) and China General Nuclear Power Corporation (CGNPC or CGN)

China's nuclear sector is dominated by two state-owned giants: CNNC and CGNPC (or simply CGN). Though both are centrally owned, they have distinct mandates and histories and operate under a model of state-guided competition. This “one industry, multiple champions” approach is a hallmark of China's strategy in critical areas such as energy and infrastructure.

Founded in 1955, CNNC originated as the Second Ministry of Machine Building Industry, in charge of nuclear industry development. In 1988, it was renamed China National Nuclear Corporation (CNNC) and transformed into a state-owned enterprise. CNNC was instrumental in developing China's first nuclear weapons, submarines, and power reactors. Today, CNNC is considered the more strategic of the two companies, overseeing the full nuclear fuel chain, military nuclear assets, and civilian power plants.

⁵⁶ - State-owned Assets Supervision and Administration Commission, “Construction of the Daya Bay Nuclear Power Plant Starts on August 7, 1987”, State Council, Government of China, 7 August 2020, see http://en.sasac.gov.cn/2020/08/07/c_2014.htm, accessed 25 June 2025.

⁵⁷ - Marcus Yee, “Mobilizing Hong Kong: Nuclear Anxiety and Mass Protest against the Daya Bay Nuclear Power Plant (1979–1986)”, *Journal of Asian Studies*, Vol. 82, Issue 2, May 2025.

⁵⁸ - Sergei Trough, “China's Changing Oil Strategy and its Foreign Policy Implications”, *Brookings*, 1 September 1999, see <https://www.brookings.edu/articles/chinas-changing-oil-strategy-and-its-foreign-policy-implications/>, accessed 25 June 2025; and *China Daily*, “China's Natural Gas Output Up 7.7% in 2009, 20 February 2010.

CGN was established in 1994 to focus on civilian nuclear energy and facilitate technology transfer. Originally named China Guangdong Nuclear Power Group, it has since evolved into China General Nuclear Power Corporation (CGNPC), a commercially oriented central State-Owned Enterprise (SOE) known for its operational efficiency and international partnerships.

Nuclear energy in China is treated not merely as a commercial venture but as a strategic imperative. CNNC and CGN are tasked with ensuring energy security, stabilizing electricity supply, and supporting China's low-carbon transition. While profitability matters—especially to sustain Research and Development (R&D) in advanced technologies—short-term gains are considered secondary to broader national goals.

Projects are typically led by CNNC or CGN, often in joint ventures with local governments and state-owned grid operators. Central government approval signals strong political backing and minimizes future policy risk. Financing is generally provided by the SOEs themselves, local authorities, and state-owned banks offering long-term, low-interest loans underpinned by implicit sovereign guarantees. Land use and licensing processes are streamlined accordingly.

Regulated tariffs—set or approved by the National Development and Reform Commission (NDRC)—offer nuclear operators predictable revenue for 15 to 20 years. In many regions, nuclear plants are given priority grid access over coal-fired plants for environmental reasons. (See [China's Construction Costs and Capabilities](#) for details.)

In 2024, China National Nuclear Power Co., Ltd. (CNNP), CNNC's primary domestic operating platform, managed 25 reactors with a combined installed capacity of 23.6 GW (gross).⁵⁹ Including Zhangzhou-1, which entered commercial operation in January 2025, CNNP had a total of 26 reactors online, with a net capacity of 23.2 GW.

CGN Power, the main listed subsidiary of CGN Group, operated 28 commercial reactors, making it a central player in China's nuclear landscape.⁶⁰ Those represented 29.6 GW net.

Targets vs. Reality

China has dominated global nuclear power development over the past quarter-century, though its ambitious latest Five-Year Plan targets have proven challenging to meet.

The 10th Five-Year Plan (2001–2005) put forward a policy of “moderate development of nuclear power,” targeting around 8.6 GW gross operating capacity by 2005,⁶¹ with 7.1 GW gross achieved in reality. (All Five-Year Plan capacity numbers quoted hereunder are gross gigawatts).

During this period, China connected six new units to the grid—including two French 900-MW reactors at Ling Ao and two Canadian 668-MW CANDU 6 reactors at Qinshan—and completed the development of the CPR-1000, China's indigenized version of the French M310 900-MW design that would become the workhorse of its early nuclear fleet.

59 - CNNC, “中国核能电力股份有限公司2024年年度报告”, April 2025, see <https://pdf.valueonline.cn/web/viewer.html?v=20200509&file=https%3A%2F%2Fydannouncementbucket.obs.myhuaweicloud.com%2F20250429%2F202504291745836431328097938.pdf>, accessed 3 May 2025.

60 - CGN, “中国广核电力股份有限公司 2024 年年度报告摘要”, March 2025, see https://file.finance.sina.com.cn/211.154.219.97:9494/MRGG/CNSESZ_STOCK/2025/2025-3/2025-03-27/10811761.PDF, accessed 3 May 2025.

61 - State Council, “中华人民共和国国民经济和社会发展第十个五年计划纲要”, Government of China, approved 15 March 2001, see https://www.gov.cn/gongbao/content/2001/content_60699.htm, accessed 2 August 2025.

The 11th Five-Year Plan (2006–2010) called on China to pursue “an active development of nuclear power” with a target of 10 GW gross operating by 2010.⁶² With 10.9 GW gross operating at the end of 2010, that target was slightly over-achieved.

This period saw the construction starts for Westinghouse’s two AP-1000s at Sanmen in 2009 and AREVA’s EPRs at Taishan in 2009–2010, China’s first Gen III projects. Construction commenced on 29 units, most of which were CPR-1000 reactors.

Fukushima’s March 2011 disaster fundamentally reshaped China’s nuclear trajectory during the 12th Five-Year Plan (2011–2015). The government imposed a moratorium on new approvals to conduct comprehensive safety reviews. Existing plants and Gen II reactors under construction had to undergo major upgrades including enhanced flood barriers, backup power system overhauls, and seismic reinforcements.⁶³

When approvals resumed, China adopted a strict “Gen III-only” policy requiring passive safety features and core-catchers. Operational capacity reached just 28.7 GW by 2015 versus a target of 40 GW.⁶⁴ Nevertheless, the period closed with construction beginning on Fuqing-5 and -6 as well as Fangchenggang-3, China’s first Hualong One reactors, representing its indigenous Gen III technology.

The 13th Five-Year Plan (2016–2020) aimed for 58 GW operational capacity plus 30 GW under construction while establishing the Hualong One as an exportable technology and advancing systems like the high-temperature gas-cooled reactor (HTR-PM) and fast reactors.⁶⁵

However, domestic capacity reached only 51 GW by 2020 and 17.5 GW under construction constrained by the ongoing inland reactor ban—a controversy unheard of in other nuclear countries limiting nuclear power plant development to the seashore—and extended construction timelines for Generation III units.

In August 2019, the U.S. added CGN to its Entity List,⁶⁶ citing national security concerns regarding alleged attempts to acquire U.S. technology for military purposes.⁶⁷ This restricted CGN’s access to certain technologies and affected its international partnerships, including

62 - 苏嘉, “技术引进与自主创新: 新中国核电技术发展历程”, 当代中国史研究, as released on 中华人民共和国史网, 11 November 2024, see http://www.hprc.org.cn/gsjj/whs/kjs/202411/t20241111_5801649.html, accessed 5 May 2025; and State Council, “中华人民共和国国民经济和社会发展第十一个五年规划纲要”, Government of China, adopted 14 March 2006, see https://www.gov.cn/gongbao/content/2006/content_268766.htm, accessed 2 August 2025.

63 - Ministry of Ecology and Environment, “国务院批复《核安全与放射性污染防治‘十二五’规划及2020年远景目标》”, as published by National Energy Administration, Government of China, 17 October 2012, see https://www.nea.gov.cn/2012-10/17/c_131911605.htm, accessed 28 May 2025; and Xinhua News Agency, “China Suspends Approvals for New Nuclear Plants”, as published by Beijing Review, 17 March 2011, see https://www.bjreview.com/headline/txt/2011-03/17/content_344175.htm; and Government of China, “The Sixth National Report Under the Convention on Nuclear Safety”, August 2013, see <https://nnsa.mee.gov.cn/english/resources/national/201805/P020180524592077508293.pdf>; both accessed 2 August 2025.

64 - State Council, “国务院关于印发能源发展“十二五”规划的通知”, 1 January 2013, Government of China, as published by National Energy Administration, see https://www.nea.gov.cn/2013-01/28/c_132132808.htm, accessed 3 August 2025.

65 - National Development and Reform Commission, “电力发展“十三五”规划 (2016-2020年)”, National Energy Administration, Government of China, November 2016, see <https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/201612/P020190905497888172833.pdf>, accessed 6 May 2025; and State Council, “国务院关于印发“十三五”国家科技创新规划的通知”, Government of China, 28 July 2016, published 8 August 2016, see https://www.gov.cn/zhengce/content/2016-08/08/content_5098072.htm, accessed 5 May 2025.

66 - The Entity List corresponds in practice to blacklisting of designated companies making it virtually impossible for U.S. trading partners to keep engaging in business with them.

67 - Bureau of Industry and Security, “Addition of Certain Entities to the Entity List, Revision of Entries on the Entity List, and Removal of Entities From the Entity List”, Department of Commerce, United States Government, *Federal Register*, Vol. 84, No. 157, August 2019, see <https://www.federalregister.gov/documents/2019/08/14/2019-17409/addition-of-certain-entities-to-the-entity-list-revision-of-entries-on-the-entity-list-and-removal>, accessed 5 May 2025.

involvement in nuclear projects in the United Kingdom. Later, CNNC was also added to the Entity List.⁶⁸ The sanctions reinforced China's focus on self-reliance, accelerating the transition from foreign technologies to the domestically developed Hualong One design.

With an operating capacity of around 61 GW as of mid-2025, the 14th Five-Year Plan (2021–2025)⁶⁹ target of 70 GW operational capacity is out of reach. According to plans, 4.5 GW are scheduled to come online in 2025, but no new reactor started up in the first half of the year. COVID-19 pandemic disruptions to global supply chains, combined with delays caused by mandatory safety upgrades, have created persistent bottlenecks. First-of-a-kind Hualong One projects saw numerous delays (see Figure 23).

Meanwhile, plans for innovative projects like offshore floating nuclear power platforms appear to have stalled, with 2023 reports suggesting the program may have been suspended over safety and feasibility concerns.⁷⁰

The Localization of China's Nuclear Industry

China's nuclear sector has progressed from technology importer to developing indigenous capabilities over four decades through industrial policy, corporate initiative, and regulatory frameworks. The development of local nuclear technology and independent construction capabilities has remained a consistent priority since the beginning of China's nuclear power program. Developments include the Hualong One reactor. According to CNNC, for the first such reactor to be commissioned (Fuqing-5), all the key components and parts have been manufactured in China with the project's localization rate exceeding 85 percent.⁷¹ China also developed a localized supply chain for the HTR-PM.

The path to technological independence involved ongoing debates between proponents of importing foreign technology to accelerate learning and advocates for greater self-reliance. CGN was initially tasked with pursuing technology transfer through international partnerships.

Historians Chen Yue and Li Yunyi from the Chinese Academy of Sciences have documented this process by evaluating projects like Daya Bay and Ling Ao, both developed in cooperation with French company EDF.⁷² The following paragraphs are mainly based on their work.

At Daya Bay-1, constructed from 1987 to 1993, French teams led design, construction, and operations. EDF maintained approval authority for technical decisions and typically preferred

68 - Bureau of Industry and Security, "Export Administration Regulations—Control Policy: End-User and End-Use Based—Supplement No.4 to Part 744 – Entity List", U.S. Department of Commerce, 10 February 2023.

69 - National Development and Reform Commission, "十四五"现代能源体系规划, National Energy Administration, Government of China, see https://www.ndrc.gov.cn/xwdt/tzgg/202203/t20220322_1320017.html, accessed 3 August 2025; and *Xinhua*, " (两会受权发布) 中华人民共和国国民经济和社会发展第十四个五年规划和2035年远景目标纲要-新华网", 13 March 2021, see http://www.xinhuanet.com/2021-03/13/c_1127205564.htm, accessed 9 April 2025.

70 - Stephen Chen, "China Suspends Plan to Build Floating Nuclear Reactors in the South China Sea", *South China Morning Post*, 31 May 2023, see <https://www.scmp.com/news/china/science/article/3222289/china-suspends-plan-build-floating-nuclear-reactors-south-china-sea>, accessed 15 July 2023.

71 - *China Daily*, "First nuclear unit with Hualong One reactor connected to grid in Fujian", as published by State Council, Government of China, 28 November 2020, see https://english.www.gov.cn/news/photos/202011/28/content_WS5fc1a672c6d0f72576940d2e.html, accessed 28 May 2025.

72 - Yue Chen and Yunyi Li, "From Chooz to the Ling'ao NPP: The Technology Transfer of Pressurized Water Reactor Technology from France to China", Institute for the History of Natural Sciences, Chinese Academy of Sciences, *Chinese Annals of History of Science and Technology*, June 2024, see <https://www.sciengine.com/doi/pdfView/D3770741D6E04EC5A8C14FB86650AF53>, accessed 3 August 2025.

French and, to some degree, British suppliers. Although full design blueprints and core technology rights were not transferred, Chinese personnel gained practical experience in construction, installation, and project management by working alongside French and British engineers.

Concurrently, CNNC pursued an independent approach with Qinshan-1, China's first domestically designed and built nuclear plant. Construction lasted from 1985 to December 1991 with commercial operation only beginning in 1994.

The Ling Ao Phase I project (1997–2002) marked a shift toward localization. While Unit 1 used imported equipment, Unit 2 incorporated domestically manufactured key components such as steam generators, reactor internals, turbine and control rod drive mechanisms—often produced under French supervision.

This approach facilitated knowledge transfer while establishing foundations for local industry. Dongfang Boiler Factory, for example, through this collaboration developed expertise in manufacturing key components including steam generators, boron injectors, safety injection boxes, and voltage regulators. That led Dongfang to become a preferred supplier for subsequent projects like Qinshan-3, Yangjiang, and Ningde.

For Ling Ao Phase II (2005–2011), CGN developed the CPR-1000, a modified version of the French M310 design featuring over 300 technical improvements, including digital safety systems, modernized control rooms, and more efficient turbines. Most design, manufacturing, and construction work was conducted domestically. China also integrated knowledge from other reactor types, including two Canadian CANDU 6 (Qinshan III, 1998–2003) and two Russian VVER-1000 (Tianwan, 1999–2007) designs. Workforce development was supported by onsite vocational training programs for nuclear engineers and technical staff.

Despite progress, localization of certain nuclear island components—particularly in metallurgy, pumps, and instrumentation and control systems—remained challenging. The 2006 Westinghouse agreement to supply four AP-1000 reactors helped address these gaps through included technology transfers.⁷³

Chinese engineers gained access to designs and manufacturing processes for critical systems like the canned motor reactor coolant pump. Companies such as Harbin Electric Corporation and Shanghai Electric studied and adapted these technologies, conducting extensive analysis of over one hundred detailed blueprints and performing fatigue, stress, seismic, and accident simulations.

China's Construction Costs and Capabilities

China's nuclear power sector has systematically reduced construction costs while advancing its technological capabilities. According to 2022 investor disclosures from CNNC, the construction cost for Hualong One reactors stood at about CNY16,000/kW (US\$₂₀₂₂ 2,375/kW)—significantly lower than the CNY20,000/kW (US\$₂₀₂₂ 2,970/kW) for AP-1000 units built

73 - Feng Wang and Ming Lü, “出口核电项目核主泵国产化历程回顾和展望”, CZEC Operation and Maintenance Engineering Co., China National Nuclear Power Co., Ltd., 南方能源建设/Southern Energy Construction, Vol. 9, No. 2, June 2022, see <https://www.energychina.press/en/article/doi/10.16516/j.gedi.issn2095-8676.2022.02.016>, accessed 11 April 2025.

in China per the same statement⁷⁴ and a fraction of the estimated US\$15,000/kW for the two AP-1000s completed at Vogtle in the United States.⁷⁵ The industry continues working toward a target of CNY13,000/kW (US\$1,800_{/kW}) for Generation III reactors, which would match China's official Generation II construction costs.⁷⁶ There is no independent assessment of these numbers.

Several factors contribute to these apparent significant cost advantages. The sector benefits from a highly skilled workforce cultivated over three decades of continuous nuclear development, according to the analysis of the consultancy affiliated with Chinese state-owned investment holding company China Reform Holdings Corporation.⁷⁷

Working for state nuclear enterprises like CNNC remains very attractive in China, offering what many view as the “iron rice bowl”—stable, well-paid employment with strong benefits and social prestige. This was evident in CNNC's 2025 spring recruitment, which reportedly attracted nearly 1.2 million applications from over 425,000 applicants across Chinese universities—every applicant could apply for up to 20 positions—for just 8,000 job openings. CNNC employs around 180,000 people.⁷⁸

As was the case in the early years of most nuclear programs in the world, the financial model for Chinese nuclear power combines high upfront costs with favorable long-term economics. Plants carry substantial fixed costs including depreciation, financing expenses, and decommissioning funds, but benefit from relatively low variable costs after commissioning.

The National Development and Reform Commission set nuclear electricity prices at CNY430/MWh (US\$60/MWh) in 2013—below local coal power benchmarks—while granting nuclear priority grid access that supports high load factors.⁷⁹ This price level is surprisingly high considering the low investment costs claimed. For comparison, the guaranteed price for retailers of 100 TWh of French nuclear power (ARENH scheme) stands at €42/MWh (US\$47.7/MWh) since 2012.⁸⁰

Analysis from Cinda Securities, a Chinese state-owned asset management bank, assessed the nuclear Levelized Cost of Electricity (LCOE) at around CNY200/MWh (US\$₂₀₂₄27.8/MWh),⁸¹ a fraction of LCOEs in western countries (see *Nuclear Power vs. Renewable Energy Deployment*).

74 - CNNC, “中国核电2022年四季度投资者沟通情况通报”, July 2022, see https://pdf.dfcfw.com/pdf/H2_AN202301131581970800_1.pdf?1673630096000.pdf, accessed 15 April 2025.

75 - Lazard, “LCOE+—Levelized Cost of Energy+”, June 2025, see <https://www.lazard.com/media/uounhon4/lazards-lcoeplus-june-2025.pdf>, accessed 22 June 2025.

76 - 左前明 and 李春驰, “清洁高效基荷电源, 核能迎来快速发展机遇”, Cinda Securities, 24 September 2024, see https://pdf.dfcfw.com/pdf/H3_AP202409241640004023_1.pdf?1727195645000.pdf, accessed 14 April 2025.

77 - 王帅, “‘华龙一号’加速批量化建设, 核电领域投资展现新空间-”, China Reform Consulting, 14 May 2025, see <https://www.crhc.com/hydj/2024/5/403c321e2d164838bf80cbb84c03eef4.htm>, accessed 14 April 2025.

78 - Shuang Liang, “CNNC Recruitment Drive Sparks Debate”, *China Daily*, 8 April 2025, see <https://www.chinadaily.com.cn/a/202504/08/WS67f4764ca3104d9fd381e033.html>, accessed 14 April 2025.

79 - NDRC, “国家发展改革委关于完善—核上网电价机制有关问题的通知”, 15 June 2013, see https://www.ndrc.gov.cn/xxgk/zcfb/tz/201307/t20130708_963918.html, accessed 5 August 2025.

80 - French Energy Regulatory Commission, “Accès régulé à l'électricité nucléaire historique (ARENH)”, Updated 17 December 2024, see <https://www.cre.fr/electricite/marche-de-gros-de-lelectricite/acces-regule-a-lelectricite-nucleaire-historique-arenh.html>, accessed 5 August 2025. The ARENH scheme will phase out at the end of 2025.

81 - 左前明 and 李春驰, “清洁高效基荷电源, 核能迎来快速发展机遇”, Cinda Securities, 24 September 2024, see https://pdf.dfcfw.com/pdf/H3_AP202409241640004023_1.pdf?1727195645000.pdf, accessed 14 April 2025.

Cinda estimated that projects are expected to achieve around 8 percent for Gen III reactors and 10 percent internal rates of return for Gen II reactors.

China has embraced modular construction techniques, originally pioneered by Bechtel and GE for Boiling Water Reactor (BWR) designs and later adopted for Westinghouse's AP-1000. This approach involves factory prefabrication of complete components—from primary cooling system parts to steam generators and concrete containment sections—which are then assembled on site. The method is supposed to reduce Hualong One construction timelines to 5–6 years, compared to 8–10 years for conventional builds.

China's first Hualong One and AP-1000 projects significantly exceeded expected construction times.

Sanmen's AP-1000s faced long delays—construction times of 111 months for Unit 1 (2009–2018) and 104 months for Unit 2—partially due to post-Fukushima safety modifications and technical issues with the first-of-a-kind passive cooling systems and modular components, particularly the problematic main coolant pump that required redesigning. China's second AP-1000 at Haiyang took less time—still just under 100 months (2010–2018)—benefiting from lessons learned at Sanmen.

The efficiency gains for Hualong One first appeared more significant. At Fuqing, China's inaugural Hualong One unit required over 66 months from first concrete in May 2015 to grid connection in November 2020, as engineers made real-time design adjustments and established localized supply chains for critical components like reactor coolant pumps.

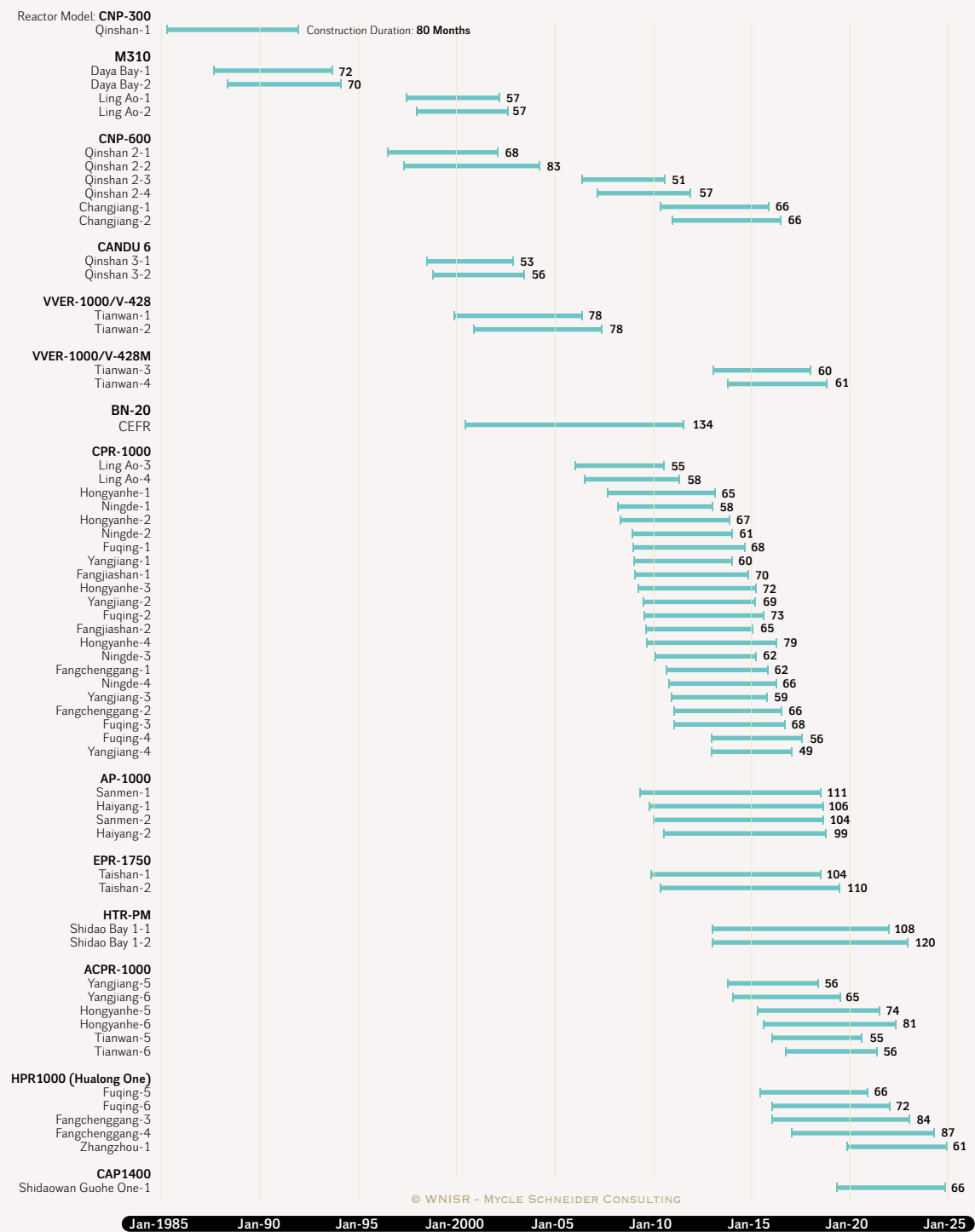
A later Hualong One project, Zhangzhou-1 (October 2019–November 2024) was completed in 61 months—5 months faster than Fuqing-5—but appears to be an outlier for the time being. Originally, Zhangzhou-1 was supposed to be an AP-1000 but was later switched to the Chinese design.⁸² Other Hualong One projects took longer to build: 72 months for Fuqing-6, 84 months for Fangchenggang-3, and over 87 months for Fangchenggang-4 (see [Figure 23](#)).

82 - For a detailed account of the project history see David Fishman, "How Does China Build Nuclear So Fast? Can You Do it Too?", Lantau Group, on LinkedIn, 4 December 2024, see <https://www.linkedin.com/pulse/how-does-china-build-nuclear-so-fast-can-you-do-too-david-fishman-l3jvc>, accessed 28 May 2025.

Figure 23 · Forty Years of Nuclear Constructions in China, 1985–2025

40 Years of Nuclear Reactor Constructions in China 1985–2025

Reactors with First Grid Connection prior to 1 July 2025

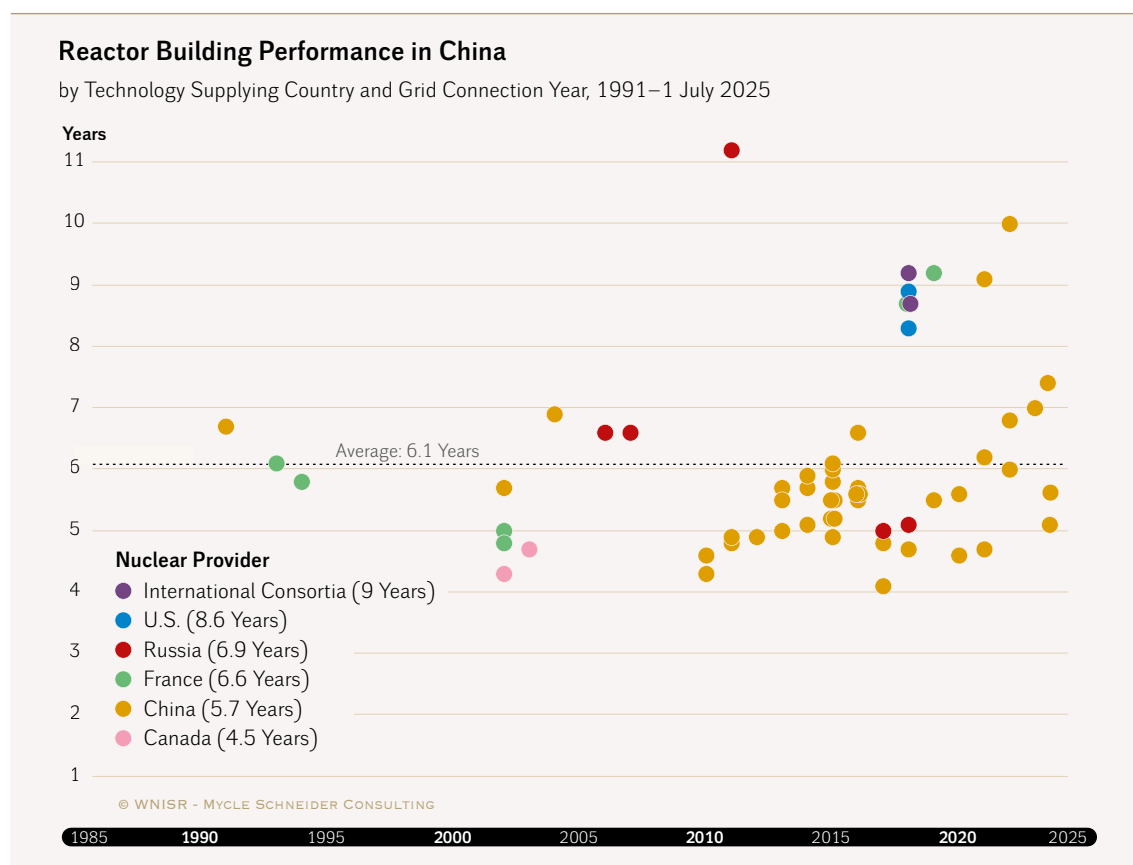


Sources: Various, compiled by WNISR with IAEA-PRIS, various years, 2025

Note: See Table 23 · Chinese Nuclear Reactors in Operation (as of 1 July 2025) in Annex 2 for construction and grid connection dates.

As of 1 July 2025, one of the 14 Hualong One units currently under construction was already exceeding the 61-months benchmark (Taipingling-1 at 65 months). While the average reactor construction times in China remain far below world average (see Figure 24), there appears to be an increasing trend of longer construction times. The reasons remain obscure.

Figure 24 · Evolution of Reactor Construction Times in China



Sources: WNISR with IAEA-PRIS, 2025

China's Growing Range of Nuclear Technologies

China's growing dominance in nuclear technology is evident in its patent filings. A 2024-study by Teva Meyer from the Université de Haute-Alsace analyzed over 56,000 unique nuclear technology patents filed globally between 1946 and 2022.⁸³ The findings reveal China's acceleration accounting for 48 percent of all nuclear-related patents filed worldwide over the past two decades, with a particularly dramatic rise after 2004.

In 2022 alone, Chinese entities were responsible for 75 percent of global nuclear patent filings. China is particularly active in the development of fourth-generation reactor designs and fuel chain technologies.

83 - Teva Meyer, "Patents for Power: Intellectual Property and the Geopolitics of Nuclear Energy Technologies", Université de Haute-Alsace, *Nuclear Engineering and Technology*, Vol. 57, Issue 7, July 2025, published online 10 January 2025, see <https://www.sciencedirect.com/science/article/pii/S1738573325000385>, accessed 11 April 2025.

Meyer's analysis suggests multiple motivations behind this patent surge. While some filings may serve performative purposes—signaling technological leadership and independence—the primary driver for patent filings appears to be China's strategic push to develop indigenous nuclear designs and localize supply chains. This effort aims to reduce dependence on foreign intellectual property, particularly in cases where export controls could potentially weaponize technological dependencies.

Beyond patents, China has made progress in deploying so-called advanced nuclear technologies. On 13 July 2021, China poured first concrete for a demonstration commercial SMR, the ACP100 or “Linglong One”, located on Hainan Island. The project aims at completion by May 2026 after only 58 months of construction.⁸⁴

According to the builder, several milestones have been achieved ahead of schedule, including the 30 November 2022 installation of nuclear island equipment, which began 75 days early.⁸⁵ Subsequent milestones included the August 2023 installation of the core reactor module,⁸⁶ completion of main structural work by February 2024,⁸⁷ and installation of the main pump in April 2025.⁸⁸

China's nuclear developments extend to alternative fuel chains. The 2-MWt liquid fuel thorium-based molten salt experimental reactor (TMSR-LF1) in Gansu Province achieved criticality on 11 October 2023, followed by full capacity operation on 17 June 2024. The reactor does not generate power. The Environmental Impact Report by the Shanghai Institute of Applied Physics (SINAP) released in October 2024 proposes to scale up the experiment and build a 10 MWe thorium-based molten salt reactor nuclear power plant with a maximum thermal output of 60 MWt, with construction proposed to begin in 2025 and the reactor projected to reach full power by 2029.⁸⁹ This reactor is expected to serve as a research facility to demonstrate system integration and validate key technologies, data, and experience needed for potential future commercial-scale TMSRs.

Non-Proliferation Concerns Around Plutonium Separation and Use

Certain of China's nuclear developments have raised concerns amongst some non-proliferation experts. Of particular note are the two CFR-600 sodium-cooled fast breeder reactors—their current operational status is unclear—which could theoretically produce significant quantities of weapons-grade plutonium of exceptional quality.

84 - NEA, “小身躯、大用途 玲龙一号不只是核能‘充电宝’——国家能源局”, National Energy Administration, 18 September 2021, see https://www.nea.gov.cn/2021-09/18/c_1310196316.htm, accessed 28 May 2025.

85 - 徐诗航, “提前75天! ‘玲龙一号’全球首个小型堆核岛安装工程开工”, China Nuclear Industry Fifth Construction Co., Ltd., 4 December 2022, see <https://www.cniec5.com/cniec5/xwzx27/jcdt38/58839/index.html>, accessed 15 April 2025.

86 - CNNC, “World's First! The Heart of Linglong One Is in Place”, as published by China Atomic Energy Authority, 10 August 2023, see <https://www.caea.gov.cn/english/n6759361/n6759362/c10087720/content.html>, accessed 5 August 2025.

87 - CNNC, “The Linglong One Completes External Dome Installation”, 7 February 2024, see https://en.cnncc.com.cn/2024-02/07/c_1023370.htm, accessed 5 August 2025.

88 - CNNC, “Main Pump Installed on Linglong One Unit of Changjiang Nuclear Power Plant”, 27 April 2025, see https://en.cnncc.com.cn/2025-04/27/c_1089207.htm, accessed 5 August 2025.

89 - Shanghai Institute of Applied Physics, “环境影响报告书:小型模块化钍基熔盐堆研究设施”, Chinese Academy of Sciences, as published by the Ministry of Ecology and Environment, Government of China, October 2024, see https://www.mee.gov.cn/ywdt/gsgg/gongshi/wqgs_1/202411/W020241126568416127023.pdf, accessed 6 May 2025.

The CFR-600 is a follow-up of the China Experimental Fast Reactor (CEFR) whose operational status is also unclear. The IAEA has simply deleted the CEFR file from its PRIS database. WNISR considers the CEFR in LTO.

While there has been no public confirmation of the CFR600 units connecting to the grid, their progress has attracted international attention due to their potential military applications. The first CFR-600, construction of which began in 2017, was originally scheduled for grid connection in late 2023. Zhang Hui, a Senior Research Associate at Harvard University's Belfer Center, reports that according to Chinese sources, the first unit has been operating at low capacity since mid-2023.⁹⁰ Satellite imagery analysis by researchers from the Sasakawa Peace Foundation supports this assessment; comparing images from 23 December 2022 and 16 October 2023 revealed steam emissions from a ventilation stack in the later image, suggesting operational activity.⁹¹ However, as of mid-2025, its operational status remains unclear, and it is not known whether it is connected to the grid. The second unit is planned for operation in 2026.

According to a 2018 bilateral agreement, Russia will supply the fuel for the first unit for its entire lifetime.⁹² Moreover, highly enriched uranium fuel, delivered by Russia under a 2019-contract for the first seven years of operation, would be subject to peaceful use restrictions according to Russian export regulations and a China-Russia nuclear cooperation agreement.⁹³ A 2019 Rosatom statement claims that the “CFR-600 will first use mixed [uranium-plutonium] oxide (MOX) fuel” and that “both the operating CEFR and the under-construction CFR-600 are designed to use MOX fuel that is not produced in China.”⁹⁴ It remains unclear with what kind of fuel the CFR-600 has or will be loaded and what the fuel management will look like in the longer term.

Further raising non-proliferation questions is China's reprocessing infrastructure. Satellite images analyzed by Harvard's Zhang Hui suggest CNNC may have begun construction on a third reprocessing plant, adjacent to two existing facilities, at its Nuclear Technology Industrial Park in Jinta, Gansu.⁹⁵

China began construction of the first two reprocessing plants (each with 200 tons/year capacity)⁹⁶ in 2015 and 2020, respectively. By late 2024, major construction appeared complete, with commercial procurement documents indicating equipment installation since 2023. Zhang

90 - Zhang Hui, “China Started Operation of its First CFR-600 Breeder Reactor”, *IPFM Blog*, International Panel on Fissile Materials, 15 December 2023, see https://fissilematerials.org/blog/2023/12/china_started_operation_o.html, accessed 3 May 2024.

91 - Yuki Kobayashi, “China's Fast Breeder Reactor Operating? Possibility of Accelerating Nuclear Arms Race”, The Sasakawa Peace Foundation, *SPF China Observer*, 30 November 2023, see <https://www.spf.org/spf-china-observer/en/eisei/eisei-detail006.html>, accessed 19 April 2025.

92 - Government of Russia and Government of China, “Официальное опубликование правовых актов—Соглашение между Правительством Российской Федерации и Правительством Китайской Народной Республики о сотрудничестве в сооружении на территории Китайской Народной Республики демонстрационного реактора на быстрых нейтронах от 8 июня 2018 года (вступило в силу 8 октября 2018 года)”, 8 June 2018, see <http://publication.pravo.gov.ru/document/0001201810260025>, accessed 19 April 2025.

93 - International Panel on Fissile Materials, “Russian Laws Prohibit Military Use of HEU Supplied to China”, 15 May 2024, see https://fissilematerials.org/blog/2024/05/russian_export_laws_prohi.html, accessed 5 August 2025.

94 - Rosatom, “Fuel for China”, Newsletter #220, August 2019, see <https://rosatomnewsletter.com/2019/08/23/fuel-for-china/>, accessed 7 August 2025.

95 - Zhang Hui, “China Starts Construction of a Third Demonstration Reprocessing Plant”, *IPFM Blog*, International Panel on Fissile Materials, 24 December 2024, see https://fissilematerials.org/blog/2024/12/china_starts_construction_2.html, accessed 7 April 2025.

96 - Metric tons of heavy metal.

estimated at the time that these plants could begin operation in 2025, five years earlier than expected.

The purpose of the potential third plant remains unclear due to limited public information. Zhang suggests it could either support the first two plants' reprocessing activities or represent a modular expansion approach. Notably, these facilities are located at the same site as a demonstration MOX fuel fabrication line (20 tons/year capacity), expected to be commissioned in 2025 to supply fuel for China's second CFR-600.

Since 1983, China has followed a plutonium separation and use policy goal aimed at managing spent fuel and reducing uranium consumption. The State Council approved a pilot reprocessing plant at Jiuquan in 1986, which conducted its first test run in 2010.⁹⁷

The dual-use potential of the plutonium fuel system has drawn some international concern. U.S. Defense reports have warned about possible military applications,⁹⁸ while China's transparency has decreased notably, e.g. it stopped reporting separated plutonium stocks to the IAEA in 2017.

The High-Temperature Reactor Program

The High-Temperature Reactor Pebble-bed Modules (HTR-PM) project at Shidao Bay represents the culmination of nearly four decades of research by Tsinghua University's Institute of Nuclear and New Energy Technology (INET), beginning with a 10-MWt test reactor in 1984.

The current demonstration plant—originally with a Reference Unit Power of 200 MWe, reduced for unknown reasons to 150 MWe—developed through collaboration between Tsinghua University, China Huaneng, and CNNC, features two reactor modules driving one common steam turbine. Construction began with first concrete poured on 9 December 2012, leading to grid connection of the first module on 20 December 2021. The exact date of the second module's grid connection has not been published, but it is likely to have taken place during the year 2022. This means that construction time was around 10 years, twice as long as planned at construction start. After the completion of a 168-hour demonstration run, the plant entered commercial operation on 6 December 2023.⁹⁹

While the HTR-PM designers claim several advantages over other technologies, the technology faces challenges. Economic viability remains to be proven, with estimated power generation costs approximately 20 percent higher than conventional pressurized water reactors due to lower power density and complex fuel fabrication.¹⁰⁰ The pebble-bed design produces bulky graphite waste, and the fuel handling systems require optimization. Current operating temperatures (~685°C) fall short of the 750°C design target, limiting efficiency for applications

97 - *The Bulletin of the Atomic Scientists*, "Reprocessing in China: A Long, Risky Journey", 10 April 2015, see https://thebulletin.org/roundtable_entry/reprocessing-in-china-a-long-risky-journey/, accessed 5 August 2025.

98 - U.S. Department of Defense, "Military and Security Developments Involving the People's Republic of China 2024", Annual Report to Congress, 2024, see <https://media.defense.gov/2024/Dec/18/2003615520/-1/0/MILITARY-AND-SECURITY-DEVELOPMENTS-INVOLVING-THE-PEOPLES-REPUBLIC-OF-CHINA-2024.PDF>, accessed 5 August 2025.

99 - Zuoyi Zhang, Yujie Dong et al., "Loss-of-Cooling Tests to Verify Inherent Safety Feature in the World's First HTR-PM Nuclear Power Plant", *Institute of Nuclear and New Energy Technology, Key Laboratory of Advanced Reactor Engineering and Safety of Ministry of Education, Tsinghua University, Joule*, Vol 8, Issue 7, 17 July 2024, see <https://www.sciencedirect.com/science/article/pii/S2542435124002903>, accessed 12 April 2025.

100 - Ibidem.

like hydrogen production. Regulatory hurdles also persist due to the novel design's lack of precedent.

The design is based on a German concept that was an industrial disaster. The 300-MW THTR (Thorium High Temperature Reactor) in Hamm-Uentrop took 14 years to build and was less than three years on the grid before being closed.¹⁰¹ Countless technical problems had convinced the owners to seal the fate of the plant. The reactor is the only one in Germany that is still in long-term enclosure, and 37 years after its closure, decommissioning has not begun (see [Germany in Decommissioning Status Report](#)).

The Chinese technology promoters plan to address the challenges of the first HTR-PM through the HTR-PM600 project, designed to expand the modular concept to six 100-MW modules driving a single turbine. This demonstration project, to be paired with Hualong One reactors in Xuwei, Jiangsu Province, is planned to supply industrial steam to nearby petrochemical facilities in Lianyungang.¹⁰²

Nuclear and Renewable Energy

In China, nuclear and renewable energy are both seen as vital for China's dual goals of carbon reduction and energy security while maintaining grid stability. They are generally not regarded as competing energy sources but as inhabiting complementary roles, aided by geographic separation: nuclear plants are located along the populous, coastal provinces, where they benefit from abundant cooling water and meet steady demand from electricity intensive sectors such as manufacturing or textiles. In contrast, large-scale wind and solar projects are concentrated in remote inland areas like Inner Mongolia, Xinjiang, and the Gobi Desert, where space and resources are plentiful.¹⁰³

This distribution reduces direct competition with nuclear delivering baseload power to coastal cities, while wind and solar transmit power over long distances through ultra-high-voltage (UHV) lines to industrial centers. However, distributed solar has been reaching a very significant share of new additions, with over 44 percent in 2023 and even 58.5 percent in 2022. In the first half of 2024, the share was still at 44 percent.¹⁰⁴ By the first quarter of 2025, the share of distributed solar jumped to 60 percent—36 GW of a total of 60 GW—according to some estimates.¹⁰⁵ (See [section on China in Nuclear Power vs. Renewable Energy Deployment](#)).

101 - IAEA-PRIS, "Country Statistics—THTR-300 (Thorium High-Temperature Reactor)", Updated 27 May 2025, see <https://pris.iaea.org/pris/CountryStatistics/ReactorDetails.aspx?current=92>, accessed 28 May 2025.

102 - CNNC, "Nuclear Power Heating Plant Approved to Be Built in Jiangsu", 23 August 2024, see https://en.cnncc.com.cn/2024-08/23/c_1023406.htm, accessed 25 June 2025; and Alina Constantin, "Advances in HTGR Development and IAEA Activities to Support Member States on HTGR Technology Development", Project Officer for HTGR Technology Development, Nuclear Power Technology Development Section, Division of Nuclear Power, IAEA, presented at "Technical Meeting on the Management of Spent Fuel (Pebbles and Compacts) from High Temperature Reactors", July 2025, see [https://conferences.iaea.org/event/414/attachments/20592/34683/Hadid%20Subki%20-%20IAEA-\(NPTDS\).pdf](https://conferences.iaea.org/event/414/attachments/20592/34683/Hadid%20Subki%20-%20IAEA-(NPTDS).pdf), accessed 5 August 2025.

103 - Baker Institute for Public Policy, "Baker Institute China Energy Map", Rice University, Undated, see <https://www.bakerinstitute.org/map-chinas-energy-infrastructure>, accessed 7 August 2025.

104 - National Energy Administration, various, compiled by WNISR2025.

105 - Yicong Zhu, Simeng Deng, and Kartik Selvaraju, "China's Rooftop Solar Installations Hit Record 36 GW in 1Q25 As New Guidelines Kick In", Rystad Energy, 18 May 2025, see <https://www.rystadenergy.com/news/china-rooftop-solar-installations-hit-record-in-1q25>, accessed 7 August 2025.

China's power grid follows a semi-regulated dispatch system that prioritizes low-carbon sources. Renewables have top priority due to policy mandates and negligible marginal costs, followed by nuclear power, which operates as high-priority baseload with minimal flexibility. Hydropower is used for peak demand, while coal and gas act as buffer sources that ramp up or down as needed.

But given China's enormous size, there are regions where nuclear competes with renewable energy for dispatch priority, for example, Guangdong, which hosts several nuclear facilities. Its nuclear fleet, dominated by large Generation II PWRs, was designed primarily for stable baseload generation. These reactors typically operate at high load factors—close to 90 percent—and are not suited for flexible load-following, meaning they cannot easily ramp output up or down in response to fluctuations in electricity demand or renewable energy supply (see [chapter on Challenges of Integrating Nuclear Power into the Energy System](#)).

During periods of low demand or high renewable output, the grid can become congested. In 2016 to 2017, this caused some nuclear power plants to reduce output or even shut down, resulting in higher system costs, wasted nuclear fuel, and unnecessary subsidies for unused renewable power.¹⁰⁶

The authors of a recent paper on the “dynamics of power curtailment in China” highlight “the necessity of mitigating grid congestion, enhancing inter-provincial transmission, and adopting market-driven pricing strategies to maintain the long-term cost-competitiveness of renewable energy.” And they stress the role of storage: “As the price of storage drops and its role in the system becomes more critical due to the rise of variable renewables, its deployment is projected to expand.”¹⁰⁷ Indeed, in 2024, China increased new grid-connected battery capacity by 130 percent to reach a total of 74 GW/168 GWh.¹⁰⁸

¹⁰⁶ - Qingfeng Bai, “可再生能源发电与核电协调调度及发展/Coordinative Dispatch and Development of Renewable Energy and Nuclear Power Generation”, CGN Power, as published in 中国电力/*Electric Power*, Vol. 53, Issue 2, February 2020.

¹⁰⁷ - Hongli Zhao, Chen Cui and Zibin Zhang, “Assessing the Dynamics of Power Curtailment in China: Market Insights from Wind, Solar, and Nuclear Energy Integration”, School of Economics and Management, Beijing Institute of Petrochemical Technology, and Central South University, *International Journal of Hydrogen Energy*, 10 April 2025, see <https://www.sciencedirect.com/science/article/abs/pii/S0360319925012741>, accessed 5 May 2025.

¹⁰⁸ - CNESA, “China National Energy Administration Released Official Report Highlighting 130% Growth in Installed Capacity of Energy Storage”, China Energy Storage Alliance, 3 August 2025, see <http://en.cnesa.org/latest-news/2025/8/3/china-releases-official-energy-storage-report-highlighting-130-growth-in-installed-capacity>, accessed 5 August 2025.

FRANCE FOCUS

Overview



Nuclear generation increased by 41.3 TWh (+12.9 percent) to 361.7 TWh, representing 67.1 percent of total French power generation in 2024.¹⁰⁹ Between 2005 and 2015, the norm was French nuclear production of 400 TWh, peaking at 430 TWh in 2005. Meanwhile, nuclear power generation declined in the rest of the EU27 (see [Figure 28](#)).

In December 2024, national utility Électricité de France (EDF) connected Flamanville-3 (FL3), its first European Pressurized Water Reactor (EPR) in the country, to the national grid, 17 years after construction start, 12 years later than planned, and 25 years after the last unit, Civaux-2, was added to the French program. So far, FL3 has not been performing as planned, and the new Authority for Nuclear Safety and Radiation Protection (ASNR) noted: “About fifty significant safety events were however declared by the licensee between commissioning and the end of 2024, a rate that is significantly higher than expected, even for a new reactor.”¹¹⁰

In June 2023, the National Assembly passed legislation for the “acceleration of procedures for the construction of new nuclear facilities near existing nuclear sites and for the operation of existing facilities” (see [France Focus](#) in [WNISR2023](#)).¹¹¹ While these measures can cut some red tape, they are unlikely to significantly ease the phenomenal industrial challenges.

In February 2022, the French President announced a plan to build six units of a new design called EPR2, with first startup targeted for 2035. Moreover, he stated that the option of building eight additional units by 2050 should be studied.¹¹²

The EPR2 still does not exist on the drawing board; no detailed design is available yet. The government estimated in an October 2021 internal note that, if everything goes well, the first EPR2 could start up by 2039–2040. In case unexpected industrial difficulties occur—as they did in the past and currently do—it could take until 2043 to commission the first EPR2, the project review stated.¹¹³

It is only on 22 July 2024 that the beginning of the development from basic to detailed design was accepted during a “Review Committee” meeting.¹¹⁴ EDF plans to provide an updated cost-

109 - EDF, “2024 Annual Results”, Press Release, Electricité de France, 21 February 2025, see <https://www.edf.fr/sites/groupe/files/epresspack/9680/PR-results-FY-2024-V21.02.2025.pdf>, accessed 13 August 2025.

110 - ASNR, “ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2024”, Autorité de sûreté nucléaire et de radioprotection/Authority for Nuclear Safety and Radiation Protection, 2025, see https://www.french-nuclear-safety.fr/annual_report/2024gb/files/assets/common/downloads/ASN%20Annual%20report%202024.pdf, accessed 15 August 2025.

111 - Government of France, “LOI no 2023-491 du 22 juin 2023 relative à l’accélération des procédures liées à la construction de nouvelles installations nucléaires à proximité de sites nucléaires existants et au fonctionnement des installations existantes”, *Journal Officiel de la République Française*, enacted 22 June 2023, promulgated 23 June 2023 (in French), see https://www.legifrance.gouv.fr/download/pdf?id=32HzSNCPyz8WLoK-WsqAqoiX_erjixoTD_Jy3AVXRfk, accessed 3 November 2023.

112 - Presidency of the French Republic, “Reprendre en main notre destin énergétique !”, Speech by Emmanuel Macron, Elysée, Government of France, 10 February 2022, see <https://www.elysee.fr/emmanuel-macron/2022/02/10/reprendre-en-main-notre-destin-energetique>, accessed 30 August 2022.

113 - Government of France, “Travaux relatifs au nouveau nucléaire—PPE 2019-2028”, as published by *Contexte*, October 2021, see https://www.contexte.com/article/energie/info-contexte-nucleaire-pas-encore-lances-les-futurs-epr-deja-en-retard-et-plus-chers_140631.html, accessed 30 August 2022.

114 - Cour des comptes, “La filière EPR : Une dynamique nouvelle, des risques persistants—Rapport de suites”, Court of Accounts, January 2025, see https://www.ccomptes.fr/sites/default/files/2025-01/20250114-La-filiere-EPR%20-une-dynamique-nouvelle-des-risques-persistants_o.pdf, accessed 22 August 2025.

assessment to the government by the end of 2025, and a Final Investment Decision (FID) is anticipated for the end of 2026.

In January 2025, the French Court of Accounts reported that “the projected profitability of the EPR2 program remains unknown at this stage, especially since the financing terms for this program have still not been determined.”¹¹⁵ The lack of an updated cost assessment, and thus the absence of a financing package and an FID, did not prevent EDF from ordering large components like reactor pressure vessels and steam generators¹¹⁶ or from starting site preparations.

On 1 January 2025, the law of 21 May 2024 took effect that laid the ground for the absorption of the Institute for Radiation Protection and Nuclear Safety (IRSN) by the Nuclear Safety Authority (ASN) and the creation of the Nuclear Safety and Radiation Protection Authority (ASNR). The legislation was implemented through a government decree issued on 3 December 2024¹¹⁷ against a remarkably broad opposition, from conservative and ultra-pro-nuclear MPs to anti-nuclear Greenpeace and IRSN’s ‘intersyndicale’, a coalition of trade unions represented at the institute and its Social and Economic Committee (CSE).¹¹⁸ The move constitutes a roll-back of a forty-year long history of the progressive establishment of a Technical Support Organization more independent of the nuclear industry, the state, and the safety authority. IRSN was originally a department of the Atomic Energy Commission (CEA); it was given an independent status and later merged with the national radiation protection office.

On 17 March 2025, President Macron chaired a session of the Nuclear Policy Council (CPN) that since 2022 “defines the broad guidelines for national nuclear policy”.¹¹⁹ Thus in the self-understanding of the presidency, it is not the parliament, but the CPN chaired by the President of the Republic that provides the framework orientation of nuclear policy for the long term.

The CPN took note of the status of the EPR2 program aiming at a first startup by 2038 and asked EDF “to step up its efforts to control costs and the schedule and to present a binding estimate of costs and deadlines by the end of the year.” The CPN has examined the financing scheme of the program based on a government loan covering at least half of the construction costs and a contract for difference at a maximum price of €₂₀₂₄ 100/MWh (US\$₂₀₂₄ 108.7/MWh). The support scheme needs to be approved by the European Commission.

The CPN also “confirmed the continued investments” into Orano’s backend strategy at the La Hague site, including the construction of additional spent-fuel storage capacities and a new uranium-plutonium mixed oxide (MOX) fuel fabrication plant—both to be commissioned by 2040. Further, the CPN “approved the principle of financing this program mainly born by EDF,

115 - Ibidem.

116 - EDF, “2025—Half-Year Results”, Presentation, 24 July 2025, see <https://www.edf.fr/sites/groupe/files/2025-07/2025-07-24-edf-half-year-results-presentation.pdf>, accessed 22 August 2025.

117 - Government of France, “Décret no 2024-1103 du 3 décembre 2024 pris en application des dispositions de l’article 14 de la loi no 2024-450 du 21 mai 2024 relative à l’organisation de la gouvernance de la sûreté nucléaire et de la radioprotection pour répondre au défi de la relance de la filière nucléaire”, *Journal Officiel*, No. 0286, 4 December 2024, see https://www.legifrance.gouv.fr/download/pdf?id=_sAus5rv8rAl2yTlzYJV5yL_Io1YsmDK6sXM7d5GJdk-, accessed 22 August 2025.

118 - E.g., see CFDT, CFE-CGC, CGT, CSE, “L’intersyndicale et le CSE de l’IRSN appellent à décaler d’un an la mise en place de la future Autorité de Sûreté Nucléaire et de Radioprotection (ASNR)”, 17 September 2025.

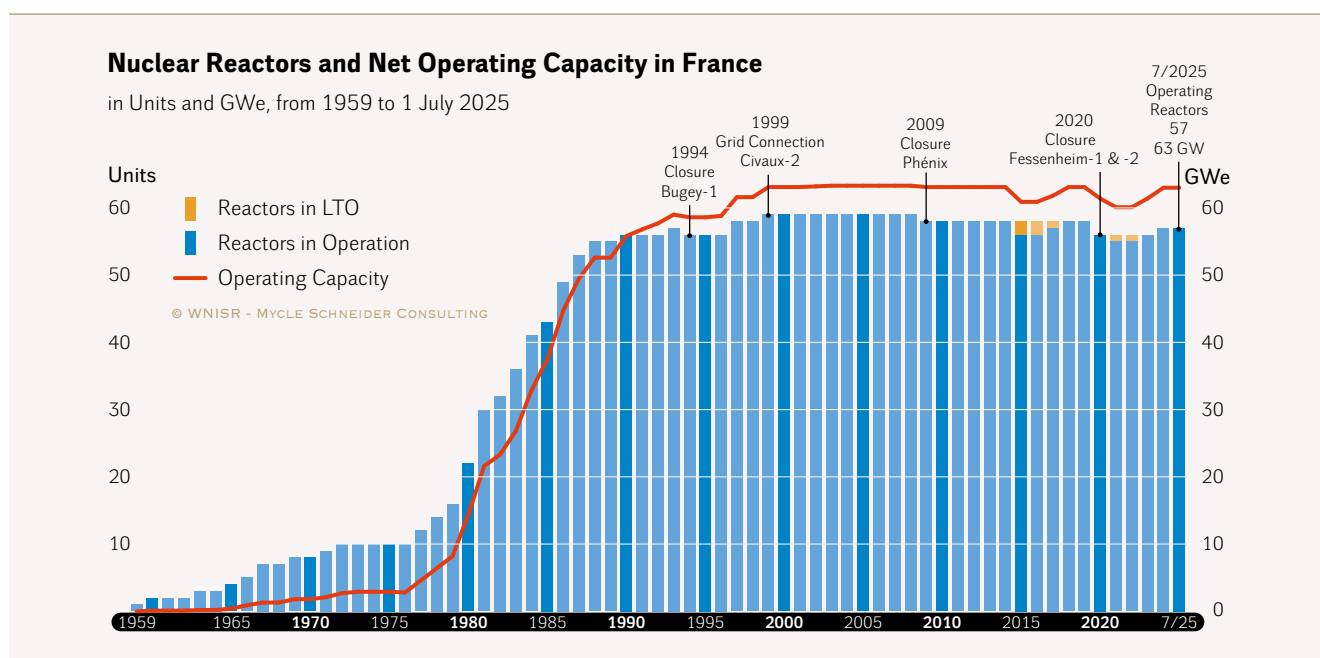
119 - Presidency of France, “Réunion du 4ème Conseil de politique nucléaire.”, Press Release, Elysée, 17 March 2025, see <https://www.elysee.fr/emmanuel-macron/2025/03/17/reunion-du-4eme-conseil-de-politique-nucleaire>, accessed 17 March 2025.

as the future customer of these facilities...”¹²⁰ None of these decisions has undergone specific parliamentary scrutiny, but they have triggered significant local opposition.¹²¹

No Reactor Under Construction in France—Again

Until the closure of the two oldest French units at Fessenheim in spring 2020, the French nuclear fleet had remained almost stable for 20 years, except for the closure of the 250-MW fast breeder Phénix in 2009 or the two units in Long-Term Outage (LTO) between 2015 and 2017. Another unit was in LTO in the period 2021–2023 (see Figure 25). Penly-1, subject to the stress-corrosion cracking issue, was offline between 2 October 2021 and 13 July 2023.¹²² No unit was offline for the entire year of 2024.

Figure 25 · Operating Fleet and Capacity in France



Sources: WNISR with IAEA-PRIS, 2025

Flamanville-3 was the first new reactor to start up since Civaux-2 was connected to the French grid 25 years earlier in December 1999.

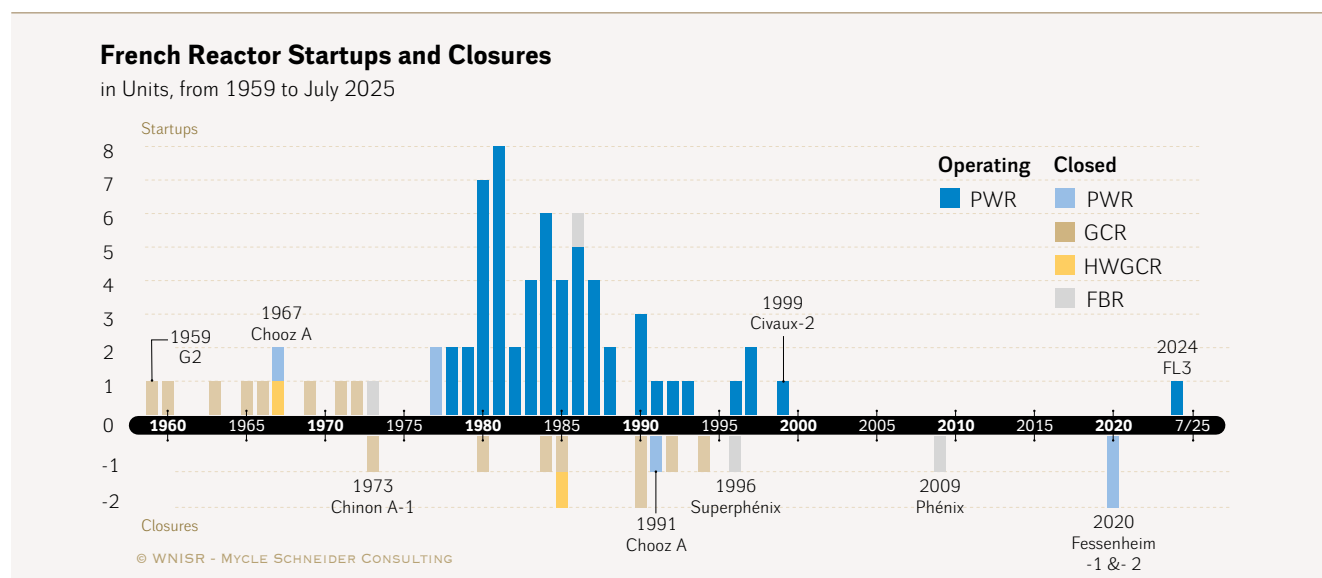
The first and only Pressurized Water Reactor (PWR) closed prior to Fessenheim was the 300-MW Chooz-A reactor, which was retired in 1991. The other closures were those of eight first-generation natural-uranium gas-graphite reactors, two fast breeder reactors, and a small prototype heavy water reactor (see Figure 26).

¹²⁰ - All quotes from previous reference.

¹²¹ - E.g., Lucas Hobe, “‘On veut nous imposer tout un monde nucléaire sans demander notre avis’ : des militants luttent contre le projet des piscines d’Orano”, *France 3 Normandie*, 20 July 2025, see <https://france3-regions.franceinfo.fr/normandie/manche/on-veut-nous-imposer-tout-un-monde-nucleaire-sans-demander-notre-avis-des-militants-luttent-contre-le-projet-des-piscines-d-orano-3190563.html>, accessed 19 August 2025.

¹²² - EDF, “Les deux unités de production de la centrale nucléaire de Penly connectées au réseau électrique national”, 13 July 2023, see <https://www.edf.fr/la-centrale-nucleaire-de-penly/les-actualites-de-la-centrale-nucleaire-de-penly/les-deux-unites-de-production-de-la-centrale-nucleaire-de-penly-connectees-au-reseau-electrique-national>, accessed 1 November 2023.

Figure 26 · Startups and Closures in France



Sources: WNISR with IAEA-PRIS, 2025

Notes: **PWR**: Pressurized Water Reactor; **GCR**: Gas-Cooled Reactor; **HWGCR**: Heavy Water Gas Cooled Reactor; **FBR**: Fast Breeder Reactor.

In 2024, the 57-reactor fleet¹²³ produced 361.7 TWh, an increase of 41.3 TWh (+12.9 percent) over the previous year; the production remained at a level below that of the pre-COVID-19 year 2019 and the ninth year in a row below 400 TWh.

In 2005, nuclear generation peaked at 430 TWh. After the construction program was completed in 1999, it took the fleet five years to build up to that maximum generation, and with a quasi-stable installed nuclear capacity between late 1999 and early 2020, performance plunged after 2015 (see Figure 27).

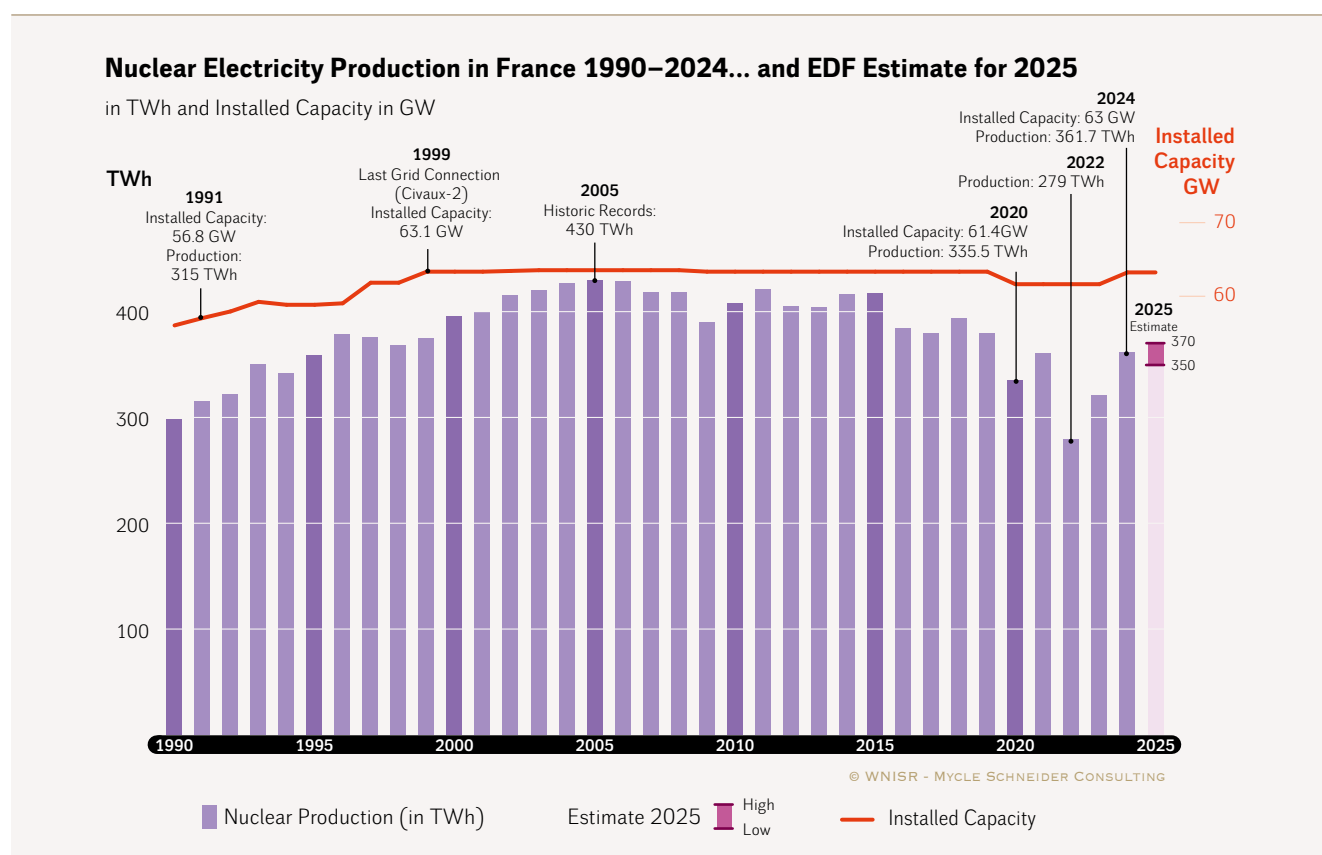
In 2024, nuclear plants provided 67.1 percent (+2.1 percentage points) of the country's electricity. The nuclear share peaked in 2005 at 78.3 percent. As of mid-year 2024, EDF estimated production in the 335–365 TWh range for 2025 and 2026.¹²⁴ In January 2025, the expected production was reevaluated at 350–370 for the years 2025–2027 (see Figure 27 and Figure 28).¹²⁵

¹²³ - All Pressurized Water Reactors (PWRs), 32 x 900 MW, 20 x 1300 MW, 4 x 1400 MW, and 1 x 1650 MW.

¹²⁴ - EDF, "2024 Half-year Results", Press Release, 26 July 2024, see <https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/2024-half-year-results-continued-progress-in-operational-performance-market-prices-decreasing-higher-nuclear-power-output-in-france-expected-at-upper-end-of-the-range-lowest-ever-carbon>, accessed 18 August 2024.

¹²⁵ - EDF, "Estimated Nuclear Generation in France for 2025, 2026 and 2027", Press Release, 30 January 2025, see <https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/estimated-nuclear-generation-in-france-for-2025-2026-and-2027>, accessed 13 August 2025.

Figure 27 · Nuclear Electricity Production vs. Installed Capacity in France



Sources: RTE, 2000–2025; and EDF, 2025

Note: In Figure 27, reactors in LTO are counted in the “installed capacity”.

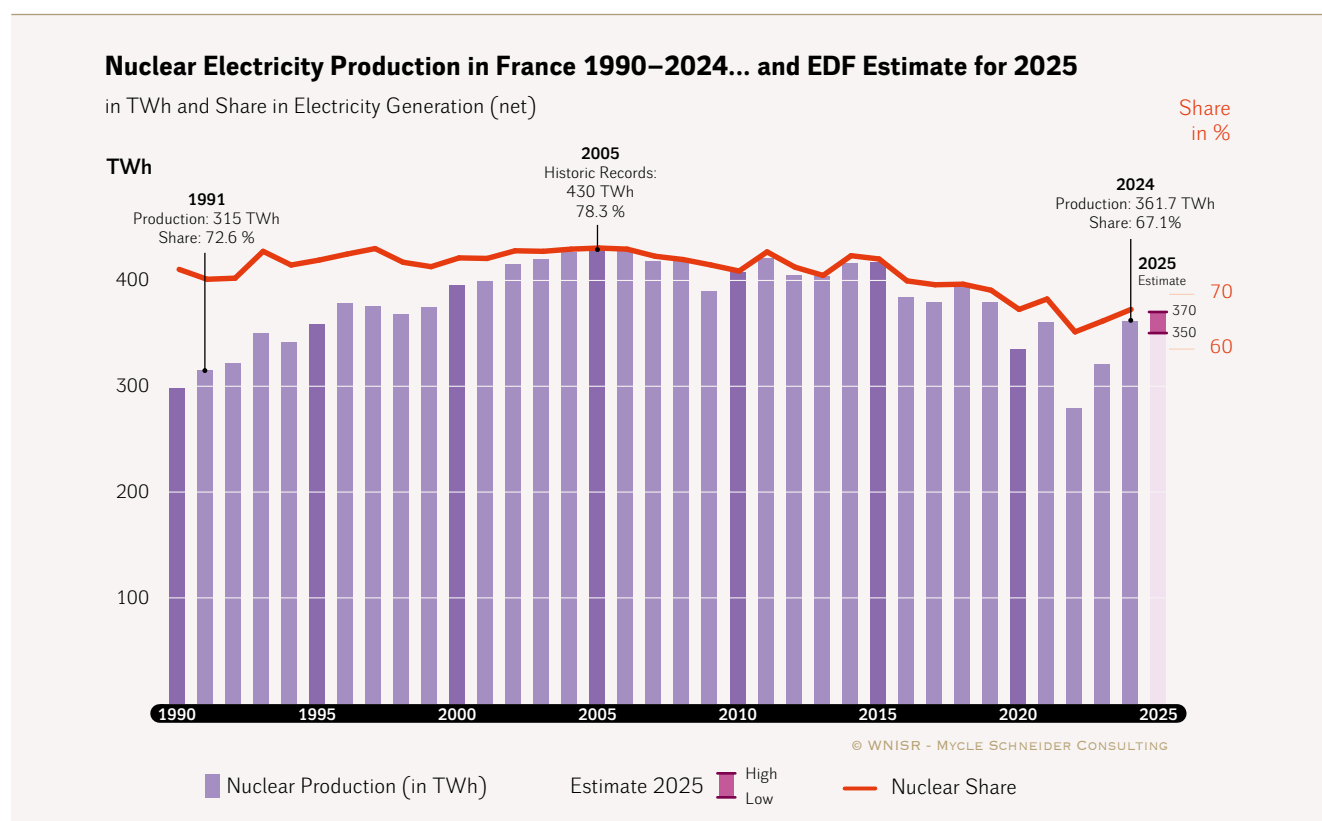
The year 2024 saw record new additions of solar capacity (+5 GW or +26 percent) to reach a total of 24.3 GW as well as a record solar generation of 24.8 TWh, a 10 percent year-on-year increase.¹²⁶ In the first half of 2025, another 2.8 GW were connected to the grid. There are now close to 1.2 million solar power facilities in metropolitan France,¹²⁷ with 63 percent (or 18 percent of the installed PV capacity) practicing partial or total self-consumption of the power they produce as of 2024. This last segment is growing fast and the installed capacity operated in some form of self-consumption has increased by 72 percent between the end of 2023 and end of 2024.¹²⁸

¹²⁶ - RTE, “Bilan électrique 2024 - Synthèse”, Réseau de Transport d'Électricité Français/France's transmission system operator, February 2024, see <https://analyseetdonnees.rte-france.com/bilan-electrique-2024/synthese>, accessed 28 March 2025.

¹²⁷ - ECO infos, “Marché photovoltaïque 2025 : Les chiffres clés”, Updated 21 July 2025, see <https://www.les-energies-renouvelables.eu/conseils/photovoltaïque/les-chiffres-essentiels-du-photovoltaïque/>, accessed 19 August 2025.

¹²⁸ - ADEME, “Les avis de l'ADEME – Autoconsommation individuelle d'origine photovoltaïque”, January 2025, see https://www.ademe.fr/wp-content/uploads/2025/01/avis-ademe-autoconsommation-photovoltaïque_-janvier-2025.pdf, accessed 19 August 2025.

Figure 28 · Nuclear Electricity Production vs. Nuclear Share in France



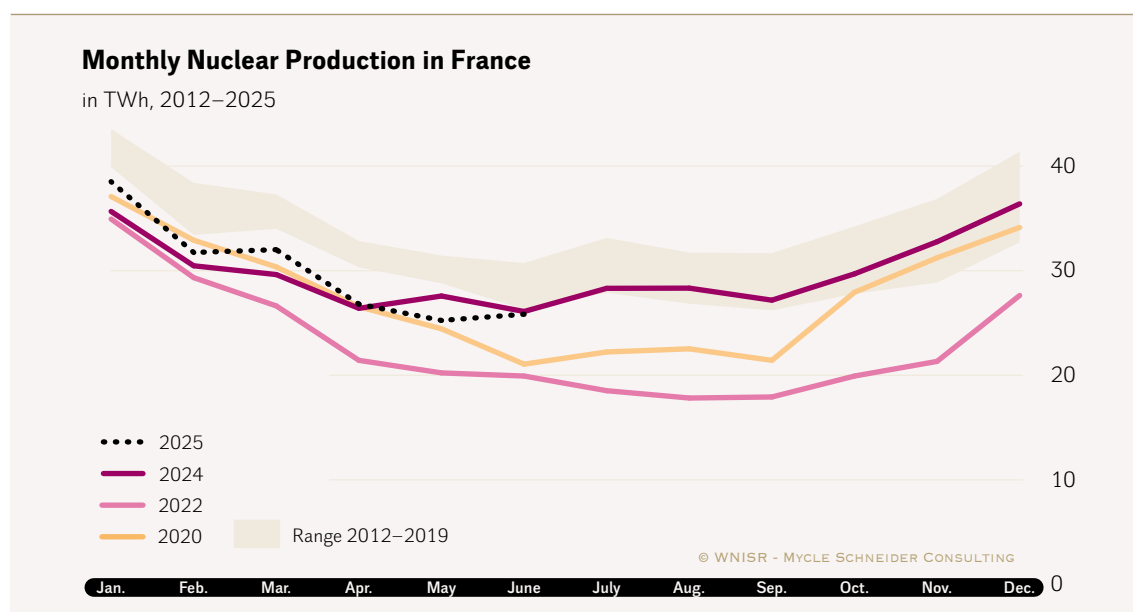
Sources: RTE, 2000–2025; and EDF, 2025

Since 2020, in every single year monthly nuclear production in the first half-year remained below the average level of the period 2012–2019. In 2024, production improved significantly especially in the crucial fourth quarter (see Figure 29).

Electricity represented 26.6 percent of final energy consumption in France in 2024. As nuclear plants provided 67.1 percent of electricity, they covered 17.9 percent of final energy. Fossil fuels covered the largest share at 57.3 percent, with oil at 39.3 percent and natural gas at 17.5 percent (coal <1 percent).¹²⁹

129 - SDES, “Tableaux de synthèse du bilan énergétique provisoire de la France en 2024”, Service des données et études statistiques, 2025, see <https://www.statistiques.developpement-durable.gouv.fr/media/8407/download?inline>, accessed 16 August 2025.

Figure 29 · Monthly Nuclear Electricity Generation, 2012–mid-2025

Sources: RTE and EDF, 2021–2025¹³⁰

Nuclear Unavailability Review 2024¹³¹

In 2024, there were 5,539 reactor-days with zero-production per reactor—a significant drop of 22 percent compared to 2023 and close to 35 percent less than in 2022, but still an average of 99 days or over three months. This includes neither load following nor other operational situations with reduced but above-zero output. The 2024 number is similar to the average 96 days outage days per reactor in pre-COVID year 2019. All fifty-six reactors (not including FL3) were subject to outages lasting from nine to 258 days (see Figure 31). No reactor has been offline the whole year.

Table 4 illustrates that while the declared “planned” outage-days dropped significantly in 2023 and 2024, the declared “forced” outages at 342 days remained on a high level in 2024, only second behind 2023 in the past six years.

¹³⁰ - RTE, “Données Mensuelles”, see <https://analysesetdonnees.rte-france.com/production/nucleaire>, last accessed 22 July 2025; and EDF, “Nuclear Generation”, 2021–2025, see <https://www.edf.fr/en/the-edf-group/dedicated-sections/investors/financial-and-extra-financial-performance/operational-performance/nuclear-generation>.

¹³¹ - Flamanville-3, which was connected to the grid in December 2024, is not included in those statistics and not represented on the figures.

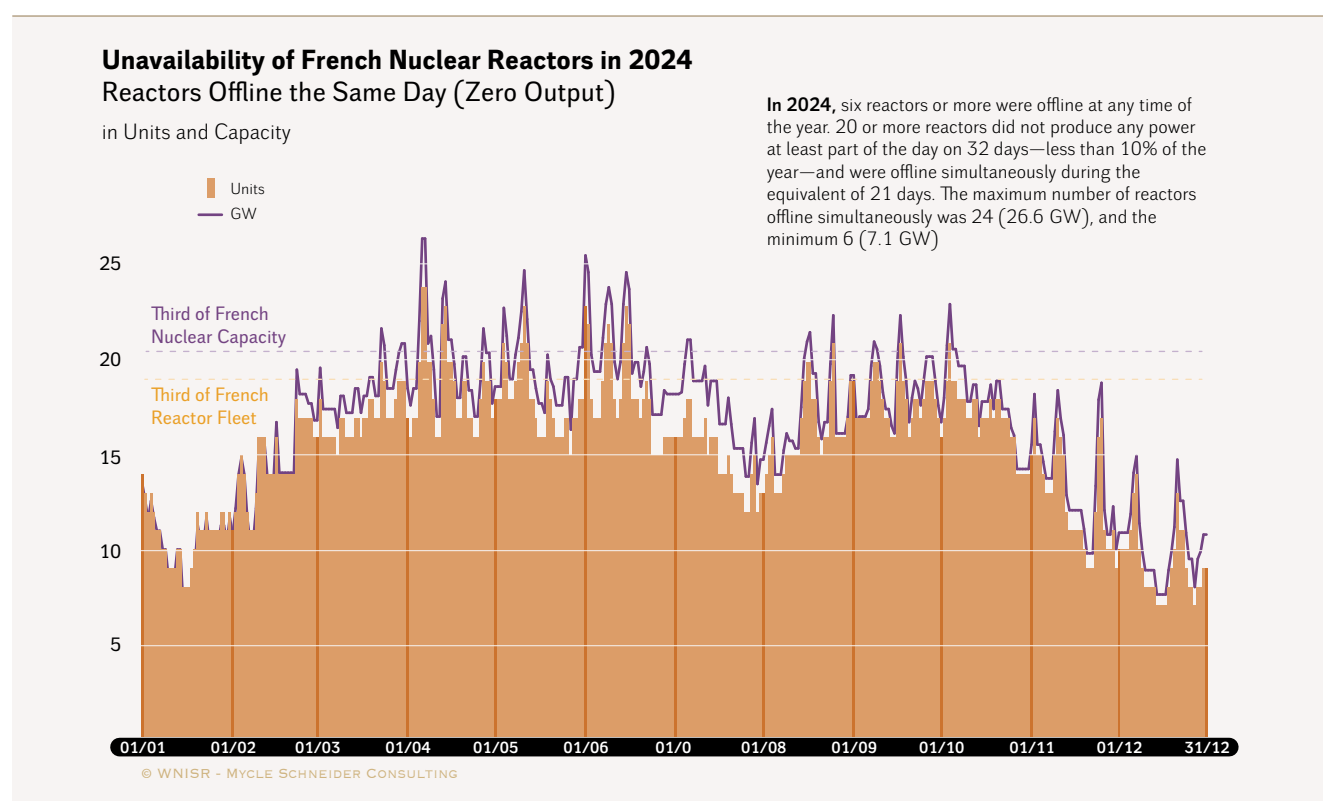
Table 4 · Total Unavailability at French Nuclear Reactors, 2019–2024 (in Reactor-Days)

	Declared Type of Unavailability			Average per Reactor
	“Planned”	Forced	Total	
2019	5,273	316	5,588	96
2020	6,179	286	6,465	115
2021	5,639	172	5,811	104
2022	8,287	278	8,515	152
2023	6,704	399	7,103	127
2024	5,197	342	5,539	99

Sources: RTE and EDF REMIT Data, 2019–2025

Note: The year 2020 does not include Fessenheim-1 and -2 that were closed during the year, and the year 2024 does not include Flamanville-3 that was briefly connected to the grid in December 2024.

Figure 30 · Reactor Outages in France in 2024



Sources: compiled by WNISR with RTE and EDF REMIT Data, 2021–2025

Notes: For each day in the year, this graph shows the total number of reactors offline, not necessarily simultaneously, as all unavailabilities do not overlap, but on the same day. This figure does not take into account Flamanville-3 that was briefly connected to the grid in December 2024.

The unavailability analysis for the year 2024 in [Figure 30](#) further shows that outage numbers and durations are down in all categories, sometimes by large margins:

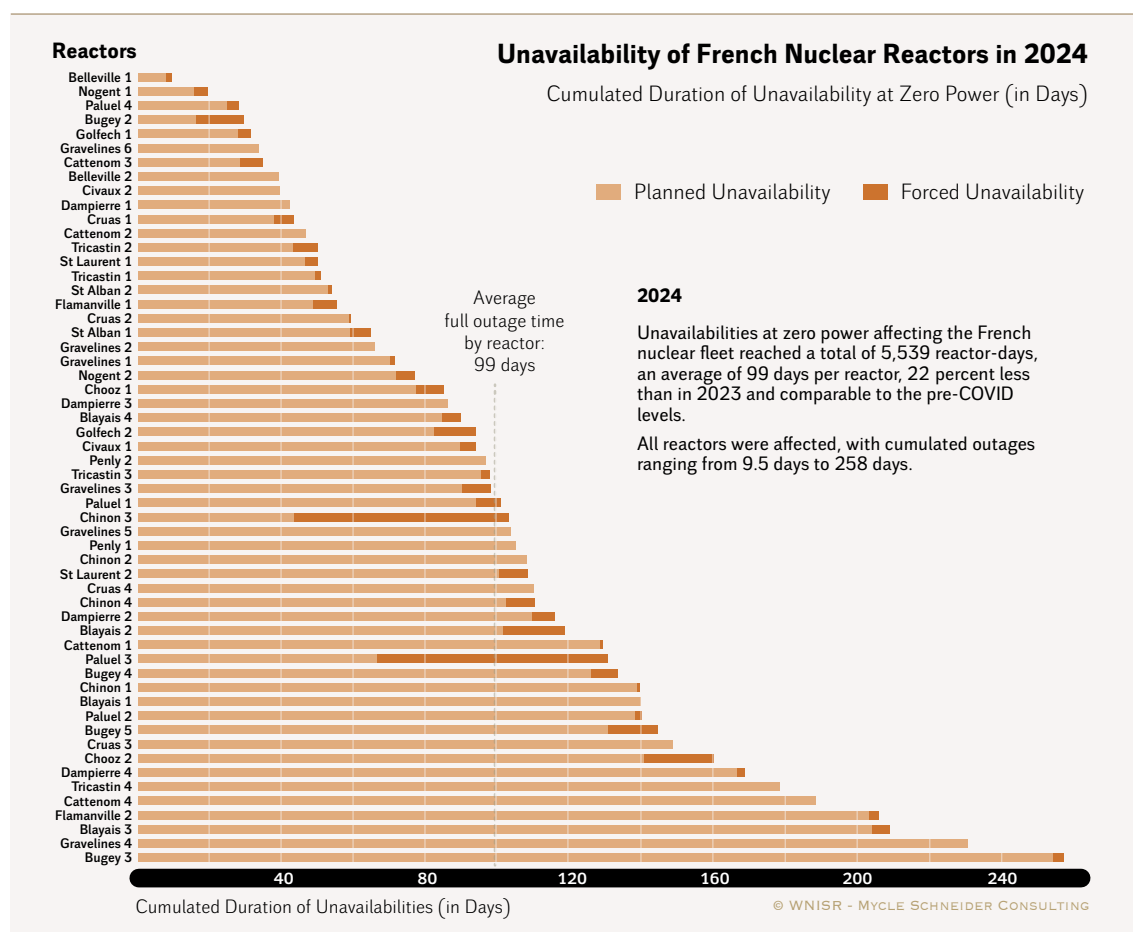
- ➔ During the whole year at least 7 units and up to 24 were down during the same day.
- ➔ On 59 days (16 percent of the year)—a remarkable decrease from 252 days (69 percent of the year) in 2023—19 or more units were shut down for at least part of the day.

- At least six reactors were down (zero capacity) *simultaneously* on any day of the year.
- At least 20 reactors were offline *simultaneously* during the equivalent of 21 days, down from 192 days in 2023.

According to EDF's classification of "planned" and "forced" unavailabilities, in 2024:

- 16 reactors did not experience any "forced" outage.
- At five units "forced" outages lasted less than one day.
- At 28 units cumulated "forced" outage duration represented between one and 10 days.
- At 7 reactors "forced" outage cumulated between 10 and 64 days over the year (see Figure 31).

Figure 31 · Forced and "Planned" Unavailability of Nuclear Reactors in France in 2024



Sources: compiled by WNISR with RTE and EDF REMIT Data, 2021–2025

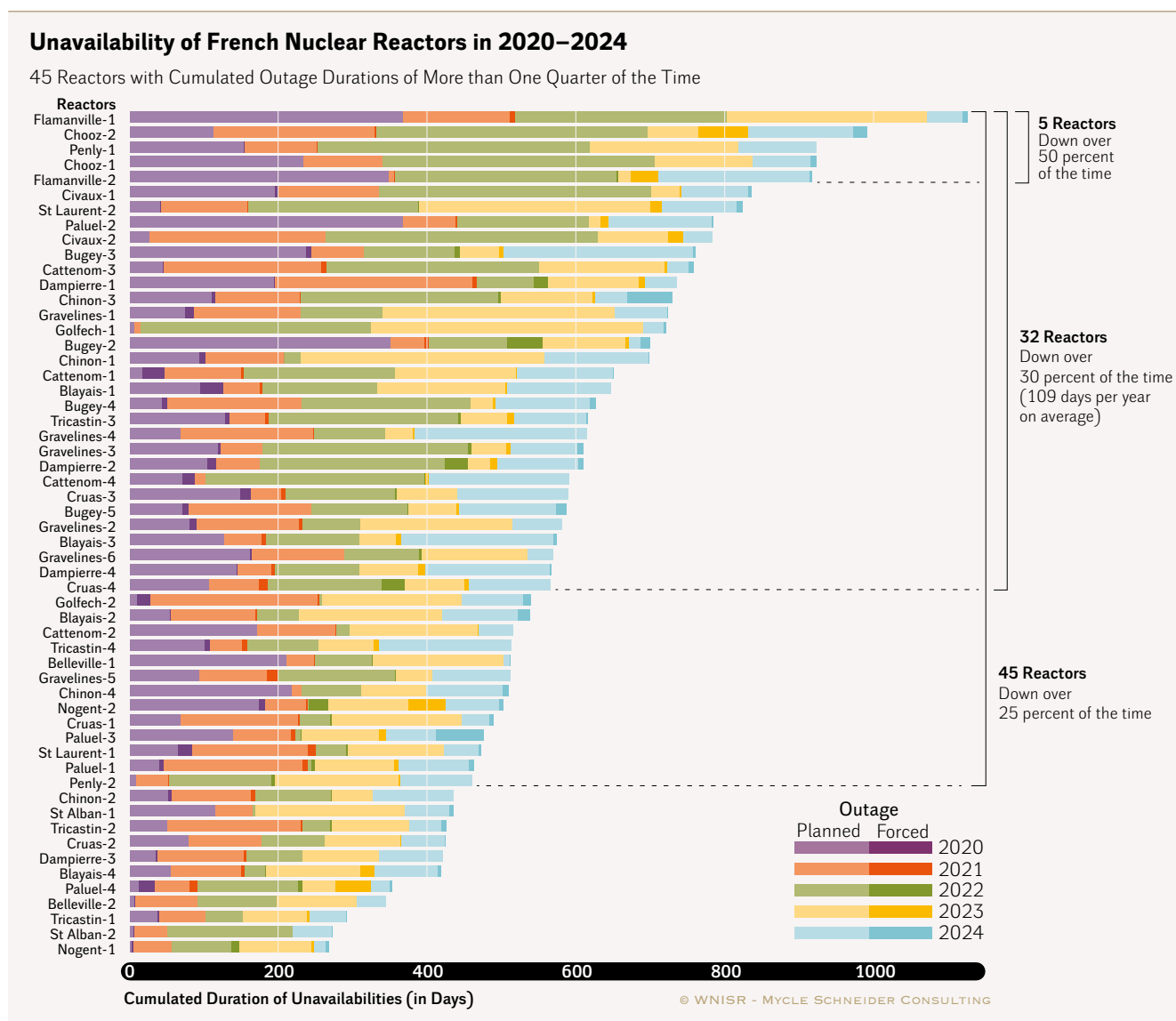
Notes: This graph only compiles outages at zero power, thus excluding all other operational periods with reduced capacity >0 MW. Impact of unavailabilities on power production is therefore significantly larger. Flamanville-3, briefly connected to the grid in December 2024, is not considered here.

"Planned" and "Forced" unavailabilities as declared by EDF.

However, EDF's declaration of "planned" vs. "forced" outages is highly misleading. EDF considers an outage as "planned", whatever the number and length of extensions (or, in rare cases, reductions) of its total duration, if the outage was first declared as "planned".

Detailed WNISR analysis for earlier years shows a different picture.

Figure 32 · Unavailability of French Nuclear Reactors, 2020–2024



Sources: compiled by WNISR with RTE and EDF REMIT Data, 2019–2025

Notes: The categorization as "planned" or "forced" outage follows EDF's classification. However, it does not reflect reality, as EDF keeps a "planned" outage in that category even if it lasts much longer than "planned".

The cumulated outage analysis over the five years 2020–2024 reveals the following (see Figure 32):

- ➔ Five reactors were down half of the time or more (Flamanville-1 and -2, Chooz-1 and -2, and Penly-1);

- ➔ 32 reactors were generating zero power for 30 percent of the time, that is 109 days, or more per year on average.
- ➔ 45 reactors were off-grid for at least one quarter of the time, in other words, they did not generate any power for the equivalent of one in four years.

Stress Corrosion Cracking and Thermal Fatigue

Severe stress corrosion cracking had been first identified in late 2021 on the safety injection systems of the four largest and most recent French reactors at Chooz and Civaux.¹³² Later, additional impacted reactors were identified and a program of pre-emptive replacement of particularly sensitive piping sections was decided for the “P4” reactor series. While apparently rare so far, the phenomenon has also been identified on other 1300-MW and some 900-MW reactors. EDF decided to inspect its entire reactor fleet by the end of 2025 and claimed that, as of mid-2024, already 50 of its 56 units had been “controlled and treated”.¹³³

In February 2023, an additional issue was identified during destructive examination at Penly-1. Close to a weld of a line of the safety injection system that had been repaired during construction of the plant, a 15.5 cm long (about one quarter of the circumference) and up to 2.3 cm deep crack (for a 2.7 cm thick tube) was identified. The origin has been determined as thermal fatigue rather than stress corrosion cracking. This discovery meant that an extensive inspection program of all repaired welds had to be added to the stress corrosion cracking investigations. According to the plan, 90 percent of the repaired welds in the safety injection and shutdown cooling systems of the entire reactor fleet were to be inspected by the end of 2024 and the remaining ones in 2025.¹³⁴

In June 2025, EDF discovered new crack indications on two welds of the Civaux-2 shutdown cooling system; one was determined as stress corrosion cracking, the other as thermal fatigue. EDF is confident that “the control tools and repair methods developed by EDF since 2022 have been mastered and industrialized.”¹³⁵

As of mid-2025, EDF displayed a message on its website saying:

Taking into account key learnings from controls and repairs undertaken in 2023 and 2024 on reactors linked to stress corrosion cracking, EDF considers that, in 2025, one planned outage out of six (...) may be extended by an average of 30 days.¹³⁶

¹³² - ASN, “Phénomène de corrosion sous contrainte détecté sur les réacteurs 1 et 2 de Civaux, B2 de Chooz et 1 de Penly”, Information Notice, 31 January 2022, see <https://www.asn.fr/l-asn-informe/actualites/phenomene-de-corrosion-sous-contrainte-detec-te-sur-certains-reacteurs>, accessed 13 November 2023

¹³³ - EDF, “EDF Group Half-Year Financial Report at 30 June 2024”, approved 25 July 2024, see <https://www.edf.fr/sites/groupe/files/2024-10/2024-10-24-half-year-results-financial-report-30-june-2024.pdf>, accessed 22 August 2025.

¹³⁴ - EDF, “Le phénomène de corrosion sous contrainte sur les circuits auxiliaires du CPP – État des lieux actualisé”, presented 4 July 2023, see https://www.anccli.org/wp-content/uploads/2023/07/Webinaire-CSC_2023-07-04_01-Etat-des-lieux_EDF.pdf, accessed 2 November 2023.

¹³⁵ - EDF, “Phénomène de corrosion sous contrainte (CSC) détecté sur une soudure du circuit de refroidissement du réacteur à l’arrêt du réacteur n°2 de Civaux”, 16 June 2025, see <https://www.edf.fr/la-centrale-nucleaire-de-civaux/les-actualites-de-la-centrale-nucleaire-de-civaux/phenomene-de-corrosion-sous-contrainte-csc-detec-te-sur-une-soudure-du-circuit-de-refroidissement-du-reacteur-a-l-arret-du-reacteur-ndeg2-de-civaux>, accessed 17 June 2025.

¹³⁶ - EDF, “List of Outages and Messages—EDF-2023-00231”, 20 December 2023, see <https://www.edf.fr/en/the-edf-group/who-we-are/activities/optimisation-and-trading/list-of-outages-and-messages/messages-list?code=edf-2023-00231>, accessed 22 August 2025.

EDF indicates that the following reactors are concerned: Blayais-4, Cruas-1, Dampierre-1, Gravelines-1, St.-Laurent B1, Tricastin-2, Belleville-1, Belleville-2, Cattenom-3, Flamanville-2, Golfech-2, and Chooz-B1.

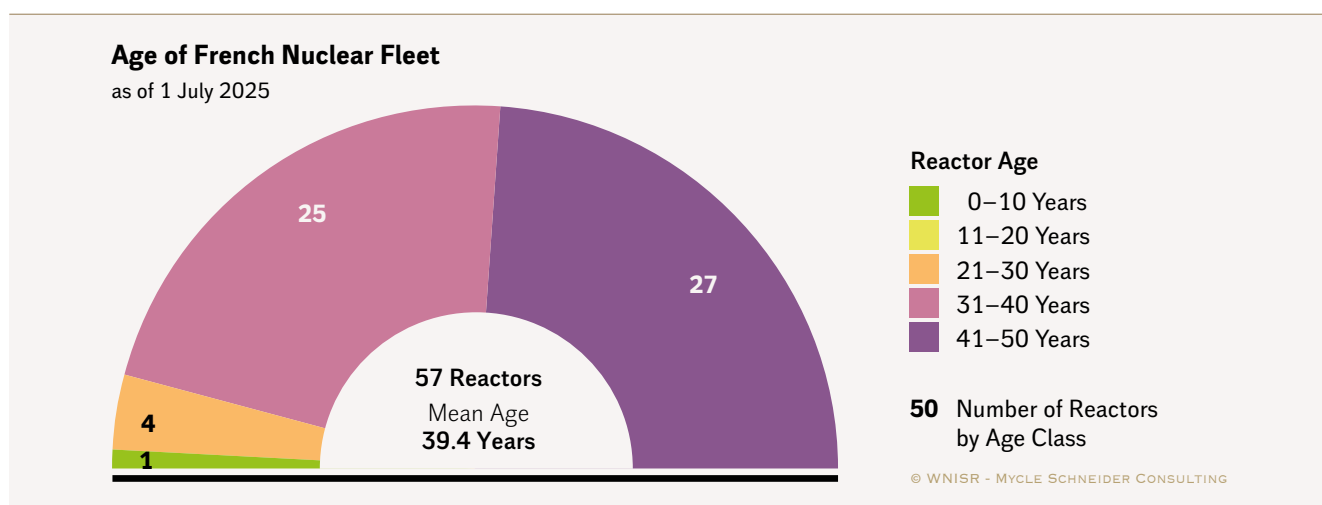
ASNR in the ASN Annual Report 2024 appears significantly more prudent as to EDF's mastering of the stress corrosion phenomenon:

On the occasion of the next periodic safety reviews, the lessons learned will need to be incorporated by EDF into its maintenance programmes. ASN in particular considers that the hypotheses concerning the lack of susceptibility to degradation mechanisms, adopted for certain zones which are not monitored by a preventive maintenance programme, must be backed up by a programme of additional investigations.¹³⁷

Decennial Inspections and Lifetime Extensions

By mid-2025, the average age of the 57 nuclear power reactors exceeded 39 years (see Figure 33); 52 operating units are now over 31 years old of which 27 are over 41 years. Lifetime extension beyond 40 years requires significant additional upgrading. Also, relicensing is subject to public inquiries reactor by reactor.

Figure 33 · Age Distribution of the French Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2025

EDF will likely seek lifetime extensions beyond the 4th Decennial Safety Review (VD4) for most, if not all, of its remaining reactors. President Macron in his February 2022 programmatic speech made it clear that the government has no intention of closing reactors anymore. He stated: “While the first extensions beyond 40 years have been implemented successfully since 2017, I’m asking EDF to examine the conditions of the [lifetime] extensions beyond 50 years, in conjunction with the nuclear safety authority.”¹³⁸

The first reactor to undergo the VD4 was Tricastin-1 in 2019, followed by Bugey-2 and -4 in 2020, and Tricastin-2 in 2021. Dampierre-1, Bugey-5, and Gravelines-1 started in 2021... until

¹³⁷ - ASNR, “ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2024”, 2025, op. cit.

¹³⁸ - Presidency of the French Republic, “Reprendre en main notre destin énergétique !”, French Government, 2022, op. cit.

the COVID-19 pandemic further disrupted the safety review schedule.¹³⁹ Until 1 July 2025, 22 units had undergone their VD4, and a further three were underway (see Table 5).¹⁴⁰

While ASN judged the VD4 premiere on Tricastin-1 “satisfactory”, it questioned whether EDF’s engineering resources were sufficient to carry out similar extensive reviews simultaneously at several sites.¹⁴¹ Beyond the human resource issue, the experience raised the question of affordability. EDF had scheduled an outage of 180 days for Tricastin-1 in 2019, which was first extended by 25 days to 205 days. Including further, unrelated unavailabilities, the reactor was ultimately in full outage for two thirds of that year (232 days). Many of the following VD4 exercises also saw significant delays between expected and real durations, e.g. Bugey-2 +118 percent compared to plan, Chinon B1 +76 percent (also holds the record outage of 467 days), or Blayais-1 +75 percent (see Table 5).

Of 22 VD4 outages completed until mid-2025, 16 were expanded, while six were completed faster than anticipated. While the delays total an extra 1,444 unplanned outage days, the six earlier completions total only 87 saved outage days, thus a net cumulated unplanned loss of 1,357 production days.

EDF expects the VD4 outages to last six months, much longer than the average of three to four months experienced through VD2 and VD3 outages. In 2023, the Chief Technical Officer of EDF Group and CEO of EDF R&D, Bernard Salha, told French Parliament that the work volume of a VD4 was five times larger than that of a VD3. He also said investments into the operating fleet had doubled over the previous decade.¹⁴²

139 - EDF, “4èmes Visites Décennales des Réacteurs du Palier 900 MW—Rapport annuel sur la mise en oeuvre des prescriptions du 4ème réexamen périodique des réacteurs 900 MWe—2022”, 2023, see <https://www.edf.fr/sites/groupe/files/2023-07/RP4-2023-v6.pdf>, accessed 28 August 2024.

140 - EDF, “4èmes Visites Décennales des Réacteurs du Palier 900 MWe—Rapport annuel sur la mise en oeuvre des prescriptions du 4ème réexamen périodique des réacteurs 900 MWe—2024”, 2025, see https://www.edf.fr/sites/groupe/files/2025-07/Rapport%20annuel_RP4_2025%20portant%20sur%20ann%C3%A9e%202024_0.pdf, accessed 22 August 2025.

141 - Bernard Doroszuk, “Présentation du rapport annuel 2019 de l’Autorité de sûreté nucléaire (ASN) sur l’état de la sûreté nucléaire et de la radioprotection en France”, President, French Nuclear Safety Authority, Hearing before The Parliamentary Office for Scientific and Technological Assessment (OPECST), French Parliament, 28 May 2020, see http://videos.senat.fr/video.1628244_5ecf547f8a96f.audition-pleniere---autorite-de-surete-nucleaire?timecode=2963962, accessed 13 August 2020.

142 - Bernard Salha, Oral Evidence before the Parliamentary Office for the Evaluation of Scientific and Technological Choices (OPECST), 16 February 2023; see OPECST, “Comptes Rendus de l’Office Parlementaire d’Evaluation des Choix Scientifiques et Technologiques—Nouvelle organisation du contrôle et de la recherche en sûreté nucléaire et en radioprotection”, French Parliament, 16 February 2023, see <https://www.senat.fr/travaux-parlementaires/office-et-delegations/office-parlementaire-devaluation-des-choix-scientifiques-et-technologiques.html>, accessed 14 November 2023.

Table 5 · Fourth Decennial Visits of French 900-MW Reactors, 2019–2025

Reactor	Capacity	Grid Connection	VD4 Outage	Expected Duration*	Total Actual Duration
Tricastin-1	915	31 May 1980	01/06/19–23/12/19	180	205
Bugey-2	910	10 May 1978	18/01/20–15/02/21	181	395
Bugey-4	880	8 March 1979	22/11/20–24/06/21	226	214
Dampierre-1	890	23 March 1980	19/06/21–05/02/22	170	231
Tricastin-2	915	7 August 1980	06/02/21–26/07/21	180	170
Bugey-5	880	31 July 1979	31/07/21–21/04/22	189	265
Gravelines-1	910	13 March 1980	14/08/21–11/04/22	188	240
Tricastin-3	915	10 February 1981	12/03/22–21/11/22	171	254
Gravelines-3	910	12 December 1980	23/03/22–22/12/22	191	275
Dampierre-2	890	10 December 1980	27/04/22–31/12/22	171	248
Blayais-1	910	12 June 1981	31/07/22–19/06/23	185	323
Saint-Laurent B-2	915	1 June 1981	20/01/23–20/11/23	223	304
Chinon B-1	905	30 November 1982	07/02/23–19/05/24	265	467
Gravelines-2	910	26 August 1980	10/06/23–07/03/24	197	272
Blayais-2	910	17 July 1982	24/06/23–31/03/24	182**	281
Dampierre-3	890	30 January 1981	23/09/23–2/03/24	170	161
Bugey-3	910	21 September 1978	11/11/23–28/08/24	177	303
Tricastin-4	915	12 June 1981	19/01/24–16/07/24	194	179
Gravelines-4	910	14 June 1981	20/01/24–07/09/24	195	231
Blayais-3	910	17 August 1983	08/06/24–26/12/24	191	201
Dampierre-4	890	30 January 1981	12/07/24–21/12/24	188	162
Cruas-3	915	14 May 1984	04/08/24–10/03/25	232	218
St-Laurent B-1	915	21 January 1981	31/01/25–14/08/25	178	195
Blayais-1	910	12 June 1981	05/04/25–09/10/25	187	
Cruas-1	915	29 April 1983	14/06/25–01/12/25	170	

Sources: compiled by WNISR with EDF REMIT-Data, 2019–2025¹⁴³

Notes: The expected duration is based on outage dates in use as of outage start or within the few days after the reactor is disconnected from the grid. For ongoing decennial visits, end of outage date is the date in use as of 20 August 2025 and can vary from the original date.

* Expected duration as of outage start - ** Original duration¹⁴⁴

On 23 February 2021, ASN issued detailed generic requirements for plant life extension.¹⁴⁵ The key aspects of ASN's decision were not the five short administrative articles but the two annexes setting the technical conditions and the timetable for work to be carried out. The challenge for operator EDF is high, as ASN outlined at the time:

Over the coming five years, the nuclear sector will have to cope with a significant increase in the volume of work that is absolutely essential to ensuring the safety of the facilities in operation.

¹⁴³ - EDF, "List of Outages", see <https://www.edf.fr/en/the-edf-group/who-we-are/activities/optimisation-and-trading/list-of-outages-and-messages/list-of-outages>, last accessed 20 August 2025.

¹⁴⁴ - Original expected duration at outage start; see EDF, "Liste des indisponibilités et des messages", February 2024, see <https://www.edf.fr/groupe-edf/ambition-neutralite-co2-pour-edf-a-l-horizon-2050/optimisation-et-trading/listes-des-indisponibilites-et-des-messages/liste-des-indisponibilites?mrid=05470-edf-t-00047355>; later cancelled and replaced.

¹⁴⁵ - ASN, "L'ASN prend position sur les conditions de la poursuite de fonctionnement des réacteurs de 900 MWe au-delà de 40 ans", Information Notice, 25 February 2021, see <https://www.asn.fr/Informer/Actualites/La-poursuite-de-fonctionnement-des-reacteurs-de-900-MWe-au-dela-de-40-ans>, accessed 25 February 2021.

Starting in 2021, four to five of EDF's 900 Megawatts electric (MWe) reactors will undergo major work as a result of their fourth ten-yearly outages. (...)

All of this work will significantly increase the industrial workload of the sector, with particular attention required in certain segments that are under strain, such as mechanical and engineering, at both the licensees and the contractors.¹⁴⁶

In fact, in 2024 seven 10-year inspections took place, five VD4 for 900-MW reactors and two VD3 for 1300-MW units. Between 2025 and 2028, four (2025, 2027, 2028) to five (2026) 10-year inspections are scheduled annually. In 2029, a VD5 of a 900-MW unit is planned for the first time, alongside four VD4s of 1300-MW reactors and the first VD3 of a 1450-MW unit. Between 2029 and 2034, each year six or seven VDs are scheduled.¹⁴⁷

ASN has shown remarkable tolerance for extended timescales of refurbishments and upgrades in the past; many of the post-Fukushima measures have not yet been implemented 14 years after the events, for example. According to some estimates, the completion of the work program could take until 2039.¹⁴⁸

Additionally, the implementation of work to be carried out as part of the lifetime extension beyond 40 years stretches over 15 years until 2036, when the last 900-MW reactor is supposed to be upgraded: Chinon B-4, connected to the grid in 1987, gets the 15-year delay to implement 15 of a total of 37 measures. By then, the unit will have operated for 49 years. This is just one example, and it is the newest of the operating 900-MW reactors. The ASN has accepted similar timescales for all 32 of the 900-MW units. The French Nuclear Safety Authorities have proven flexible, and—considering the dire state of the reactor fleet—pressure for even more flexibility might increase in the future.

On 13 October 2023, EDF applied for permission to delay many of the required upgrades of the 32-unit fleet of 900-MW units by years, “given the difficulties of meeting them”.¹⁴⁹ ASN, on 19 December 2023, modified its February 2021 publication of generic requirements, and delayed target dates for 31 of the 32 units for at least one but up to 14 upgrading work-packages (of a total of 36 per reactor) for periods of one to five years.¹⁵⁰

In the framework of the legally required upgrading work and documentary deliveries, EDF had to meet 107 deadlines in 2024. EDF claims having met all of them.¹⁵¹ Apparently, EDF has reacted to ASN's alert in 2021 on the immense workload ahead (see above), hired additional

¹⁴⁶ - ASN, “Abstracts ASN Report on the state of nuclear safety and radiation protection in France in 2020”, 2021, see <http://www.french-nuclear-safety.fr/Information/Publications/ASN-s-annual-reports/ASN-Report-on-the-state-of-nuclear-safety-and-radiation-protection-in-France-in-2020>, accessed 27 July 2021.

¹⁴⁷ - EDF, “2025—Half-Year Results”, Presentation, 24 July 2025, op. cit.

¹⁴⁸ - Manon Besnard and Yves Marignac, “Les mesures de renforcement du parc nucléaire français, dix ans après Fukushima”, Institut négaWatt, 5 March 2021, see <https://cdn.greenpeace.fr/site/uploads/2021/03/Institut-n%C3%A9gaWatt-Les-mesures-de-renforcement-du-parc-nucl%C3%A9aire-fran%C3%A7ais-10-ans-apr%C3%A8s-Fukushima-rapport-mars-2021-1.pdf>, accessed 30 August 2022.

¹⁴⁹ - ASN, “Évolutions de certaines prescriptions du 4^e réexamen périodique des réacteurs de 900 MWe”, 9 August 2024, see <https://www.asn.fr/l-asn-reglemente/consultations-du-public/evolutions-de-certaines-prescriptions-du-4e-reexamen-periodique-des-reacteurs-de-900-mwe>, accessed 30 August 2024.

¹⁵⁰ - ASN, “Décision n° 2023-DG-0774 de l'ASN du 19 décembre 2023”, 21 December 2023, see <https://www.asn.fr/reglementation/bulletin-officiel-de-l-asnr/installations-nucleaires/decisions-individuelles/decision-n-2023-dc-0774-de-l-asn-du-19-decembre-2023>, accessed 22 August 2025.

¹⁵¹ - EDF, “4^{èmes} visites décennales des réacteurs du palier 900 MWe—Rapport annuel sur la mise en œuvre des prescriptions du 4^{ème} réexamen périodique des réacteurs 900 MWe—2024”, 2025, op. cit.

staff, and adjusted the project management. EDF concludes its 2024 review on a positive note: “The analysis developed in this report does not identify any alerts concerning a risk of non-compliance with future deadlines for requirements.”¹⁵²

There are many more target dates coming up over the next two years. In 2025, 105 deadlines are expected with 30 relating to modifications to facilities while 75 relate to documentary deliverables or modifications to the plant’s operating specifications. In 2026, 82 prescription deadlines are expected with 42 relating to work on facilities and 40 relative to documentary deliverables or modifications to the facility operating reference system.¹⁵³

Financial Issues

Operating and maintenance costs of the ageing fleet of reactors have significantly increased over the past decade (see also [previous WNISR editions](#)), but whatever the uncertainties over various cost estimates might be, there is little doubt that the additional costs for refurbishment and upgrades in view of lifetime extensions remain below any cost estimate for newbuild.

Outages that systematically exceed planned timeframes are particularly costly. EDF’s net financial debt increased by about €10 billion (US\$₂₀₂₃ 10.6 billion) over the period 2019–2021 to a total of €43 billion (US\$₂₀₂₁ 51 billion) as of the end of 2021.¹⁵⁴ In 2022 alone, net debt jumped by €21.5 billion (US\$₂₀₂₂ 22.6 billion) to €64.5 billion (US\$₂₀₂₂ 67.9 billion) at the end of the year.¹⁵⁵

In 2023 and 2024, EDF profited from increased nuclear and hydro power output as well as good years for renewables’ generation. In 2023, EDF managed to go from a record loss to a €10 billion (US\$₂₀₂₃ 10.8 billion) profit and was able to reduce its debt load by an equivalent amount to €54.4 billion (US\$₂₀₂₃ 58.8 billion).¹⁵⁶ EDF’s 2024 results show a stabilization of the debt load at €54.3 billion (US\$₂₀₂₄ 59 billion). During the year, sales were down 15.7 percent “as prices fell in the countries where the Group does business”, and EDF’s extreme financial sensitivity to market prices was revealed by the fact that, “The downturn in sales prices had an estimated impact of -€18.5 bn [US\$₂₀₂₄ 20.1 billion].”¹⁵⁷

Rapidly changing market situations leading to lower average prices and, increasingly often, to very low or even negative prices on the spot market, have a significant impact on the management of France’s nuclear fleet and on financial results. In the first half of 2025, EDF saw 769 hours or 18 percent of the time with prices below €10/MWh (US\$11.4/MWh), and net income was down 21.2 percent compared to the first half of 2024. At the same time, modulation of nuclear reactors increased by 16 percent compared to the same period in 2024.¹⁵⁸

¹⁵² - Ibidem.

¹⁵³ - Ibidem.

¹⁵⁴ - EDF, “Consolidated Financial Statements at 31 December 2021”, 13 April 2021, see <https://www.edf.fr/sites/groupe/files/2022-02/annual-results-2021-consolidated-financial-statements-20220218.pdf>, accessed 4 July 2021.

¹⁵⁵ - EDF, “Consolidated Financial Statements at 31 December 2022”, 17 February 2023, see <https://www.edf.fr/sites/groupe/files/2023-02/annual-results-2021-consolidated-financial-statements-2023-02-17.pdf>, accessed 22 June 2023.

¹⁵⁶ - EDF, “Universal Registration Document 2022 Including the Annual Financial Report”, 4 April 2024, see <https://www.edf.fr/sites/groupe/files/2024-04/edf-urd-annual-financial-report-2023-en-updated-2024-04-11.pdf>, accessed 29 August 2024.

¹⁵⁷ - EDF, “2024 Annual Results”, Press Release, 21 February 2025, op. cit.

¹⁵⁸ - EDF, “2025—Half-Year Results”, Presentation, 24 July 2025, op. cit.

The 20-Year-Long Flamanville-3 EPR Saga—No End in Sight?

The 2005 decision to construct Flamanville-3 (FL3) was mainly motivated by the industry's attempt to confront the serious problem of maintaining nuclear competence. Fifteen years later, ASN still drew attention to the “need to reinforce skills, professional rigorousness and quality within the nuclear sector.”¹⁵⁹ EDF justified its refusal to provide its estimates for FL3's expected profitability for the Court of Accounts' January 2025 report by stating in particular: “The project's main issues at stake were to maintain the skills of the French nuclear industry and to prepare for the deployment of EPR technology in France and around the world.”¹⁶⁰

In December 2007, EDF started construction on Flamanville-3 (FL3) with a scheduled startup date of 2012. The project has been plagued with design issues and quality-control problems, including basic concrete and welding difficulties similar to those at the Olkiluoto (OL3) project in Finland, which started construction two and a half years earlier and was connected to the grid only in March 2022 (see [earlier WNISR editions](#)). These problems never went away.

Following numerous revisions of the original €3.3₂₀₀₇ billion (US\$₂₀₀₇4.5 billion) cost estimate, in January 2022 EDF estimated the overnight costs at €₂₀₁₅12.7 billion (US\$₂₀₁₅14 billion).¹⁶¹ In 2020, the French Court of Accounts estimated the total cost, including financing and other associated costs, at €₂₀₁₅19.1 billion (US\$₂₀₁₅21 billion).¹⁶² The court estimated that the cost of electricity from FL3 would be €₂₀₁₅110–120/MWh (US\$₂₀₁₅122–133/MWh).

These estimates have been updated by EDF and corrected by the court in its January 2025 report.¹⁶³ EDF's latest estimate of November 2023 indicates overnight costs¹⁶⁴ of €18.1 billion (US\$16.9 billion) and a total, including financing and other costs, of €22.6 billion (US\$24.4 billion) that the court upped to €23.7 billion (US\$25.6 billion), a staggering sixfold increase over the original cost estimate (inflated) of €4 billion (US\$4.3 billion) (see [Figure 34](#)).

¹⁵⁹ - ASN, “ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2020—Abstracts”, 2021, see <https://www.french-nuclear-safety.fr/content/download/178655/file/Abstracts-of-the-full-ASN-Report-on-the-State-of-nuclear-safety-and-radiation-protection-in-France-in-2020.pdf>, accessed 30 August 2022.

¹⁶⁰ - Cour des comptes, “La filière EPR : Une dynamique nouvelle, des risques persistants—Rapport de suites”, January 2025, op. cit.

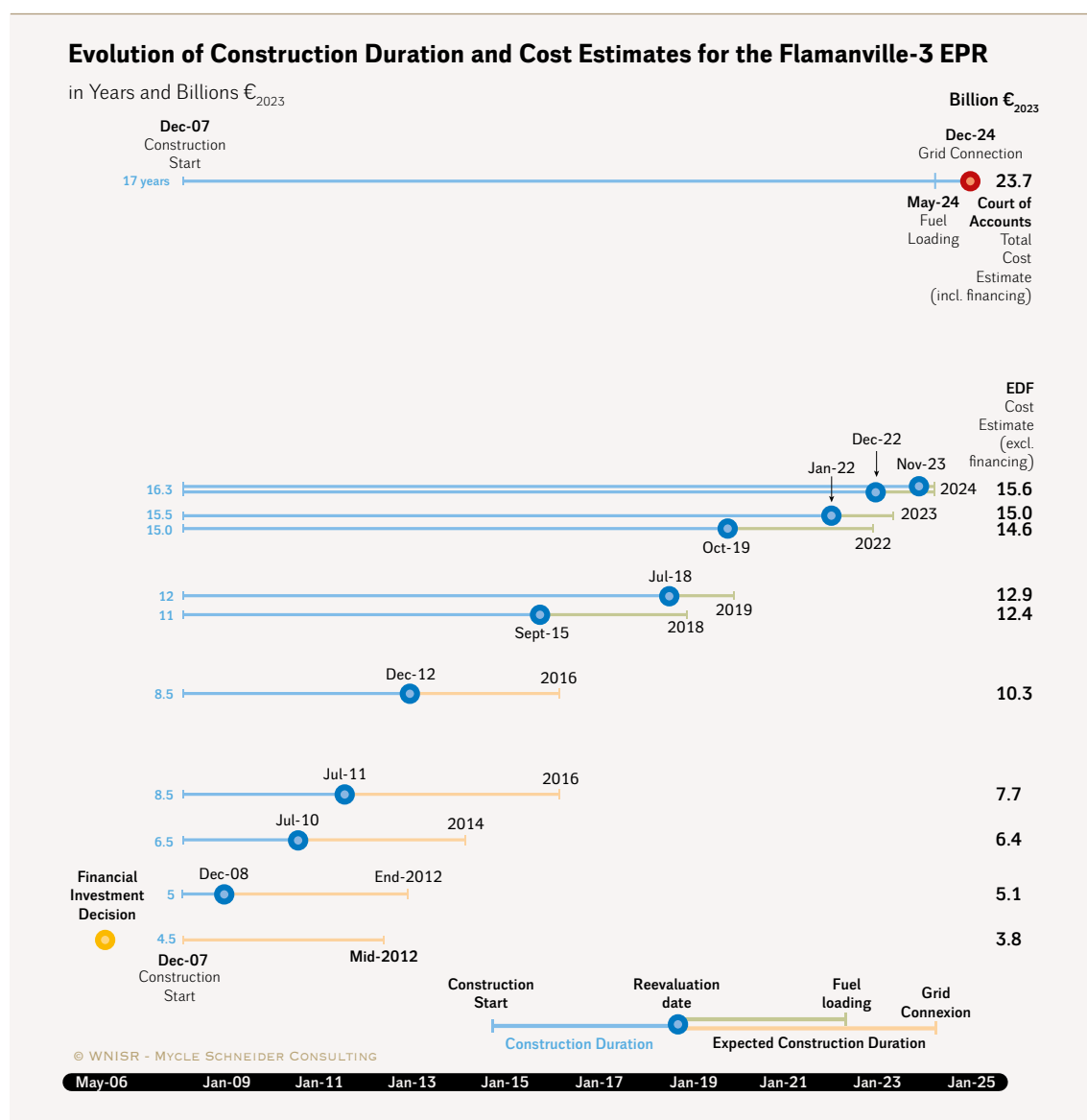
¹⁶¹ - EDF, “Update on the Flamanville EPR”, Press Release, 12 January 2022, see <https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/update-on-the-flamanville-epr>, accessed 31 August 2022.

¹⁶² - Cour des comptes, “La filière EPR”, Cour des Comptes, 9 July 2020. See [WNISR2020](#) for excerpts from the report.

¹⁶³ - Cour des comptes, “La filière EPR : Une dynamique nouvelle, des risques persistants—Rapport de suites”, January 2025, op. cit.

¹⁶⁴ - All numbers from the report and their translation to US\$ in 2023 currency value.

Figure 34 · Construction Times and Project Cost Estimates for Flamanville-3



Source: Cour des comptes, 2025

The court regrets FL3's "poor projected profitability". To achieve a rate of return of 4 percent (real term) FL3's power would need to sell at €138/MWh (US\$149/MWh), provided the plant reaches a load factor of 75 percent—the average lifetime load factor of the four latest French reactors at Chooz and Civaux is around 70 percent. The court further states that "for sales prices below €90/MWh [US\$97/MWh], it seems difficult to envisage a rate of return reaching 2 percent." The average spot market price for base load power in the first half of 2025 stood at €66.70/MWh (US\$75.7/MWh) in France.¹⁶⁵

The fuel issue that struck the Taishan EPRs (in China) and kept Unit 1 off-grid for over one year had consequences for FL3. EDF decided to refabricate 64 of the 241 fuel assemblies that had already been produced. These were approved by ASN and delivered to the site. Fuel loading

¹⁶⁵ - EDF, "2025 Half-Year Financial Report at 30 June 2025", 24 July 2025, see <https://www.edf.fr/sites/groupe/files/2025-07/2025-07-24-edf-half-year-results-financial-report.pdf>, accessed 23 August 2025.

was finally completed in May 2024, and subsequently, EDF representatives repeatedly stated the reactor startup would be “imminent” with grid connection happening “a few weeks later”.

FL3’s first criticality took place on 3 September 2024, and it was finally connected to the grid a few *months* later on 21 December 2024, 17 years after construction start and 12 years later than planned.

The startup procedures appear as laborious as the construction and, according to ASNR, “the first months of operation showed that EDF needs to reinforce its oversight and control of operational activities.”¹⁶⁶

The EPR2 Project

As early as August 2023, EDF had applied for a building permit for the first pair of the “sixpack” to be built at the Penly site. The ASN states in its Annual Report 2024 that the application “is being examined and should reach a conclusion in 2027.” Site preparation has begun, nevertheless. The other pre-selected sites for a pair of EPR2 units are Bugey and Gravelines, and EDF is in the course of filing all administrative applications to implement these projects. Public debates, part of the procedure, already took place for all three sites: for Penly between 27 October 2022 and 27 February 2023, for Gravelines 17 September 2024 to 17 January 2025, and for Bugey 28 January to 15 May 2025.¹⁶⁷

Michel Badré, former president of the Environmental Authority and of the Special National Commission for Public Debate (CPDP), in charge of the public debate on the EPR2 projects in Penly, summed up his sobering conclusion from the procedure in an October 2024 presentation:¹⁶⁸

Two criteria for assessing the usefulness of the debate:

- Did it provide the public with adequate information? To date, no.
- Did it allow the public to participate in the decision-making process? No.

The Court of Accounts concludes its already mentioned 2025 report on the EPR by stating:

This analysis shows that, although the French nuclear industry has begun to organize itself to implement the strategy it set out in 2022, it is far from ready and still has many challenges to overcome, some of which are concerning.¹⁶⁹

The court warns that “the accumulation of risks and constraints could lead to the failure of the EPR2 program.” Therefore, it has issued two key recommendations:

- Postpone the final investment decision on the EPR2 program until financing has been secured and detailed design studies have progressed in line with the target schedule for the first nuclear concrete pour [the official construction start].

¹⁶⁶ - ASNR, “ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2024”, 2025, op. cit.

¹⁶⁷ - CNDP, “Les projets en débat”, undated, see <https://www.debatpublic.fr/les-projets-en-debat-170>, accessed 23 August 2025.

¹⁶⁸ - Michel Badré, “Retour sur le débat public EPR2 – Penly”, before the High Committee for Transparency and Information on Nuclear Safety (HCTISN), 15 October 2024, see http://www.hctisn.fr/IMG/pdf/5_241015_hctisn_presentation_mb.pdf, accessed 23 August 2025.

¹⁶⁹ - Cour des comptes, “La filière EPR : Une dynamique nouvelle, des risques persistants—Rapport de suites”, January 2025, op. cit.

- Ensure that any new international project in the nuclear field generates quantifiable gains and does not delay the EPR2 program schedule in France.

The analysis is based on some raw numbers. At the end of 2023, EDF's overnight cost estimate for the first three pairs of EPR2s was reevaluated at just under €80 billion (US\$₂₀₂₃ 86.4 billion), 30 percent higher than the previous estimate from only one year earlier. In the underlying assumptions, the construction start of the first Penly unit was delayed from end of 2027 to September 2028 and its startup from September 2036 to July 2038—that is already three years later than assumed at the beginning of the official EPR2 planning.

The two nuclear companies EDF and Orano/AREVA alone have absorbed €23.7 billion (US\$₂₀₂₄ 25.8 billion) or 86 percent of all public cash injections to industrial companies by the State's Holdings Agency (APE).

The amounts of money invested into the EPR2 project prior to any construction start are quite extraordinary. The EPR2 Project Review Committee stated in its November 2024 report: “It should be noted that €3 billion [US\$₂₀₂₄ 3.3 billion] will already have been spent by EDF by the end of 2024, while an additional €2 billion [US\$₂₀₂₄ 2.2 billion] is planned for 2025 and €3 billion [US\$₂₀₂₄ 3.3 billion] for 2026, while the final investment decision (FID) cannot be taken before mid-2026, in a timetable that remains optimistic.”¹⁷⁰ A total of €8 billion (US\$₂₀₂₄ 8.7 billion) is to be spent prior to the FID. Reportedly, EDF later decided to reduce expenditures in 2025 from €2 billion to €1.1–1.3 billion,¹⁷¹ which does not change the order of magnitude of the extraordinary financial engagement prior to the official decision to go ahead.

It is obvious that the French state will have to shoulder much of the EPR2 investment burden. The engagement in favor of the nuclear sector is obviously not new. According to the Court of Accounts, the two nuclear companies EDF and Orano/AREVA alone have absorbed €23.7 billion (US\$₂₀₂₄ 25.8 billion) or 86 percent of all public cash injections to industrial companies by the State's Holdings Agency (APE) between 2011 and 2023.¹⁷²

Energy Planning

The French government submitted a draft Multi-Year Energy Program (PPE) 2030–2035 for public consultation between 7 March and 5 April 2025.¹⁷³ According to the government, there were 1,373 contributions to the debate.¹⁷⁴

¹⁷⁰ - Review Committee of the EPR2 Project, “Rapport au Président Directeur Général d'EDF—Revue de maturité du programme EPR2”, Comité de Revue du Projet EPR2, July 2024.

¹⁷¹ - Amélie Laurin, “EDF donne un coup de frein aux investissements dans ses futurs réacteurs nucléaires”, *Les Echos*, 20 December 2024, see <https://www.lesechos.fr/industrie-services/energie-environnement/edf-donne-un-coup-de-frein-aux-investissements-dans-ses-futurs-reacteurs-nucleaires-2138635>, accessed 21 April 2025.

¹⁷² - Cour des comptes, “Dix ans de politiques publiques en faveur de l'industrie : des résultats encore fragiles”, Court of Accounts, 28 November 2024, see <https://www.ccomptes.fr/sites/default/files/2024-11/20241128-10-ans-de-politiques-publiques-en-faveur-industrie.pdf>, accessed 23 August 2025.

¹⁷³ - Government of France, “Stratégie française pour l'énergie et le climat—Programmation pluriannuelle de l'énergie (2025–2030, 2031–2035)”, March 2025, see https://www.consultations-publiques.developpement-durable.gouv.fr/IMG/pdf/o2__projet_de_ppe_3.pdf, accessed 23 August 2025.

¹⁷⁴ - Ministry for Town and Country Planning and Decentralization, and Ministry for the Ecological Transition, Biodiversity, Forests, Marine Affairs and Fisheries, “Consultation du public sur le projet de troisième édition de la Programmation pluriannuelle de l'énergie (PPE)”, Government of France, Updated 30 July 2025, see <https://www.consultations-publiques.developpement-durable.gouv.fr/consultation-du-public-sur-le-projet-de-troisieme-a3142.html?lang=fr>, accessed 19 August 2025.

The plan does not count on any additional operating reactor by 2035 but, rather prudently, on a stable, annual production 360 TWh—EDF aims for 400 TWh by 2030—from the current fleet of 57 reactors. Operational lifetime extensions beyond 50 and 60 years and uprating possibilities would be assessed and implemented where possible and meeting safety criteria. No closures are foreseen in that period. The construction of “at least” a further 13 GW, equivalent to eight EPR2s, would be studied and the construction of “at least” one prototype SMR would be launched around 2030. And, just like in the 1970s, the plan envisions a “fleet of fast neutron reactors” operating with plutonium fuels “by the end of the century at the latest”.

However, the “Central Scenario” envisages strong growth for renewables, including more than doubling solar capacity to 54 GW generating 66 TWh by 2030 and expanding to 65–90 GW/92–110 TWh by 2035. Onshore wind is to grow by about half to 33 GW/72 TWh by 2030 and to 40–45 GW/91–103 TWh by 2035, with offshore wind to reach 3.6 GW/14 TWh by 2030 and 18 GW/71 TWh by 2035.

EDF is clearly opposed to high solar power targets and at the same time reveals that it is already experiencing (unspecified) constraints on the nuclear fleet never seen before due to variable generation demand:

The range mentioned in the consultation document on the PPE for solar PV, and even more so its upper limit of 100 GW¹⁷⁵ in 2035, seems to us significantly too high for this timeframe. Such a level would lead to an imbalance in the French electricity production mix and in the supply/demand balance. In particular, the opportunities for nuclear power are already declining; thus, the sharp variations in power demand on the nuclear fleet over short periods are causing¹⁷⁶ constraints on equipment and organizations that have never been encountered before.¹⁷⁷

Conclusion

Nuclear production has improved in 2024 but remains far below the average level in the decade that ended in 2015. The fourth decennial inspections demand significant outage times, and new cases of stress corrosion cracking and thermal fatigue recreate uncertainty and additional inspection needs.

The overall number of outage days went down significantly in 2024, but the number of unplanned outage days (according to EDF definition) is the second highest level of the past six years.

The first EPR Flamanville-3 was finally connected to the grid in December 2024. The commissioning process has been difficult, and the unit has been off-grid most of the time due to excessive inspection needs, numbers of incidents, and repair work.

Consequently, there is now no reactor under active construction in France.

¹⁷⁵ - 90 GW in the March 2025 draft government report (see previous reference). The 100 GW number was featured in a December 2024 draft version of the Decree relative to the PPE.

¹⁷⁶ - The French original says “font apparaître” which can mean reveal or cause.

¹⁷⁷ - EDF, “Concertation nationale sur l’énergie et le climat—Le point de vue d’EDF sur les documents de planification énergie climat soumis à la concertation—Cahier d’acteur N°363”, 2024.

The newbuild plans proceed, with bulldozers having started earthworks at the Penly site, while the Flamanville-3 EPR successor EPR2 still does not even exist on paper. That means that reliable cost estimates are hardly possible. EDF is to supply an updated calculation to the government by the end of 2025. The final investment decision is expected for the end of 2026. Construction start—first concrete for the foundation of the reactor building—has been delayed to September 2028.

The expected startup of the first EPR2 at Penly has been officially delayed from the originally planned 2035 to 2038.

Meanwhile, the renewables buildout is accelerating, especially with solar adding a record 5 GW in 2024. EDF is worried that the implementation of envisaged high solar capacity targets for 2030/2035 could threaten already “declining opportunities” for nuclear power and increase the need for reactors ramping up and down to follow fluctuating renewable output, which in turn has detrimental effects on equipment and organization.

The publication of the Multi-Year Energy Program (PPE) 2030–2035, supposed to frame energy policy for the next decade, has been delayed multiple times and is expected to happen once the National Assembly reconvenes after the summer break and gets a chance to comment.

JAPAN FOCUS



Overview

During Financial Year (FY) 2024, which runs from April 2024–March 2025, the number of nuclear reactors considered “operable” increased from 12 to 14 with a gross capacity of 13.3 GW.¹⁷⁸ As no additional reactor has been declared for permanent closure during the past year, the total number of closed reactors remains unchanged at 27,¹⁷⁹ including 22 units officially closed following the Fukushima accidents in 2011 (see Table 6 for details).

In November 2024, for the first time since the establishment of the new regulator in 2012, a nuclear reactor—Tsuruga-2—failed the restart safety review under the new regulations.

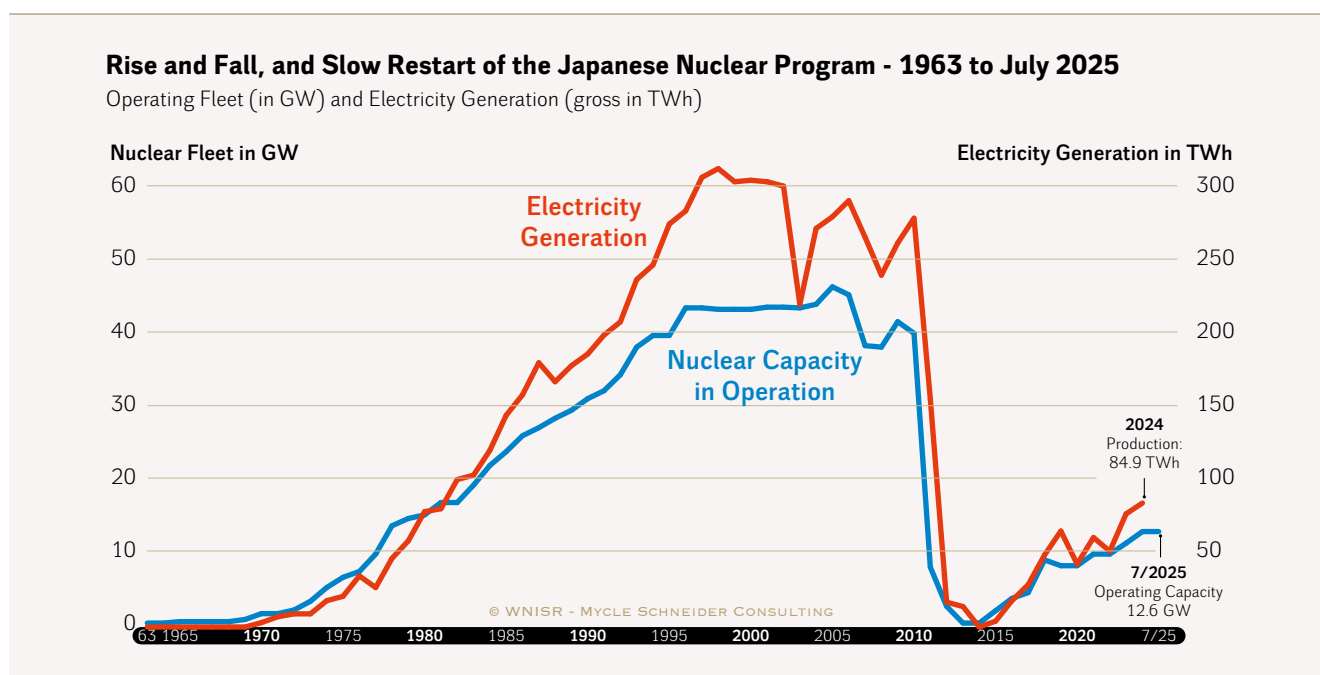
Total nuclear power generation increased by 9.5 percent, from 77.5 TWh in 2023 to 84.9 TWh (gross) in 2024. (See Figure 35) The share of nuclear power in the total power generation also increased from 7.7 percent in 2023 to 8.4 percent in 2024.¹⁸⁰

¹⁷⁸ - IAEA-PRIS indicates 12.6 GW net. Unless indicated otherwise, the sources used throughout this section are JAIF, “日本の原子力発電炉（運転中、建設中、計画中等）”, Japan Atomic Industrial Forum, as of 12 May 2025, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2025/05/jp-npps-operation20250512.pdf; and JAIF, “Current Status of Nuclear Power Plants in Japan”, as of 12 May 2025, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2025/05/jp-npps-operation20250512_en.pdf, accessed 5 June 2025.

¹⁷⁹ - Ibidem; and IAEA-PRIS, “Country Statistics—Japan”, Updated 11 July 2025, see <https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=JP>, accessed 12 July 2025.

¹⁸⁰ - Energy Institute, “Statistical Review of World Energy 2025—Consolidated Dataset”, 2025.

Figure 35 - Rise and Fall of the Japanese Nuclear Program



Sources: WNISR with Energy Institute and IAEA-PRIS, 2025

The current reactor fleet consists of 33 units (33.1 GW gross) of which 25 units (24.8 GW gross) have applied for an operating license under the new post-Fukushima regulations.¹⁸¹ Japan's nuclear safety review process consists of three steps carried out simultaneously:¹⁸²

1) Review of “changes in reactor installation” → Permission

Under the new regulatory standards, which incorporate lessons learned from the accidents at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi Nuclear Power Station, licensing criteria have been strengthened for seismic events, tsunamis, and other hazards. These new standards are applied retroactively by backfitting existing reactors. Moreover, in cases where an accident or natural disaster exceeds the assumptions outlined in the revised criteria, countermeasures are required to prevent core damage, prevent containment vessel failure, and suppress the release of radioactive materials.

In the review for changes to the installation permit, the location, structure, and equipment of the nuclear reactor facility as well as the technical capabilities of the operator are evaluated for compliance with these standards.

2) Review of “plan for construction works” → Approval

This review verifies whether the detailed design of the nuclear reactor facility, as well as the methods of design and quality control during construction, are consistent with the installation permit and meet regulatory standards.

¹⁸¹ - JAIF, “日本の原子力発電所（運転中、建設中、計画中等）”, as of 12 May 2025, op. cit.

¹⁸² - NRA, “The Flow of Review and Inspection for Checking Conformity to New Regulatory Requirements”, Nuclear Regulation Authority of Japan, Undated, see <https://www.nra.go.jp/english/regulatory/20150826.html>, accessed 15 July 2025.

3) Review of “operational safety program” → Approval

This review assesses whether the safety measures stipulated in the reactor’s safety regulations are adequate for preventing disasters involving nuclear fuel materials, objects contaminated by nuclear fuel materials, and power reactors.

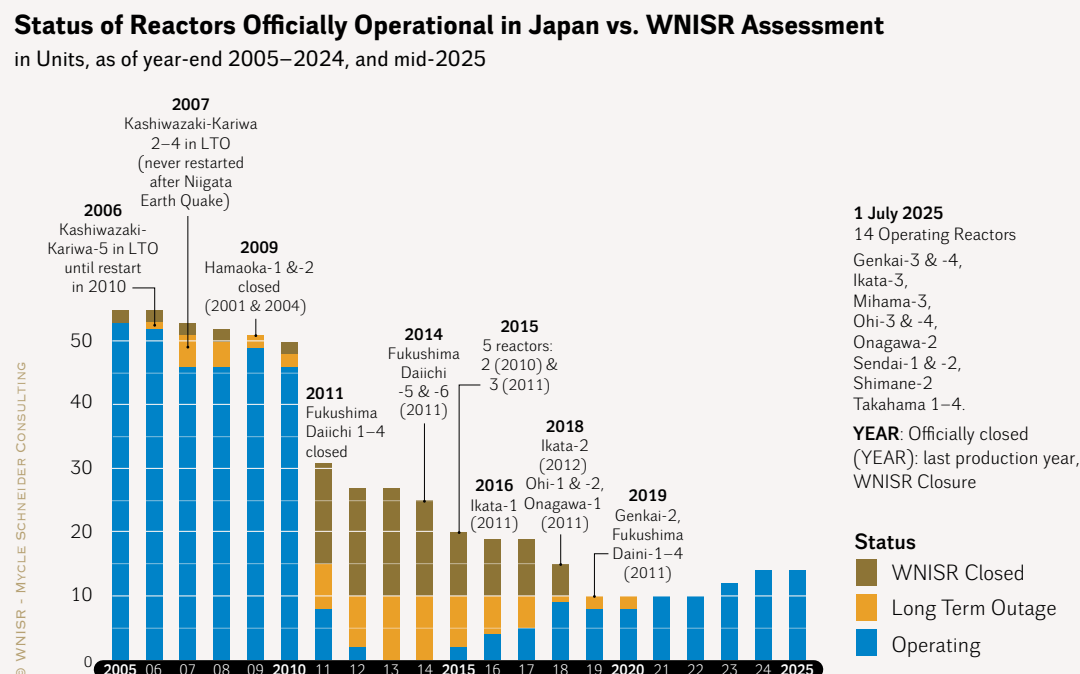
Generally speaking, passing the review of “changes in reactor installation” is regarded as passing the Nuclear Regulation Authority (NRA) review in Japan. However, the other two reviews must also be passed before the reactor can be put into operation.

So far, 17 units have passed the “changes in reactor installation” and the “plan for construction works” reviews while seven applications remain under review. The NRA is expected to issue an operating license for Tomari-3 of the Hokkaido Electric Power Company in the summer of 2025.

As of 1 July 2025, twelve of the 14 operable reactors were operating, while two—Ohi-3 and Takahama-4—were under periodic inspection since June 2025.¹⁸³

WNISR considers 19 units in Long-Term Outage (LTO). In 2022, the IAEA adopted a new category called “Suspended Operation”. In 2024, it reclassified 19 reactors to be in Suspended Operation that WNISR considers in LTO. In other words, Japan and the IAEA have adopted an approach similar to the LTO concept that WNISR introduced in 2014. (See Figure 36).

Figure 36 · Status of the Japanese Reactor Fleet



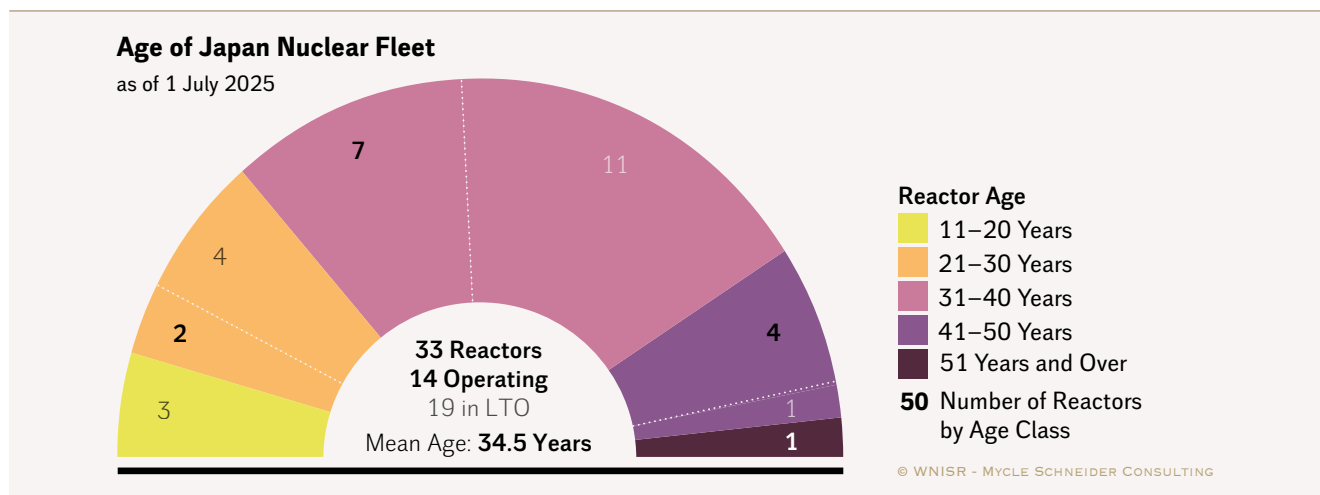
Sources: Various, compiled by WNISR, 2025

For the first time in 13 years since the Fukushima disaster was triggered, two Boiling Water Reactors (BWRs), Onagawa-2 and Shimane-2, resumed operation in late 2024.

¹⁸³ - NRA, “原子力発電所の現在の運転状況”, Updated July 2025, see https://www.nra.go.jp/jimusho/uten_jokyo.html, accessed 15 July 2025.

As of mid-2025, the Japanese nuclear fleet consisting of 33 units, including 19 in LTO, had reached a mean age of 34.5 years, with 24 units aged over 31 years, of which five are over 41 years and one (Takahama-1) over 51 years old (see Figure 37).

Figure 37 · Age Distribution of the Japanese Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2025

Regulatory Measures—First Rejection of Restart Application

The following overview summarizes events between mid-2024 and mid-2025.

Kashiwazaki Kariwa-6 and -7

On 27 February 2025, TEPCO announced a multi-year delay in targeted completion dates of the “Specific Major Accident Response Facilities”—designed in particular to counter terrorist acts—at Units 6 and 7 of the Kashiwazaki Kariwa nuclear power station (Niigata Prefecture) from September 2026 to September 2031 and from March 2025 to August 2029, respectively.¹⁸⁴ Thus, the restart of Unit 7, which had been scheduled for the end of 2025, will be significantly delayed again.

Nuclear operators are obliged under the post-3/11 safety and security regulations to install these facilities at each nuclear power plant. The main facility has a backup function for a situation in which equipment would not be available in a wide area due to large-scale damage, such as following an intentional aircraft crash. There is a grace period of five years from the approval of the design and construction plan for the facility, with NRA-stipulated completion deadlines of September 2029 for Unit 6 and October 2025 for Unit 7. If the facilities cannot be installed within the grace period, the reactors will not be permitted to operate.

Units 6 and 7 passed the NRA’s review of “changes in reactor installation” in 2017, but in 2021 the NRA ordered TEPCO not to load fresh nuclear fuel at Kashiwazaki Kariwa after discovering

¹⁸⁴ - TEPCO, “柏崎刈羽原子力発電所 特定重大事故等対処施設の「発電用原子炉設置許可に係る工事計画変更届出」の提出について”, 27 February 2025, see <https://www4.tepco.co.jp/about/ir/library/disclosure/pdf/250227-1.pdf>, accessed 12 May 2025.

deficiencies in anti-terrorism measures within the plant.¹⁸⁵ The ban was lifted in 2023, and TEPCO has continued discussions with the Niigata Prefecture's governor to obtain his consent to restart the plant. TEPCO cited a shortage of materials and staffing as factors contributing to the installation delay.¹⁸⁶

In light of the current circumstances, Takeyuki Inagaki, the director of the Kashiwazaki Kariwa plant, held a press conference on 25 June 2025, announcing a change in strategy: the plant will no longer prioritize restarting Unit 7 and will instead focus on restarting Unit 6. Fuel loading for Unit 6 was completed on 21 June 2025. The plant still has a four-year grace period to install Specific Major Accident Response Facilities. During the press conference, Director Inagaki did not specify when Unit 6 would be restarted.¹⁸⁷

Ohma

On 6 September 2024, J-Power, owner of the Ohma nuclear power plant in Aomori Prefecture, informed the town of Ohma that it will postpone the start of safety work, which was scheduled to begin in the second half of 2024.¹⁸⁸

According to IAEA-PRIS, construction of the Ohma plant began in May 2010, as the world's first commercial nuclear power plant designed to operate solely on MOX fuel, a mixture of plutonium and uranium extracted from spent nuclear fuel.¹⁸⁹ However, construction work was halted after the 2011 events at TEPCO's Fukushima Daiichi facilities.¹⁹⁰

In October 2012, J-Power announced its decision to resume construction of the plant and stressed that it had “not yet set a date for the commencement of operation but intends to review the matter in the future based on progress in construction.”¹⁹¹ But construction activities were limited, until they were eventually stopped in 2021. The Ohma construction history to 2021 is presented in an IAEA report, which exposes that due to new regulations under discussion in 2012, “construction efforts were made within the limited scope that would not be affected by new regulations”, and states:

After the new regulatory standards became effective in July 2013, the progress of work has been practically restricted by factors such as the inability to have regulatory inspection (pre-service inspection).

At present [as of 2021], it was forced to preserve the equipment for a long period of time at the construction site and the vendors factories.

¹⁸⁵ - Ibidem.

¹⁸⁶ - *The Genshiryoku Sangyo Shimbun*, “柏崎刈羽6・7号機 特重施設整備時期が変更”, 28 February 2025, see <https://www.jaif.or.jp/journal/japan/26997.html>, accessed 12 May 2025; and TEPCO, “2025 年 2 月 27 日所長会見 所感”, 27 February 2025, see https://www.tepco.co.jp/niigata_hq/data/press_conference/kk-np/pdf/2024/20250227.pdf, accessed 13 July 2025.

¹⁸⁷ - TEPCO, “2025 年 6 月 25 日所長会見 所感”, 25 June 2025, see https://www.tepco.co.jp/niigata_hq/data/press_conference/kk-np/pdf/2025/20250625.pdf, accessed 12 May 2025.

¹⁸⁸ - Ohma City Council, “おおま議会だより”, 11 November 2024, see https://www.town.ooma.lg.jp/council_newsletter/2024/files/202411.pdf, accessed 10 June 2025.

¹⁸⁹ - J-Power, “大間原子力開発の経緯”, Undated, see <https://www.jpowers.co.jp/bs/nuclear/oma/history.html>, accessed 15 July 2025.

¹⁹⁰ - Osamu Tsukimori, “J-Power Halts Construction Work on Ohma Nuclear Plant”, *Reuters*, 31 March 2011, see <https://jp.reuters.com/article/japan-nuclear-ohma-idINL3E7EV1FU20110331/>, accessed 12 July 2025.

¹⁹¹ - J-POWER, “Resumption of Construction of the Ohma Nuclear Power Plant”, 1 October 2012, see https://www.jpowers.co.jp/english/news_release/news/news121001.pdf, accessed 11 July 2025.

Since 2014, preservation measures have been implemented with consideration of long term preservation.¹⁹²

According to a J-Power spokesperson, no construction work is being carried out as of mid-2025. The project is still under safety review by the NRA. A safety improvement plan to comply with the new regulatory standards was scheduled to be finalized this year but has been postponed to autumn 2026 when it is to be submitted to Aomori Prefecture and Ohma Town. Following that step, J-Power will seek final approval for the plan from the NRA, aiming to commence operation within fiscal year 2030.¹⁹³

WNISR considers the reactor construction as suspended.

Onagawa-2

On 15 November 2024, Tohoku Electric Power Company's Onagawa-2 (Miyagi Prefecture) was reconnected to the grid after several delays.¹⁹⁴ It was the 13th nuclear reactor and the first BWR—the same basic design as the Fukushima Daiichi Nuclear Power Station's reactors—to be restarted since the March 2011 Fukushima events. All other reactors in Japan that were previously restarted since 3/11 were PWRs. It is also the first time since the 2011 Great East Japan Earthquake that a nuclear power plant in the affected area has resumed operation.¹⁹⁵ Work on safety upgrades at the Onagawa nuclear power plant began in May 2013. The 800-meter long seawall was raised to 29 meters above sea level as a tsunami response measure, and various measures have been taken in order to secure “electricity and cooling functions in case of severe accidents.”¹⁹⁶ Tohoku Electric Power Co. applied to the NRA for a safety review in December 2013, and the review of “changes in reactor installation” was permitted in February 2020.¹⁹⁷ Since then, in order to receive construction and operating permits, efforts were made to strengthen safety, including seismic reinforcement work. Implementation work was completed in May 2024. By late February 2023, Tohoku Electric Power Co. had passed the review of “operational safety program”. So it received the operating license.¹⁹⁸ Tohoku Electric Power Co. must still install the “Specific Major Accident Response Facilities” by December 2026.¹⁹⁹

192 - IAEA, “Ageing Management of Nuclear Power Plants during Delayed Construction Periods, Extended Shutdown and Permanent Shutdown Prior to Decommissioning”, May 2021, see <https://www-pub.iaea.org/MTCD/Publications/PDF/TE-1957web.pdf>, accessed 11 July 2025.

193 - Spokesperson, personal communication, Public Relations Department, J-Power, 14 July 2025.

194 - Tohoku Electric Power Co., “Onagawa Nuclear Power Station Unit 2 Connects to the Grid”, Press Release, 15 November 2024, see https://www.tohoku-epco.co.jp/english/press/_icsFiles/afiedfile/2024/11/15/1245885.pdf, accessed 21 November 2024.

195 - *The Yomiuri Shimbun*, “女川原発2号機が13年7か月ぶりに再稼働、被災地で初…12月にも営業運転を開始”, 30 October 2024, see <https://www.yomiuri.co.jp/science/20241029-OYT1T50136/>, accessed 13 May 2025.

196 - Tohoku Electric Power Co., “Onagawa Nuclear Power Station Unit 2 Starts Commercial Operation”, Press Release, 26 December 2024, see https://www.tohoku-epco.co.jp/english/press/_icsFiles/afiedfile/2024/12/26/1246004.pdf, accessed 12 July 2025.

197 - Tohoku Electric Power Co., “女川原子力発電所2号機の新規制基準への適合性審査に係る原子炉設置変更許可について”, Press Release, 26 February 2020, see https://www.tohoku-epco.co.jp/pastnews/atom/1205931_1065.html; and Tohoku Electric Power Co., “Integrated Report 2020”, September 2020, see https://www.tohoku-epco.co.jp/ir/report/integrated_report/pdf/tohoku_report2020en.pdf; both accessed 13 July 2025.

198 - Tohoku Electric Power Co., “女川原子力発電所 審査状況”, Undated, see https://www.tohoku-epco.co.jp/electr/genshi/safety/topics/o_regulations.html, accessed 15 July 2025.

199 - Tohoku Electric Power Co., “女川原子力発電所2号機における特定重大事故等対処施設の設置に係る原子炉設置変更許可について”, Press Release, 5 October 2023, see https://www.tohoku-epco.co.jp/news/atom/1237339_2549.html, accessed 15 July 2025.

Shimane-2

On 23 December 2024, Chugoku Electric Power Company reconnected Unit 2 at its Shimane plant, almost 13 years after it was shut down in 2012.²⁰⁰ About 450,000 people live within a 30-kilometer radius of the plant. Since the Fukushima events of 2011 began, Shimane-2 is the 14th reactor and only the second BWR to be restarted, following Tohoku Electric Power Co.'s Onagawa-2 in November 2024. In 2021, Shimane-2 passed NRA's review of "changes in reactor installation".²⁰¹ Chugoku Electric Power Co. completed safety work in October 2024 and placed nuclear fuel in the reactor in November.²⁰² Unit 2 is the only operating nuclear reactor in Japan located in a prefectural capital (Matsue-City).

Shimane-3

Chugoku Electric Power Company plans to start operation of Shimane-3 by the end of FY2030, and the unit is undergoing a safety review.²⁰³ On 3–4 April 2025, the NRA inspected Chugoku Electric Power Company's Shimane-3. The inspection team checked the reactor containment vessel's structure and its piping system which sends steam to the turbine. The NRA's inspection of Shimane-3 is meant to provide a reference for future safety reviews.

At present, there is no active construction work at the unit, as it is undergoing NRA inspections under the new regulatory standards. Prior to the Fukushima Daiichi events in 2011, the containment vessel and the pressure vessel had already been installed within the reactor building. Fourteen years later, the primary operations are focused on quality-control inspections.²⁰⁴

WNISR considers the reactor construction as suspended.

Takahama-1 and -2

On 16 October 2024, the NRA approved the management policy for Kansai Electric Power Co. (KEPCO)'s Takahama-1 reactor (in the Fukui Prefecture) for the next 10 years.²⁰⁵ Unit 1 began operation in 1974. In May 2024, Unit 1, which began operation in 1974 and marked 50 years of operation on 27 March 2024, and Unit 2, which began operation on 17 January 1975 and has also passed the 50-year mark, were both approved to operate for up to 60 years.²⁰⁶

200 - Chugoku Electric Power Company, "島根原子力発電所2号機の発電機並列（再稼働）について", Press Release, Energia, 23 December 2024, see https://www.energia.co.jp/atom_info/press/2024/15694.html, accessed 13 July 2025; and JAIF, "Shimane-2 Becomes Japan's Second BWR to Resume Power Generation", 26 December 2024, see <https://www.jaif.or.jp/en/news/7318>, accessed 11 July 2025.

201 - JAIF, "Current Status of Nuclear Power Plants in Japan", as of 12 May 2025, op. cit.

202 - Chugoku Electric Power Company, "島根原子力発電所2号機における安全対策工事の完了について", Press Release, Energia, 28 October 2024, see https://www.energia.co.jp/atom_info/press/2024/15586.html; and Chugoku Electric Power Company, "島根原子力発電所2号機における燃料装荷の終了について", Energia, 3 November 2024, see https://www.energia.co.jp/assets/20241103a_1.pdf; both accessed 13 July 2025.

203 - NRA, "島根原子力発電所の現地視察の実施 議事要旨", Nuclear Regulatory Authority, 4 April 2025, see <https://www.da.nra.go.jp/view/NRA100009604?contents=NRA100009604-002-005#pdf=NRA100009604-002-005>, accessed 10 June 2025.

204 - Spokesperson, personal communication, Public Relations Department, Chūgoku Electric Power Company 14 July 2025.

205 - KEPCO, "高浜発電所1号機の高経年化対策に係る原子炉施設保安規定の変更認可", Kansai Electric Power Co., 16 October 2024, see https://www.kepcoco.jp/corporate/pr/2024/pdf/20241016_2j.pdf, accessed 18 October 2024.

206 - Nanako Takehara, "NRA Extends Operating Lifetimes of Takahama-3 & -4 from 40 to 60 Years", JAIF, 4 June 2024, see <https://www.jaif.or.jp/en/news/7094>, accessed 14 July 2024; and KEPCO, "高浜発電所3、4号機の運転期間延長認可", Press Release, 29 May 2024, see https://www.kepcoco.jp/corporate/pr/2024/pdf/20240529_2j.pdf, accessed 16 August 2025.

Tokai-2

On 23 August 2024, Japan Atomic Power Company (JAPC) announced a new postponement of the estimated completion of safety measures required for the restart of Tokai-2 in Tokai-mura, Ibaraki Prefecture, from September 2024 to December 2026, following the discovery of a deficiency in the foundation of the seawall under construction at the plant. At the same time, the company also informed the NRA, Ibaraki Prefecture, Tokai Village, and other surrounding municipalities about the discovery.²⁰⁷ JAPC indicated that it intends to do additional reinforcement work in the surrounding ground, leaving the foundation in place. The NRA still has to examine whether this additional work would meet the safety criteria. Tokai-2 passed the NRA's safety review in 2018 for "changes in reactor installation" to meet regulatory standards set in 2012.²⁰⁸ But JAPC still needs construction and operating permits before restarting the reactor.

Tomari-3

On 30 April 2025, the NRA granted permission to review of "changes to the reactor installation" for Unit 3 at the Hokkaido Electric Power Company's (Hokuden for short) Tomari nuclear power plant (Tomari-mura), which is effectively a certificate of acceptance for safety examination.²⁰⁹ Tomari-3 was shut down in May 2012. It is the newest nuclear reactor in Japan, having started operation in 2009 with a net design capacity of 866 MW. The draft of the review report went through a public comment process and was scheduled to be approved in the summer of 2025.²¹⁰

In 2013, Hokuden applied to the NRA to restart Tomari-3, but it took the NRA more than 11 years to examine whether the faults on the site were active or not. One of the factors that prolonged the NRA review was the difficulty of proving the non-existence of active fault lines on the site. Reportedly, Hokuden was unable to provide convincing evidence primarily due to a lack of personnel with expertise. It took eight years to produce the evidence that there was no active fault with assistance from other electric power companies and experts. Hokuden is notably proceeding with the construction of a seawall to protect against tsunamis in order to receive the operating permit. It is aiming to restart operating Unit 3 in 2027.²¹¹

207 - JAPC, "東海第二発電所の原子炉設置変更許可に係る工事計画変更の届出について", 23 August 2024, see <https://www.japc.co.jp/news/press/2024/pdf/240823.pdf>, accessed 10 June 2025; and JAIF, "Current Status of Nuclear Power Plants in Japan", as of 13 August 2024, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2024/05/jp-npps-operation20240508_en.pdf, accessed 18 August 2024.

208 - JAPC, "東海第二発電所の新規規制基準への適合性確認審査に係る—工事計画認可について", 30 October 2018, see <https://www.japc.co.jp/news/press/2018/pdf/301018.pdf>, accessed 13 July 2025; and *The Ibaraki Shimbun* "防潮堤工法「実現性ない」 東海第2 規制委、再説明求める 茨城", 30 August 2024, see https://ibarakinews.jp/news/newsdetail.php?f_jun=17249392983815, accessed 12 May 2025.

209 - NRA, "北海道電力株式会社泊発電所の発電用原子炉の設置変更許可(3号発電用原子炉施設の変更)に関する意見の聴取について", 30 April 2025, see https://www.aec.go.jp/kaigi/teirei/2025/siryoi18/3-1_sankou.pdf, accessed 10 May 2025; and JAIF, "Current Status of Nuclear Power Plants in Japan", as of 12 May 2025, op. cit.

210 - *Nihon Keizai Shinbun*, "泊原発3号機の再稼働、規制委が「合格」 運転再開は2027年めど", 30 April 2025, see <https://www.nikkei.com/article/DGXZQQUA288LV0Y5A420C2000000/>, accessed 15 July 2025.

211 - NHK, "泊原発3号機「事実上の合格」審査書案取りまとめ 原子力規制委", 30 April 2025, see <https://www3.nhk.or.jp/news/html/20250430/k10014793251000.html>, accessed 10 May 2025; and Hokuden, "Overview of the FY2026 HEPCO Group Management Plan", 30 April 2025, see https://www.hepco.co.jp/english/ir/pdf/management_plan_fy2026.pdf, accessed 13 July 2025.

Tsuruga-2—Restart Application Rejected

On 13 November 2024, the NRA formally decided that the Japan Atomic Power Company (JAPC)’s Tsuruga-2 in Fukui Prefecture does not comply with regulatory safety standards. This is the first reactor that failed its restart safety review since the establishment of the NRA in 2012. Under the new regulatory safety standards developed after the Fukushima accidents were triggered in 2011, a reactor cannot be restarted if there is an active fault directly under the reactor. The NRA concluded that Tsuruga-2 did not meet safety standards because JAPC failed to prove that there was no active fault.²¹² At a press conference following the regular meeting, NRA’s Chairman Shinsuke Yamanaka emphasized, “We made a solid decision from a scientific and technical standpoint.” JAPC indicated its intention to submit a new application to the NRA in order to resume operations.²¹³

Legal Cases Against the Restart of Reactors

Various legal cases against the operation of existing reactors continue. The following are three key decisions from the past year, all of which rejected the plaintiffs’ requests for injunctions.

Sendai-1 and -2 – Volcanic Eruption and Earthquake Risks

On 21 February 2025, the Kagoshima District Court ruled against the plaintiffs in a trial in which over 3,000 people, including local residents, demanded an injunction against the operation of Units 1 and 2 of the Kyushu Electric Power Company (Kyuden)’s Sendai nuclear power plant in Kagoshima Prefecture, on the grounds that “there is no concrete risk of an accident caused by volcanic eruption or earthquake.” In 2012, the plaintiffs had filed a lawsuit against Kyuden and the national government, demanding an injunction against the operation of the plant, claiming that “there are five calderas near the plant that have caused huge eruptions in the past, and the possibility of a catastrophic eruption cannot be ignored.” After a lengthy hearing, the Kagoshima District Court ruled that Kyuden’s assessment—that “the possibility of a catastrophic eruption occurring during the operational period of the plant is sufficiently small”—was based on a “reasonable scientific basis, consistent with the ‘Volcano Guide’ used by the NRA to assess eruption risk, and not unreasonable.” The plaintiffs reportedly intend to file an appeal with the High Court.²¹⁴

²¹² - NRA, “日本原子力発電株式会社敦賀発電所の発電用原子炉設置変更許可申請書（2号発電用原子炉施設の変更）に対する処分”, 13 November 2024, pp. 1-3, see <https://www.da.nra.go.jp/view/NRA100006314?contents=NRA100006314-004-007#pdf=NRA100006314-004-007>, accessed 10 June 2025.

²¹³ - JAPC, “敦賀発電所2号機の実績と現状”, Undated, see https://www.japc.co.jp/plant/tsuruga/shinsa/tsuruga2_necessity1.html, accessed 13 June 2025.

²¹⁴ - Kagoshima District Court, “判決”, 21 February 2025, see <https://www.datsugenpatsu.org/bengodan/wp-content/uploads/2025/02/250221%E5%88%A4%E6%B1%BA.pdf>; and NHK, “川内原発 運転差し止め訴訟 原告の訴え退ける判決 鹿児島地裁”, 21 February 2025, see <https://www3.nhk.or.jp/news/html/20250221/k10014729411000.html>; both accessed 10 May 2025.

Ikata-3 – Active Fault Line Below Site and Volcanic Risks in Question

On 5 March 2025, the Hiroshima District Court dismissed a lawsuit filed by local populations and others seeking an injunction against the continued operation of Unit 3 of the Shikoku Electric Power Company's Ikata nuclear plant in Ehime Prefecture, on the grounds that no concrete danger of harm to the lives or health of the plaintiffs had been found. In addition, while the residents argued that there was a possibility of an active fault line near the plant but that an adequate survey had not been conducted, the court ruled that "there is no evidence to suggest that the survey conducted by Shikoku Electric Power Co. was inadequate." Furthermore, the residents claimed that a pyroclastic flow could reach the vicinity of the Ikata facilities in case of an eruption of the same magnitude as the massive eruption that occurred 90,000 years ago at Mount Aso in Kumamoto Prefecture across the sea. In response, the Hiroshima District Court concluded, "It cannot be said that Shikoku Electric Power Co. underestimated the possibility of an eruption at Mount Aso."²¹⁵ The plaintiffs appealed the court decision.

Ikata-3 – Offshore Fault Line in Question

On 18 March 2025, a ruling was also handed down in another lawsuit aiming at the Ikata-3 restart license. The Matsuyama District Court ruled against the lawsuit, stating that there was no concrete danger to the plaintiffs' lives or bodies. The plaintiffs had argued that Shikoku Electric Power Co. did not take into account the possibility of larger earthquake shocks stemming from the fault zone extending offshore to the north of the Ikata site. However, the court ruled that Shikoku Electric Power Co. made its evaluation based on its knowledge of lateral displacement faults and the results of further investigations, and no critical issues would have been identified.²¹⁶

Spent Fuel Management

On 6 November 2024, Japan's first offsite interim dry storage facility, for spent nuclear fuel generated by commercial nuclear power plants, began operations in Mutsu City, Aomori Prefecture. The facility is designed to store fuel from two electric power companies, TEPCO and JAPC, for up to 50 years. NRA issued an operating license to the facility's operator, Recyclable Fuel Storage Company (RFS), the same day the inspection of the facility had been completed.²¹⁷

In August 2024, RFS signed a safety agreement with Aomori Prefecture and Mutsu City.²¹⁸ This agreement is not part of the NRA's licensing process, but it is meant to build trust between the

²¹⁵ - Hiroshima District Court "判決", 5 March 2025, pp. 1–139, see https://saiban.hiroshima-net.org/honso/pdf/20250305_hanketu.pdf, accessed 10 May 2025.

²¹⁶ - Matsuyama District Court, "判決", 18 March 2025, pp. 231–483, see <https://www.ikata-tomeru.jp/wp-content/uploads/2025/03/250318%E5%88%A4%E6%B1%BA%E6%AD%A3%E6%9C%AC.pdf>, accessed 10 May 2025.

²¹⁷ - *The Yomiuri Shimbun* "全国初の使用済み核燃料の中間貯蔵施設、青森・むつ市で操業開始…「核燃料サイクル」担う", 6 November 2024, see <https://www.yomiuri.co.jp/science/20241106-OYT1T50175/>, accessed 10 May 2025; and RFS, "リサイクル燃料備蓄センターの事業開始について", Press Release, 6 November 2024, see <https://www.rfsc.co.jp/ssl/disclosure/koukaisiryuu/osirase/press%E2%91%A1/kaisio1.pdf>, accessed 13 July 2025.

²¹⁸ - RFS, "むつ中間貯蔵施設が事業開始", 7 November 2024, see <https://www.jaif.or.jp/journal/japan/25485.html>, accessed 10 May 2025; and Aomori Prefecture, Mutsu City, and Recycle Fuel Storage Company, "リサイクル燃料備蓄センター周辺地域の安全確保及び環境保全に関する協定書", 9 August 2024, see <https://www.rfsc.co.jp/ssl/disclosure/koukaisiryuu/ankenkyoutei/ankenkyouteio1.pdf>, accessed 13 July 2025.

two parties. The agreement gives the governor and mayor substantial insight and monitoring possibilities, as well as veto power over project operation.

On 26 September 2024, 12 tons of fuel were delivered to this interim storage facility for the first time from TEPCO's Kashiwazaki Kariwa plant. RFS plans to accept a total of 96 tons by the end of FY2026. Currently, a building with a maximum capacity of 3,000 tons has been completed, and another building will be added. In the future, the two buildings are designed to store up to 5,000 tons of fuel.²¹⁹

Startup of Reprocessing Plant at Rokkasho Mura Delayed—Again

On 29 August 2024, Japan Nuclear Fuel Limited (JNFL), the operator of the spent nuclear fuel reprocessing plant under construction in Rokkasho Village, Aomori Prefecture, announced that it was postponing the plant's target completion date from the end of September 2024 to the end of FY2026. The company also postponed the completion of its MOX fuel fabrication facility, which was also scheduled for completion by the end of September 2024, to the end of FY2027.²²⁰ The reprocessing plant is a facility for extracting plutonium from spent nuclear fuel for reuse in nuclear power plants and is at the core of the government's official spent nuclear fuel management policy. It was planned to be completed by 1997, but due to repeated problems and tightened safety standards post-3/11, the completion date has been pushed back many times, with the latest delay reportedly marking the 27th postponement.²²¹

KEPCO Planning to Ship Spent Fuel to France for Reprocessing

On 13 February 2025, Kansai Electric Power Company (KEPCO) submitted a new roadmap to Fukui Prefecture and the prefectural municipalities regarding the removal of spent nuclear fuel from three nuclear power plants operating in the prefecture. In October 2023, KEPCO had issued the Roadmap for Spent-fuel Measures to Fukui Prefecture and its plan to build a dry cask storage facility at three nuclear power plants. But because of the delay in the start of operations at JNFL's reprocessing plant in Rokkasho, Aomori Prefecture, where the spent fuel is to be shipped for reprocessing, KEPCO needed to revise the roadmap. The new plan states that the amount of spent fuel to be shipped to France, to which the reprocessing of spent fuel will be outsourced starting in FY2027, would be doubled to 400 tons including 20 tons of MOX. The original plan announced in 2023 was to transfer 200 tons of spent fuel including 10 tons of MOX fuel to France.²²²

KEPCO operates seven reactors in Fukui Prefecture, the largest number in Japan. However, due to the repeated delays of the commissioning of the Rokkasho Mura reprocessing plant and

219 - *The Yomiuri Shimbun*, “全国初の使用済み核燃料の中間貯蔵施設、青森・むつ市で操業開始…「核燃料サイクル」担う”, November 2024, op. cit.; and RFS, “金属キャスクの輸送終了について”, 26 September 2024, see <https://www.rfsc.co.jp/ssl/disclosure/koukaisiryoy/osirase/press/yusou01.pdf>, accessed 13 July 2025.

220 - JNFL “再処理施設の使用計画”, Press Release, Japan Nuclear Fuel Limited, 29 August 2024, see <https://www.jnfl.co.jp/ja/release/press/2024/detail/file/20240829-2-1.pdf>, accessed 15 June 2025; and JNFL, “Change in Schedule for Completion of Rokkasho Reprocessing Plant and MOX Fabrication Plant”, Press Release, 29 August 2024, see <https://www.jnfl.co.jp/en/release/president-talk/2024/202408.html>, accessed 13 July 2025.

221 - NHK, “核燃料再処理工場 ‘完成目標2026年度中に延期’ 青森県に報告”, 29 August 2024, see <https://www3.nhk.or.jp/news/html/20240829/k10014563901000.html>, accessed 10 May 2025.

222 - KEPCO “使用済燃料対策ロードマップの見直し”, 13 February 2025, see https://www.kepc.co.jp/corporate/pr/2025/pdf/20250213_1j.pdf, accessed 10 May 2025.

the lack of dry storage facilities, spent fuel cannot be removed from the plants. Spent nuclear fuel continues to accumulate at the nuclear power plants and 87 percent of the storage capacity in pools had been saturated as of January 2025. Fukui Prefecture has insisted that KEPCO remove the spent fuel from the prefecture.²²³ The company anticipates that the reprocessing plant in Rokkasho Village, Aomori Prefecture, will begin operation by FY2027, and that a total of about 198 tons will be shipped there between the beginning of FY2028 and the end of FY2030.²²⁴

KEPCO emphasizes that if it follows the roadmap, the amount of spent fuel removed would eventually exceed the amount generated, and thus it estimates that the amount stored would decrease starting in 2033.²²⁵ But the utilization rate of the spent fuel pools of the seven reactors currently in operation is nevertheless expected to reach approximately 97 percent as of the end of FY2032 and stand still at 96 percent at the end of FY2034. Furthermore, the roadmap stipulates that the reprocessing plant must be completed and begin operation by the end of FY2026, and if the operation is delayed, KEPCO will be forced to revise its plans.

KEPCO had announced it would suspend the operation of Takahama-1 and -2, which have been in operation for more than 40 years, as well as Mihama-3, if Fukui Prefecture did not approve the plan, but on 24 March 2025, Fukui Prefecture announced it would accept KEPCO's new plan.²²⁶

High Level Radioactive Waste Disposal Plans

The Nuclear Waste Management Organization of Japan (NUMO) conducts a three-stage survey to select a final disposal site to determine whether it is suitable for construction of a disposal facility: a “literature survey”, an “overview survey”, and a “detailed survey”. Of these, the literature survey analyzes documents and data, including ancient as well as updated documents, on the geology of the study area.²²⁷ Since high-level radioactive waste continues to emit strong radiation for a long period of time, the Japanese government intends to bury it deep underground for final disposal.

On 22 November 2024, NUMO released a report, constituting the first literature review in Japan on the selection of a final disposal site for high-level waste from reprocessing plants in geological formations, on the town of Suttsu and the village of Kamoenai, Hokkaido, was

²²³ - NHK, “関西電力 使用済み核燃料 新たな搬出計画示す”, 13 February 2025, see <https://www3.nhk.or.jp/lnews/fukui/20250213/3050019931.html>, accessed 10 May 2025.

²²⁴ - KEPCO, “使用済燃料対策ロードマップの見直し”, 13 February 2025, see https://www.kepc.co.jp/corporate/pr/2025/pdf/20250213_1j.pdf, accessed 15 July 2025.

²²⁵ - Ibidem.

²²⁶ - NHK, “関電 使用済み核燃料搬出計画 杉本知事が容認”, 24 March 2025, see <https://www3.nhk.or.jp/lnews/fukui/20250324/3050020226.html>, accessed 15 July 2025.

²²⁷ - NUMO, “文献調査とはどのようなものですか?”, Nuclear Waste Management Organization, Undated, see <https://www.numo.or.jp/q-and-a/100089.html>, accessed 10 June 2025.

submitted to the mayors of these two municipalities. The report was also submitted to the Governor of Hokkaido.²²⁸

For the first time in Japan, the first phase in the selection of a disposal site, i.e. the literature review, had been in progress since 2020, covering the town of Suttu and the village of Kamoenai.²²⁹

NUMO's report concluded that the project could proceed to the overview study, which is the second step in the selection process for the final disposal site. In this study, sample gathering by bore holes is aimed at informing the geological survey, which requires the consent of the local government. But the Hokkaido Governor has reportedly expressed his opposition to the overview survey.²³⁰

In addition to these two municipalities, a literature review is being conducted since June 2024 in Genkai Town, Saga Prefecture, where the Kyushu Electric Power Co.'s Genkai plant is located.²³¹ This is the first town with a nuclear power plant site that accepted the survey.

Closed Power Reactors in Japan

No additional reactors operating or in outage at the time of the Fukushima events, were formally declared for decommissioning in the year to 1 July 2025. The 22 Japanese reactors now confirmed to be closed and decommissioned total 15.5 GW or just under 35 percent of nuclear capacity prior to 3/11 (see Figure 35 and Table 6). In total, Japan has 27 closed reactors with 27.1 GW (see Japan in Decommissioning Status Report).

228 - NUMO, “北海道寿都郡寿都町文献調査報告書 要約書”, November 2024, see https://www.numo.or.jp/chisoushobun/survey_status/suttu/pdf/oo_suttu_youyakusho.pdf; and NUMO, “北海道古宇郡神恵内村文献調査報告書 要約書”, November 2024, see https://www.numo.or.jp/chisoushobun/survey_status/kamoenai/pdf/oo_kamoenai_youyakusho.pdf; both accessed 10 June 2025; also NUMO, “NUMO Delivered the Literature Survey Reports to Suttu Town, Kamoenai Village and Hokkaido Prefecture”, 22 November 2024, see https://www.numo.or.jp/en/what/topics_241122.html, accessed 14 July 2025.

229 - NUMO, “Implementation of Literature Survey in Suttu Town and Kamoenai Village, Hokkaido”, 17 November 2020, see https://www.numo.or.jp/en/what/topics_201117.html, accessed 14 July 2025; and NHK, “核のごみ「文献調査」報告書 全国初 北海道寿都町などに提出”, 22 November 2024, see <https://www3.nhk.or.jp/lnews/saga/20241122/5080018425.html>, accessed 10 May 2025.

230 - *The Yomiuri Shimbun*, “「核のごみ」最終処分地選定巡り、NUMOが文献調査報告書を北海道・寿都町に提出…次の調査への自治体判断が焦点に”, 22 November 2024, see <https://www.yomiuri.co.jp/national/20241122-OYT1T50061/>, accessed 10 June 2025.

231 - NUMO, “Implementation of Literature Survey in Genkai Town, Saga Prefecture”, 10 June 2024, see https://www.numo.or.jp/en/what/topics_240610.html, accessed 14 July 2025.

Table 6 · Official Reactor Closures Post-3/11 in Japan (as of 1 July 2025)

Operator	Reactor (Type)	Capacity (MW)	Startup Year	Closure Announcement ^(a) dd/mm/yy	Official Closure Date ^(b) dd/mm/yy	Last Production	Age ^(c)
TEPCO	Fukushima Daiichi-1 (BWR)	439	1970	-	19/04/12	2011	40
	Fukushima Daiichi-2 (BWR)	760	1973	-	19/04/12	2011	37
	Fukushima Daiichi-3 (BWR)	760	1974	-	19/04/12	2011	36
	Fukushima Daiichi-4 (BWR)	760	1978	-	19/04/12	2011	33
	Fukushima Daiichi-5 (BWR)	760	1977	19/12/13	31/01/14	2011	34
	Fukushima Daiichi-6 (BWR)	1 067	1979	19/12/13	31/01/14	2011	32
	Fukushima Daini-1 (BWR)	1 067	1981	31/07/19	30/09/19	2011	30
	Fukushima Daini-2 (BWR)	1 067	1983	31/07/19	30/09/19	2011	28
	Fukushima Daini-3 (BWR)	1 067	1984	31/07/19	30/09/19	2011	26
	Fukushima Daini-4 (BWR)	1 067	1986	31/07/19	30/09/19	2011	24
KEPCO	Mihama-1 (PWR)	320	1970	17/03/15	27/04/15	2010	40
	Mihama-2 (PWR)	470	1972	17/03/15	27/04/15	2011	40
	Ohi-1 (PWR)	1 120	1977	22/12/17	01/03/18	2011	34
	Ohi-2 (PWR)	1 120	1978	22/12/17	01/03/18	2011	33
KYUSHU	Genkai-1 (PWR)	529	1975	18/03/15	27/04/15	2011	37
	Genkai-2 (PWR)	529	1980	13/02/19	13/02/13	2011	31
SHIKOKU	Ikata-1 (PWR)	538	1977	25/03/16	10/05/16	2011	35
	Ikata- 2 (PWR)	538	1981	27/03/18 ^(d)	27/03/18	2012	30
JAEA	Monju (FBR)	246	1995	12/2016 ^(e)	05/12/17	LTO ^(f) since 1995	-
JAPC	Tsuruga -1 (BWR)	340	1969	17/03/15	27/04/15	2011	41
CHUGOKU	Shimane-1 (PWR)	439	1974	18/03/15	30/04/15	2010	37
TOHOKU	Onagawa-1 (BWR)	498	1983	25/10/18	21/12/18 ^(g)	2011	27
TOTAL: 22 Reactors /15.5 GWe							

Sources: JAIF and JANSI, compiled by WNISR, 2025

Notes: This table only lists the 22 reactors closed after the Fukushima accidents, thus not including the Fugen Advanced Thermal Reactor (ATR), Japan Power Demonstration Reactor (JPDR), as well as Hamaoka-1 & -2 and Tokai-1.

BWR: Boiling Water Reactor; **PWR:** Pressurized Water Reactor; **FBR:** Fast Breeder Reactor; **LTO:** Long-Term Outage.

JAPC: Japan Atomic Power Company; **JAEA:** Japan Atomic Energy Commission

(a) – Unless otherwise specified, all announcement dates from JANSI, “Licensing Status for the Japanese Nuclear Facilities”, Japan Nuclear Safety Institute, 26 February 2020, see <http://www.genanshin.jp/english/facility/map/>, accessed 27 July 2020.

(b) – Unless otherwise specified, all closure dates from individual reactor’s page via JAIF, “NPPs in Japan”, Japan Atomic Industrial Forum, see <http://www.jaif.or.jp/en/npps-in-japan/>, as of 27 July 2020.

(c) – Note that WNISR considers the age from first grid connection to last production day.

(d) – WNN, “Shikoku Decides to Retire Ikata 2”, 27 April 2018, see <http://www.world-nuclear-news.org/C-Shikoku-decides-to-retire-ikata-2-2703184.html>, accessed 22 July 2018.

(e) – *The Mainichi*, “Japan Decides to Scrap Trouble-Plagued Monju Prototype Reactor”, 21 December 2016, see <http://mainichi.jp/english/articles/20161221/p2g/oom/odm/0500000c>, accessed 21 December 2016.

(f) – The Monju reactor was officially in Long-Term Shutdown or LTS (IAEA-Category Long Term Shutdown) since December 1995. Officially closed in 2017.

(g) – The decision to close the reactor was announced in October 2018.

New Energy Policy and the Role of Nuclear Energy

On 18 February 2025, the Japanese government approved the Seventh Strategic Energy Plan, the mid- to long-term energy policy guideline revised approximately every three years, during a cabinet meeting.²³² In order to achieve carbon neutrality by 2050, the plan includes the objective to “maximize the use of renewable energy as our major power source” in the future, but also sets out to “maximize the use of both renewables and nuclear power.” Specifically, the plan sets the share of each power source in total power generation in 2040 at 40–50 percent for renewable energy and 20 percent for nuclear energy, which is not different from the previous target for 2030 as defined by the Sixth Strategic Energy Plan. Thermal power generation is still planned to represent 30–40 percent.²³³

The plan also claims the merits of nuclear energy: “Nuclear power has features such as excellent supply stability and technological self-sufficiency rate, cost levels comparable to other energy sources with little price fluctuation, and stable power generation at a constant output.”²³⁴ The goal to “reduce dependence on nuclear energy as much as possible”—explicitly stated in the Fourth, Fifth, and Sixth Strategic Energy Plans since the Fukushima events in 2011—has been deleted from the latest plan.²³⁵

The Seventh Strategic Energy Plan translates the shift in law and policy and clarifies the expected use of nuclear power generation. In 2023, Japan’s parliament passed the, so-called, “GX bundled bill”, which includes an amendment to the Nuclear Reactor Regulation Law, Electricity Utility Industry Law, and Atomic Energy Basic Law. Those three laws specify the main features of the new policy as follows:

Extension of the ‘licensing period’ (generally 40 years and 60 years for exceptional cases) allowing operators to apply for an extension corresponding to “certain shutdown period[s] due to ‘non-technical’ or ‘unplanned’ reasons.”²³⁶

Thus, it can be said that the Seventh Strategic Energy Plan represents a fundamental change in energy policy in Japan since 2011. Independent experts, e.g., the Renewable Energy Institute, and environmental NGOs have opposed this new nuclear energy policy based in particular on the following arguments.

First, public opinion surveys (see [next section](#)) suggest that the majority of the population is still in favor of reducing dependency on nuclear power and eventual phaseout. Second, uncertainty regarding nuclear power’s expansion is too large to rely on. Thirdly, the target share of renewable energy is too low. The plan calls for a 40–50 percent renewable energy

²³² - Ministry of Economy, Trade and Industry, “Cabinet Decision on the Seventh Strategic Energy Plan”, Government of Japan, 18 February 2025, see https://www.meti.go.jp/english/press/2025/0218_001.html, accessed 14 July 2025.

²³³ - Agency of Natural Resources and Energy, “The 7th Strategic Energy Plan”, Ministry of Economy, Trade and Industry, Government of Japan, February 2025, p. 14, see https://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/7th_outline.pdf, accessed 12 May 2025.

²³⁴ - Ibidem, p. 7.

²³⁵ - NHK, “エネルギー基本計画決定 “再エネ最大電源に 原子力も活用”, 18 February 2025, see <https://www3.nhk.or.jp/news/html/20250218/k10014725571000.html>, accessed 12 May 2025.

²³⁶ - Agency for Natural Resources and Energy, “原子力発電事業の運転延長認可制度について”, Ministry of Economy, Trade and Industry, Government of Japan, Updated 30 May 2025, see https://www.enecho.meti.go.jp/category/electricity_and_gas/electric/summary/operational_period/index.html, accessed 15 July 2025.

ratio by FY2040, which is much less ambitious than in other countries.²³⁷ Finally, economic competitiveness of nuclear power is not demonstrated and thus it would be less expensive to rely on renewable energy.

Even according to the Ministry of Economy, Trade and Industry (METI)'s own latest estimate, nuclear power is not necessarily the cheapest electricity source as suggested in previous estimates. The Agency for Natural Resources and Energy (ANRE) of METI now estimates that the cost per kWh in 2040, including government subsidies for each power source, would be ¥7.0–8.9 (US\$0.05–0.06) for commercial solar, ¥7.8–10.7 (US\$0.05–0.07) for residential solar, and ¥12.5 (US\$0.09) for nuclear power. But ANRE suggests that renewable energy sources may need “adjustment for stabilization of power grid” (firming) which includes batteries and other technical equipment, and that if those costs were included, nuclear power would then have a cost advantage. According to the adjusted cost estimate, by 2040, the cost per kWh for nuclear power would be ¥16.4–18.9 (US\$0.11–0.13)—unclear why nuclear goes up too—compared to ¥15.3–36.9 (US\$0.11–0.26) for commercial solar and ¥19.5–25.2 (US\$0.13–0.17) for onshore wind turbines.²³⁸ (For details on system issues, see [Challenges of Integrating Nuclear Power into the Energy System](#)).

Furthermore, the Seventh Strategic Energy Plan includes the promotion of the construction of “next-generation advanced reactors” with enhanced safety features. This is the first time since 3/11 that the Strategic Energy Plan explicitly mentions the construction of new reactors. As a specific measure, the plan allows electric companies that are close to decommissioning their nuclear reactors to build new next-generation innovative reactors on the sites of existing nuclear power plants they own.²³⁹

Prospects for Nuclear Power vs. Renewable Energy Deployment

The Seventh Strategic Energy Plan represents a major shift as it allows for the construction of new reactors in Japan for the first time since the Fukushima disaster began. It also aims to maximize the use of nuclear energy.

A recent public-opinion survey suggests split views on the use of nuclear energy. According to the survey published in March 2025 by Japan Atomic Energy Relations Organization, over 58 percent of respondents said they would accept the use of nuclear energy for the time being.²⁴⁰ However, there appears not to be much support for the construction of new nuclear reactors. In a public opinion poll conducted by public television station NHK in January 2025, only 21 percent of the respondents favored increasing the share of nuclear energy, a smaller fraction than those who prefer the “status quo” (30 percent) or who believe it “should be

237 - Renewable Energy Institute, “エネルギー基本計画案について”, 23 January 2025, see <https://www.renewable-ei.org/activities/column/REupdate/20250123.php>, accessed 15 June 2025.

238 - Agency of Natural Resources and Energy, “発電コスト検証に関するとりまとめ（案）”, METI, Government of Japan, 16 December 2024, pp. 5–6, see https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/mitoshi/cost_wg/2024/data/05_05.pdf, accessed 12 May 2025.

239 - Agency of Natural Resources and Energy, “The 7th Strategic Energy Plan”, February 2025, op. cit., p. 7.

240 - JAERO, “News Release—Summary 原子力に関する世論調査 (2024年度)”, Japan Atomic Energy Relations Organization, March 2025 see https://www.jaero.or.jp/_files/poll/summary_2024.pdf, accessed 15 May 2025.

reduced” (31 percent).²⁴¹ It remains less certain how the policy could impact the potential construction of new reactors. In addition, many issues associated with the decommissioning of the Fukushima Daiichi reactors remain unresolved (see [Fukushima Status Report](#)). Also, legal cases against restarting reactors and in favor of compensation for the impact of the Fukushima disaster continue. It remains unclear how Japan’s future nuclear energy policy will unfold.

According to Energy Institute, non-hydro renewables accounted 15 percent of total energy generation in 2024, (with solar at 9.5 percent, followed by geothermal at 4.5 percent, and wind at 1.1 percent). Including hydro, renewables accounted for 22.9 percent, with a small increase of 0.8 percentage point over the year. The production and share of solar almost tripled over the last decade, from 3.4 percent in 2015. Wind production and share more than doubled over the same period, but remained very low. The share of hydro has remained quite stable over the years at 7–8 percent.²⁴² Japan remains heavily reliant on fossil fuels to generate electricity, as natural gas (31.3 percent), coal (29.6 percent) and oil (2.26 percent) combined covered 63 percent of power production in 2024.

Overseas, the introduction of wind power generation has made progress, especially in Europe, but it is slowing down due to rising construction costs, policy hurdles, and local opposition. A similar trend can be observed in Japan. Mitsubishi Corporation, a general trading company, has announced that it is reviewing its plans for offshore wind power generation off the coast of Akita and Chiba prefectures. Geothermal power generation also remains at a marginal 0.3 percent.²⁴³

To achieve the maximum electricity supply target from renewable energy sources for FY2040 in the Seventh Strategic Energy Plan, an increase of about 24 percent over the next 15 years would be required.

RUSSIA FOCUS



Overview

In 1954, the Soviet Union was the first country to produce nuclear electricity for the grid. Since then, Russia has significantly influenced the global industry and turned—by far—into the largest exporter of reactors, currently constructing 23 large units²⁴⁴ (19 outside the country) and three small modular reactors of the world’s total of 63 projects in active building, as of 1 July 2025.

Russia has the fourth largest operating nuclear power fleet, with a total net capacity of 26.8 GW and 36 operational reactors across several designs: 10 pressure-tube Light Water Cooled Graphite Moderated Reactors (seven Chornobyl-type RBMKs and three EGP-6s), 24 PWRs

²⁴¹ - NHK, “今後の原発割合 回答分かれる NHK世論調査”, 15 January 2025, see <https://www3.nhk.or.jp/news/html/20250115/k10014692651000.html>, accessed 15 May 2025.

²⁴² - Energy Institute, “Statistical Review of World Energy 2025—Consolidated Dataset”, 2025.

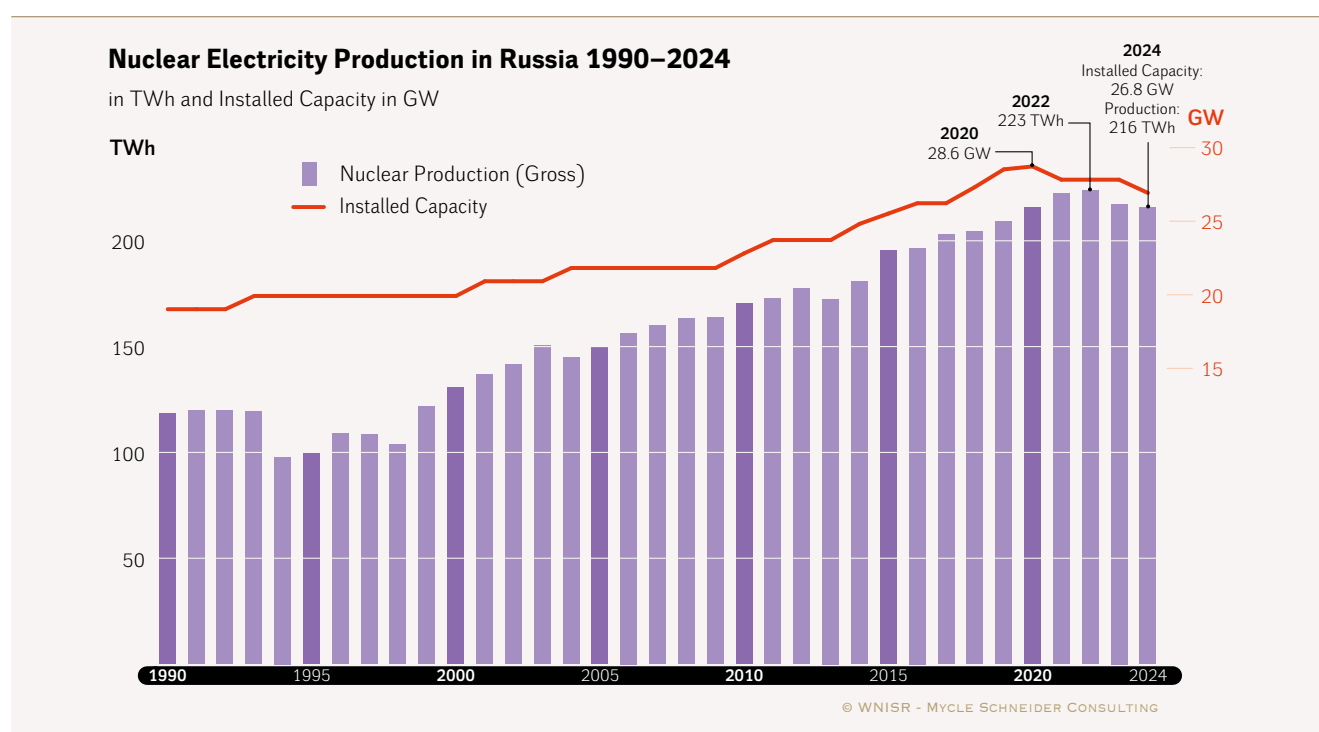
²⁴³ - ISEP, “国内の2023年度の自然エネルギー電力の割合と導入状況 (速報)”, Institute for Sustainable Energy Policies, 17 September 2024, see <https://www.isep.or.jp/archives/library/14885>, accessed 15 June 2025.

²⁴⁴ - In addition, Rosatom is also the technology provider and subcontractor of Slovakia’s Mochovce-4 project.

(five VVER-440s, 13 VVER-1000s, four VVER-1200s, and two small KLT-40 “floating reactors”), and two Fast Breeder Reactors or FBRs (BN-600 and BN-800). Eleven reactors at different Russian power plants are closed: eight pressure-tube reactors (four RBMKs, two AMBs, one EGP-6, and one AM-1 reactor at Russia’s first plant in Obninsk) and three PWRs.

In 2024, nuclear energy contributed 17.8 percent of the country’s power mix, generating 216 TWh²⁴⁵ of gross electricity. This marks the second consecutive annual decline in gross nuclear electricity production from a record high of 223 TWh in 2022²⁴⁶ (see Figure 38). The share of nuclear power in Russia’s total electricity generation also declined for the fourth consecutive year from its peak of 20.3 percent in 2020, during the pandemic.²⁴⁷

Figure 38 · Nuclear Production Versus Installed Capacity in Russia



Sources: WNISR with IAEA-PRIS and Energy Institute, 2025

Note: Capacity as of year-end.

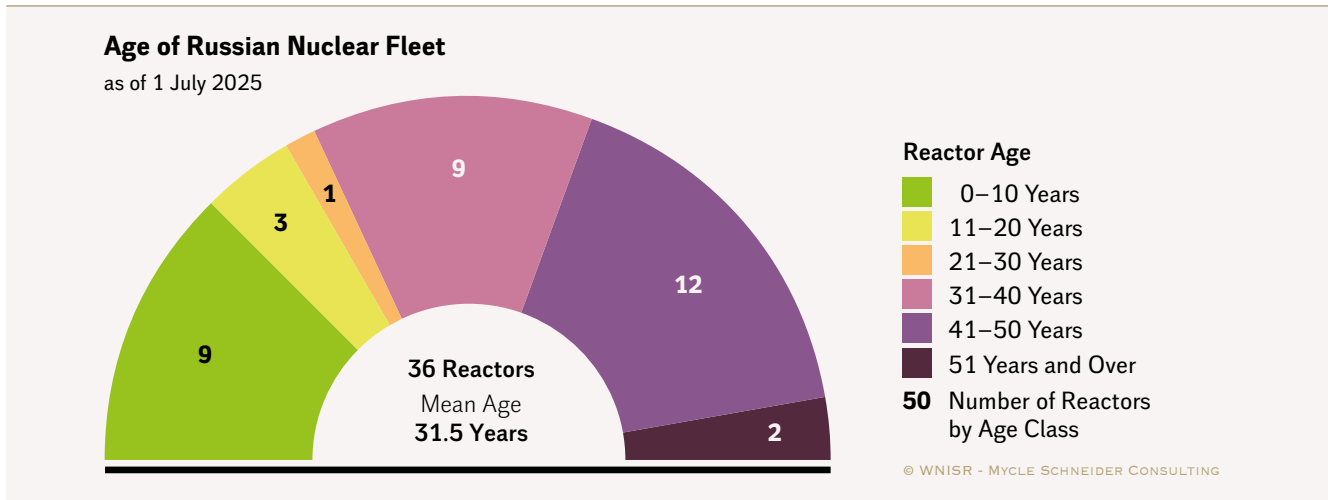
The main reason for this decline is the country’s aging nuclear fleet with the gradual closure of end-of-lifetime units on one hand, and delays in constructing replacement capacities on the other hand. Since 2018, Russia has begun decommissioning the first Soviet-era gigawatt-class reactors. As shown on Figure 39, besides a small 10-MW reactor at Bilibino, four large first-generation RBMK units at the Leningrad and Kursk nuclear power plants—each with a service life of around 45 years—have already been closed. The last one was shuttered on

²⁴⁵ - TASS, “Выработка электроэнергии в РФ выросла в 2024 году на 2,4%”, *Russian News Agency*, 5 February 2025, see <https://tass.ru/ekonomika/23063431>, accessed 23 April 2025.

²⁴⁶ - Rosanergoatom, “Росэнергоатом: АЭС России вошли в 2023 год с новым рекордом, превышающим 223,3 млрд кВтч”, *Rosatom*, 1 January 2023, see <https://www.rosenergoatom.ru/zhurnalistam/main-news/42743/>, accessed 23 April 2025.

²⁴⁷ - Dmitry Gorchakov, “Rosatom’s Output Dropped Over the Last Year. We Look at Three Reasons Why”, *Bellona*, 13 March 2024, see <https://etc.bellona.org/2024/03/13/rosatoms-output-dropped/>, accessed 23 April 2025.

Figure 40 · Age Distribution of the Russian Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2025

Nevertheless, 64 percent of all operating Russian reactors, including all RBMKs, all VVER-440s, and eight of 13 VVER-1000s, are running with extended lifetimes (beyond 30 years) (See [Table 7](#)). The oldest operating unit—Novovoronezh-4, a VVER-440—reached 53 years of service in 2025.

Due to technological challenges and economic impracticality, four first-generation RBMK reactors were denied lifetime extensions beyond 45 years and were closed upon reaching this limit between 2018 and 2024, and the remaining three EGP-6 units are expected to be closed by the end of 2025 after 50 years of operation. Meanwhile, several VVER units have already received licenses to operate for up to 60 years.

Table 7 · Status of the Russian Nuclear Reactor Fleet (as of 1 July 2025)

Reactor Model/ Reactor	Net Capacity (MW)	Grid Connection	Design Lifetime (in years)	Closure Date/ License Expiration Date	Age at Closure (End of License/ Planned Closure) ^(a)
LGWR					
AM					
APS-1 Obninsk	5	27/06/1954	n/a	Closed on 29 April 2002	47.8
Beloyarsk-1	102	26/04/1964	n/a	Closed on 1 January 1983 ^(b)	18.7
Beloyarsk-2	146	29/12/1967	n/a	Closed on 1 January 1990 ^(b)	22
EGP 6					
Bilibino-1	11	12/01/1974	30	Closed in March 2018 ^(c)	44.2
Bilibino-2	11	30/12/1974	30	Licensed to December 2025 ⁽ⁱ⁾	(51)
Bilibino-3	11	22/12/1975	30	Licensed to December 2025 ⁽ⁱ⁾	(50)
Bilibino-4	11	27/12/1976	30	Licensed to December 2025 ⁽ⁱ⁾	(49)
RBMK^(d)					
Kursk-1	925	19/12/1976	30	Closed on 19/12/2021	45
Kursk-2	925	28/01/1979	30	Closed on 31/01/2024	45
Leningrad-1	925	21/12/1973	30	Closed on 22/12/2018	45
Leningrad-2	925	11/07/1975	30	Closed on 22/11/2020	45.4
Kursk-3	925	17/10/1983	30	Licensed to 31/12/2028 ^(e)	(45/50)
Kursk-4	925	02/12/1985	30	Licensed to 21/12/2030 ^(e,8)	(45/50)
Leningrad-3	925	07/12/1979	30	Licensed to 2030 ⁽³⁾	(50)
Leningrad-4	925	09/02/1981	30	Licensed to December 2025 ⁽⁴⁾	(45/50)
Smolensk-1	925	09/12/1982	30	Licensed to December 2027 ⁽⁵⁾	(45/50)
Smolensk-2	925	31/05/1985	30	Licensed to 2030 ⁽⁶⁾	(45/50)
Smolensk-3	925	17/01/1990	30	Licensed to December 2034 ⁽ⁱ⁾	(45/50)
PWR					
VVER V-120					
Novovoronezh-1	197	30/09/1964	20	Closed on 16 February 1988	24
Novovoronezh-2	336	27/12/1969	20	Closed on 29/08/1990	21
VVER V-440					
Novovoronezh-3	385	27/12/1971	30	Closed on 25/12/2016	45
Kola-1	411	29/06/1973	30	Licensed to July 2033 ⁽ⁱ⁾	(60)
Kola-2	411	09/12/1974	30	Licensed to December 2034 ⁽ⁱ⁾	(60)
Kola-3	411	24/03/1981	30	Licensed to 2027 ⁽⁷⁾	(46)
Kola-4	411	11/10/1984	30	Licensed to December 2039 ⁽⁸⁾	(55)
Novovoronezh-4	385	28/12/1972	30	Licensed to December 2032 ⁽ⁱ⁾	(50)
VVER-1000					
Balakovo-1	950	28/12/1985	30	Licensed to December 2045 ⁽⁸⁾	(60)
Balakovo-2	950	08/10/1987	30	Licensed to October 2043 ⁽ⁱ⁾	(56/60)
Balakovo-3	950	25/12/1988	30	Licensed to December 2048 ⁽ⁱ⁾	(60)
Balakovo-4	950	11/04/1993	30	Licensed to 2051 ⁽⁹⁾	(58/60)
Kalinin-1	950	09/05/1984	30	Licensed to June 2044 ⁽¹⁰⁾	(60)
Kalinin-2	950	03/12/1986	30	Licensed to November 2038 ⁽ⁱ⁾	(56/60)
Kalinin-3	950	16/12/2004	30	Licensed to October 2034 ⁽¹¹⁾	(30/60)
Kalinin-4	950	24/11/2011	30	Licensed to October 2041 ⁽¹¹⁾	(30/60)
Novovoronezh-5	950	31/05/1980	30	Licensed to 2035 ⁽⁷⁾	(55/60)

Reactor Model/ Reactor	Net Capacity (MW)	Grid Connection	Design Lifetime (in years)	Closure Date/ License Expiration Date	Age at Closure (End of License/ Planned Closure) ^(a)
Rostov-1	989	30/03/2001	30	Licensed to January 2031 ⁽¹¹⁾	(30/60)
Rostov-2	950	18/03/2010	30	Licensed to September 2039 ⁽¹¹⁾	(29/60)
Rostov-3	950	27/12/2014	30	Licensed to November 2044 ⁽¹¹²⁾	(30/60)
Rostov-4	979	02/02/2018	30	Licensed to December 2057 ⁽¹¹¹⁾	(39/60)
VVER-1200					
Leningrad 2-1	1101	09/03/2018	60	Licensed to December 2057 ⁽¹¹¹⁾	(29/60)
Leningrad 2-2	1101	23/10/2020	60	Licensed to July 2050 ⁽¹¹¹⁾	(30/60)
Novovoronezh-2-1	1100	05/08/2016	60	Licensed to March 2046 ⁽¹¹¹⁾	(30/60)
Novovoronezh-2-2	1101	01/05/2019	60	Licensed to February 2049 ⁽¹¹¹⁾	(30/60)
KLT-40S “Floating”					
Akademik Lomonosov-1	32	19/12/2019	40 ⁽¹³⁾	Licensed to June 2029 ⁽¹³⁾	(10/40)
Akademik Lomonosov-2	32	19/12/2019	40	Licensed to June 2029 ⁽¹³⁾	(10/40)
FBR					
BN-600	560	08/04/1980	30 ⁽¹⁴⁾	Licensed to 2040 ⁽¹⁵⁾	(60)
BN-800	820	10/12/2015	40 ⁽¹⁴⁾	Licensed to December 2043 ⁽¹¹⁶⁾	(28/60)

Sources: Various, compiled by WNISR, 2025

Notes:

- (a) For operating reactors, age at the end of current valid license (as of 1 July 2025)/expected further extension.
- (b) No or scarce production data available for Beloyarsk-1 and -2 in IAEA-PRIS; official closure from IAEA-PRIS but does not reflect the actual production of those reactors.
- (c) Bilibino-1 was officially closed in January 2019, but according to IAEA-PRIS it was disconnected from the grid in March 2018; see IAEA-PRIS, “Operating Experience with Nuclear Power Stations in Member States – 2019 Edition”, see <https://www.iaea.org/publications/13575/operating-experience-with-nuclear-power-stations-in-member-states>.
- (d) Planned extension to 50 years for the seven RBMKs.

Sources:

- (1) Federal Environmental Industry and Nuclear Supervision Service and Rosatom, “The Ninth National Report of the Russian Federation on the Fulfillment of the Commitments Resulting From the Convention on Nuclear Safety To the Joint Eighth/Ninth Review Meeting of the Contracting Parties under the Convention on Nuclear Safety”, 2022, see https://www.iaea.org/sites/default/files/24/02/cns_8th_and_9th_rm_national_report_russian_federation.pdf.
- (2) Rosenergoatom, “ОТЧЕТ по экологической безопасности за 2024 год”, Rosatom, 2025, see <https://www.rosenergoatom.ru/upload/iblock/3ce/zimykcxqewv05x2kcv6hctzlz3t2lb.pdf>.
- (3) Rosenergoatom, “Ленинградская АЭС получила лицензию Ростехнадзора на эксплуатацию энергоблока №3 до 2030 года”, Press Release, 3 February 2025, see <https://www.rosenergoatom.ru/zhurnalistam/news/47889/>, accessed 8 June 2025.
- (4) Rosenergoatom, “Годовой отчет 2010”, 2011, see https://report.rosatom.ru/go/rosenergoatom/go_rosenergoatom_2010/go_rosenergoatom_2010.pdf.
- (5) AK&M, “Smolensk NPP Has Received a License from Rostekhnadzor for the Operation of Power Unit No.1 until 2027”, 27 December 2022, see <https://www.akm.ru/eng/news/smolensk-npp-has-received-a-license-from-rostechnadzor-for-the-operation-of-power-unit-no-1-until-2027>; and Rosatom, “ОТЧЕТ по экологической безопасности Смоленской АЭС за 2023 год”, 2024, see https://www.report.rosatom.ru/go/2023/eco/rea/%Do%A1%Do%BC%Do%BE%Do%BB%Do%B5%Do%BD%D1%81%Do%BA%Do%B0%D1%8F_%Do%90%Do%AD%Do%A1.pdf.
- (6) Rosenergoatom, “Смоленская АЭС получила лицензию Ростехнадзора на безопасную эксплуатацию энергоблока №2 ещё на 5 лет - до 2030 года”, Press Release, 2 June 2025, see <https://www.rosenergoatom.ru/zhurnalistam/news/48487/>.
- (7) WNA, “Nuclear Power in Russia”, Updated 1 May 2025, see <https://world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power>.
- (8) Federal Environmental Industry and Nuclear Supervision Service and Rosatom, “The Seventh National Report of the Russian Federation on the Fulfillment of Commitments Resulting From the Convention on Nuclear Safety”, 2016, see https://www.iaea.org/sites/default/files/russia-national-report-7th-rm-cns_en.pdf.
- (9) Interfax, “Балаковская АЭС продлила на 28 лет лицензию на эксплуатацию энергоблока №4”, 22 December 2023, see <https://www.interfax.ru/russia/937618>.
- (10) Rosenergoatom, “Калининская АЭС получила лицензию Ростехнадзора на эксплуатацию энергоблока №1 в продленном сроке до 2044 года”, Press Release, 30 June 2025, see <https://www.rosenergoatom.ru/zhurnalistam/news/48650/>.
- (11) See list of all Rosenergoatom licenses at [Вystavitsya-schet.rf](https://www.vystavitsya-schet.rf), “Проверка контрагента—АО ‘КОНЦЕРН РОСЭНЕРГОАТОМ’”, 2025, see <https://vystavitsya-schet.rf/vipiska-egrul/5087746119951/>.

(12) Rosenergoatom, “Материалы обоснования лицензии на осуществление деятельности в области использования атомной энергии «Эксплуатация энергоблока №3 Ростовской АЭС в 18-месячном топливном цикле на мощности реакторной установки 104% от номинальной с вентиляторными градирнями», see https://www.rosenergoatom.ru/stations_projects/sayt-rostovskoy-aes/bezopasnost-i-ekologiya/.

(13) Akademik Lomonosov Floating Nuclear Power Plant, “Floating Nuclear Power Plant Akademik Lomonosov Has Received an Operating License”, Rosatom, 28 June 2019, see <https://fnpp.info/latest-news/floating-nuclear-power-plant-akademik-lomonosov-has-received-an-operating-license>, accessed 15 August 2025.

(14) Ilya Pakhomov, “BN-600 and BN-800 Operating Experience”, Institute for Physics and Power Engineering, State Scientific Center of the Russian Federation, as presented at GEN IV International Forum, 19 December 2018, see https://www.gen-4.org/gif/upload/docs/application/pdf/2019-01/gifiv_webinar_pakhomov_19_dec_2018_final.pdf.

(15) Rosenergoatom, “Белоярская АЭС получила лицензию Ростехнадзора на продление эксплуатации энергоблока №3 до 2040 года”, Press Release, 1 April 2025, see <https://www.rosenergoatom.ru/zhurnalistsam/news/48170/>.

(16) Rosenergoatom, “Environmental report of the Beloyarsk NPP for 2023”, 2024, see <https://www.rosenergoatom.ru/upload/iblock/f36/xeoquobgew6ajiumj678vhiuouyg8p5.pdf>.

Since late 2022, Rosatom has been considering new types of lifetime extensions not previously applied in Russia. One example is the planned five-year extension for seven second-generation RBMK reactors, bringing their operational life to 50 years. The first such license was issued in February 2025 for Leningrad-3.²⁵¹

In 2025, a license was also issued to extend the operation of Russia’s oldest fast reactor, the BN-600, to 60 years.²⁵² For the first time, an extension beyond 60 years has also been proposed for two VVER-440 units (now over 50 years old) at the Kola nuclear power plant,²⁵³ though no licenses have been granted yet.

The cost of current lifetime extension procedures is undisclosed, but past cases—like the RUB₂₀₁₂ 17 billion (US\$₂₀₁₂ 551 million) 15-year extension of Leningrad-4 in 2010²⁵⁴—suggest it is likely to reach hundreds of millions of dollars per unit.

Nuclear Newbuild

In its March 2021 strategic review, Rosatom stated that nuclear energy should supply 25 percent of the country’s electricity generation by 2045 in line with a target set by the President. According to Rosatom CEO Alexey Likhachev, this would require the commissioning of 24 units, including at new sites and in new regions.²⁵⁵

As of mid-2025, Russia has seven reactors under construction simultaneously: five nuclear power units, with capacities ranging from 300 MW to 1200 MW (two VVER-TOI units at Kursk II, two VVER-1200 units at Leningrad II, and the BREST-OD-300 SMR in Seversk), as well as at least one barge with two SMR modules. This is the highest number of reactors simultaneously under construction in Russia in a decade.

²⁵¹ - Rosenergoatom, “Ленинградская АЭС получила лицензию Ростехнадзора на эксплуатацию энергоблока №3 до 2030 года”, Press Release, 3 February 2025, see <https://www.rosenergoatom.ru/zhurnalistsam/news/47889/>, accessed 8 June 2025.

²⁵² - Rosenergoatom, “Белоярская АЭС получила лицензию Ростехнадзора на продление эксплуатации энергоблока №3 до 2040 года”, Press Release, 1 April 2025, see <https://www.rosenergoatom.ru/zhurnalistsam/news/48170/>, accessed 8 June 2025.

²⁵³ - TASS, “Росатом планирует продлить сроки эксплуатации атомных станций с реакторами ВВЭР”, 18 September 2024, see <https://tass.ru/ekonomika/21895237>, accessed 2 July 2025.

²⁵⁴ - Titan-2 Holding, “Завершен инвестиционный проект по продлению срока эксплуатации энергоблока №4 Ленинградской АЭС”, 30 January 2012, see <https://www.titan2.ru/news/novosti-kholdinga/750-zavershen-investitsionnyj-proekt-po-prodleniyu-sroka-ekspluatatsii-energobloka-4-leningradskoj-aes>, accessed 24 April 2025.

²⁵⁵ - Евгений Погонин, “К 2045 году доля атомной энергетики в энергобалансе России должна достичь 25 %”, Страна РОСАТОМ, Rosatom, 9 March 2021, see <https://strana-rosatom.ru/2021/03/09/k-2045-godu-dolya-atomnoj-energetiki-v-ener/>, accessed 9 June 2025.

Two large units are under construction at Kursk II (Kursk 2-1 and 2-2) to replace old RBMK reactors, two of which have already closed. These VVER-TOI (VVER V-510) units with a net capacity of 1200 MW—the most powerful ever built in Russia—will be the first of the latest Russian designs (Generation III+), and they are also earmarked for export. When construction started on Unit 1 in April 2018 (see [Annex 5](#)), completion was scheduled for 2022 or 2023. Recent plans call for the unit to be commissioned by the end of 2025.²⁵⁶ Cost estimates for the two units have also reportedly almost doubled—from RUB225 billion in 2016²⁵⁷ to RUB459 billion in 2022 (US\$₂₀₂₂ 6.7 billion)²⁵⁸.

First concrete at Unit 3 of Kursk II is planned for December 2025.²⁵⁹ The corresponding license was issued in March 2025.²⁶⁰ Work on Unit 4 is expected to begin afterwards.

Another two large VVER-1200 units, Leningrad 2-3 and 2-4, are under construction at Leningrad II; these units are also called Leningrad-7 and -8 (when counting existing reactors at the site)²⁶¹ and March 2025,²⁶² respectively, with startups planned for Unit 7 in 2030 and Unit 8 in 2032.²⁶³ As in the Kursk case, new units at the Leningrad site are to replace aging RBMK reactors, with two already closed.

At the Smolensk nuclear power plant, which operates the three most recent RBMKs, site preparations for two VVER-TOI units began in 2024, with first concrete for the reactor building of Unit 1 planned for March 2027²⁶⁴ and commissioning of both units set for 2033 and 2035.²⁶⁵

Construction of an innovative small (300 MW) fast reactor design, the BREST-OD-300, using liquid lead as a coolant and uranium-plutonium nitride fuel started in June 2021.²⁶⁶ The

256 - WNN, “Grid Connections in Turkey and Bangladesh Among Rosatom’s 2025 Priorities”, 13 March 2025, see <https://world-nuclear-news.org/articles/first-kwh-from-turkey-and-bangladesh-rosatoms-2025-priorities>, accessed 20 May 2025; and Daria Bystrova, “Шесть вызовов ближайших шести лет: в «Росатоме» прошел день информирования”, *Страна Росатом*, 10 March 2025, see <https://strana-rosatom.ru/2025/03/10/shest-vyzovov-blizhajshih-shesti-let-v-r/>, accessed 18 March 2025.

257 - РИА Новости, “Эксплуатацию первой очереди Курской АЭС-2 планируют начать в 2022 году”, 31 March 2016, Updated 2 March 2020, see <https://ria.ru/20160331/1400720355.html>, accessed 20 May 2025.

258 - Polina Smertina, “Нынче дорог каждый атом”, *Kommersant*, 23 August 2022, see <https://www.kommersant.ru/doc/5524836>, accessed 25 May 2025.

259 - NEI Magazine, “First Concrete for Kursk-II’s Third Unit Set for December”, *Nuclear Engineering International*, 28 February 2025, see <https://www.neimagazine.com/news/first-concrete-for-kursk-iis-third-unit-set-for-december/>, accessed 21 May 2025.

260 - Rosenergoatom, “«Росэнергоатом» получил лицензию Ростехнадзора на размещение ядерной установки энергоблока № 3 с реактором ВВЭР-ТОИ Курской АЭС-2”, Press Release, 4 March 2025, see <https://www.rosenergoatom.ru/zhurnalistam/news/48031/>, accessed 8 June 2025.

261 - Rosatom, “Main Construction Stage Started at Leningrad NPP Unit 7”, Press Release, 15 March 2024, see <https://www.rosatom.ru/en/press-centre/news/-main-construction-stage-started-at-leningrad-npp-unit-7/>, accessed 19 March 2024

262 - Rosatom, “First Concrete Poured for the Foundation of the Reactor Building of Unit 4 at Leningrad NPP-2”, Press Release, 20 March 2025, see https://www.rosatom.ru/en/press-centre/news/first-concrete-poured-for-the-foundation-of-the-reactor-building-of-unit-4-at-leningrad-npp-2/?sphrase_id=6678050, accessed 20 May 2025.

263 - NEI Magazine, “Leningrad Units 7&8 Scheduled for Commissioning by 2032”, 23 January 2025, see <https://www.neimagazine.com/news/leningrad-units-7-8-scheduled-for-commissioning-by-2032/>, accessed 2 July 2025.

264 - TITAN-2, “TITAN-2 Holding Started Site Grading at the Site of New Power Units of the Smolensk NPP-2”, 21 August 2024, see <https://www.titan2.ru/en/media-press/lenta-novostej/46-projects-news/2617-titan-2-holding-started-site-grading-at-the-site-of-new-power-units-of-the-smolensk-npp-2/>; and Rosenergoatom, “Смоленская АЭС-2 получила разрешение на возведение обеспечивающих объектов строительно-монтажной базы для новых энергоблоков”, Press Release, 31 January 2025, see https://www.rosenergoatom.ru/stations_projects/sayt-smolenskoy-aes/press-tsentr/novosti/47882/, both accessed 14 August 2025.

265 - Rosenergoatom, “Смоленская АЭС-2 включена в генеральную схему размещения объектов электроэнергетики до 2042 года”, Press Release, 20 January 2025, see <https://www.rosenergoatom.ru/zhurnalistam/news/47822/>, accessed 9 June 2025.

266 - TVEL “Rosatom Starts Construction of Unique Power Unit with BREST-OD-300 Fast Neutron Reactor”, Press Release, Rosatom, 8 June 2021, see https://www.tvcl.ru/en/press-center/news/?ELEMENT_ID=8787, 10 July 2021.

reactor's cost is said to be RUB₂₀₂₁ 100 billion (US\$₂₀₂₁ 1.4 billion). The objective for BREST-OD-300 is to start up in 2028, which, if achieved, would be impressive given that it is the first of its kind, but the project is not there yet.

Rosatom is involved in the construction of four small Floating Nuclear Power Plants (FNPP), each equipped with two RITM-200C reactors, to supply energy to mining projects in the Russian Arctic—specifically at Cape Nagloynyn in Chukotka. The first two “units” with two modules each are planned for commissioning by 2028, with the third and fourth to follow in 2029 and 2031, respectively.²⁶⁷

However, it is difficult to determine the exact number of floating nuclear units currently under active construction. Russia lacks established terminology and clear milestones for floating nuclear plants, such as “first concrete”—the beginning of concreting of the base slab of the reactor building—used for land-based reactors, making progress hard to track even in official reports and statements. Public information regarding progress on key components, such as reactor vessels and barge hulls, is also scarce, especially since at least one of the projects involves China, where information is also tightly controlled.

In 2021, Rosatom signed a US\$226 million contract with China's Wison Heavy Industry for two floating power plant hulls, with deliveries scheduled for October 2023 and February 2024.²⁶⁸ A keel-laying ceremony for the first barge was held in China in August 2022,²⁶⁹ and a third hull contract followed in 2024.²⁷⁰ However, no deliveries have been reported. In 2024, Wison's parent company withdrew from Russian projects,²⁷¹ likely due to concerns over secondary sanctions related to its involvement in the Russian Arctic LNG 2 project. It remains unclear how this decision will affect Rosatom's contracts.

According to Russian News Agency TASS, Rosatom stated on 20 May 2025 that six RITM-200 reactors for FNPPs are concurrently being manufactured.²⁷² This would suggest that three out of the four planned FNPPs are at some stage of construction. However, since the IAEA proposes to use the keel laying of the floating hull as the official starting point for the construction of a floating nuclear power plant, and given that reliable information is only available for the construction start of the first hull in August 2022, WNISR will consider only one floating power plant with two reactors as being under active construction.

At the end of December 2024, Rosatom's specific proposals to achieve the goal to supply 25 percent of the country's electricity generation by 2045 were formalized in the government-

267 - *Interfax*, “Корпус третьего энергоблока плавучей АЭС для Баимского ГОКа также изготовят в”, 7 June 2024, see <https://www.interfax.ru/spief2024/965563>, accessed 21 May 2025.

268 - Xu Yihe and Vladimir Afanasiev, “Wison To Build Nuclear Power Floaters For Russia”, *Upstream*, 16 September 2021, see <https://www.upstreamonline.com/rigs-and-vessels/wison-to-build-nuclear-power-floaters-for-russia/2-1-1068362>, accessed 21 May 2025.

269 - Rosatom, “Keel-Laying Ceremony For The First Arctic-Type Floating Power Unit With RITM-200 Transport Reactor Vessels”, Press Release, 30 August 2022, see <https://rosatom-mena.com/press-centre/news/keel-laying-ceremony-for-the-first-arctic-type-floating-power-unit-with-ritm-200-transport-reactor-v/>, accessed 20 May 2025.

270 - *Interfax*, “Корпус третьего энергоблока плавучей АЭС для Баимского ГОКа также изготовят в Китае”, 7 June 2024, see <https://www.interfax.ru/spief2024/965563>, accessed 21 May 2025.

271 - *Kommersant*, “Wison не сработалось в России”, 21 June 2024, see <https://www.kommersant.ru/doc/6776043>, accessed 21 May 2025.

272 - WNN, “First RITM-400 Reactor Unit Manufactured For New Generation Icebreaker”, 21 May 2025, see <https://world-nuclear-news.org/articles/first-ritm-400-reactor-unit-manufactured-for-new-generation-icebreaker>; and TASS, “Росатом в настоящий момент одновременно изготавливает 10 реакторов серии РИТМ”, 20 May 2025, see <https://tass.ru/ekonomika/23994309>; both accessed 24 May 2025.

approved General Scheme for the Placement of Energy Facilities through 2042.²⁷³ According to the document, by 2042 Rosatom plans to have built 38 new nuclear reactors (see Table 8), including 12 SMRs, with a total capacity of around 294 GW. This is larger than the total capacity of Russia's current nuclear fleet. According to the plan, by 2042 the share of nuclear energy in Russia's electricity mix would be 24 percent.

Table 8 · Nuclear Reactors Under Construction and Planned in Russia

Plant	Reactor Design	Capacity Per Unit (MWe)	Reactors (Barges)	Capacity Per Site (MWe)	Construction Start	Planned Startup	Site
Kursk II	VVER-TOI	1 200	4	4 800	29/04/2018 15/04/2019 No	2025/27 2031/34	Active
Leningrad II	VVER-1200	1 150	2	2 300	14/03/2024 20/03/2025	2030/32	Active
Novovoronezh II	VVER-optim	1 200	1	1 200	No	2036	Active
Beloyarsk	BN-1200M (fast reactor)	1 250	1	1 250	No	2034	Active
BREST ODEK	BREST-OD-300 (fast reactor)	300	1	300	08/06/2021	2028	New
Baimsky GOK (FNPP)	RITM-200C (2 per barge)	106	8 (4)	424	30/08/2022* No	2028 2029/31	New
Chukotka SMR	Shelf-M	10	1	10	No	2030	New
Kola II	VVER-600S	600	3	1 800	No	2035/37/40	Active
South	VVER-optim	1 200	2	2 400	No	2036/39	New
Primorsk	VVER-1000	1 000	2	2 000	No	2033/35	New
Norilsk SMR	RITM-400	80	4	420	No	2032/34/36/37	New
Yakutsk SMR	RITM-200N	55	2	110	No	2031	New
Smolensk II	VVER-optim	1 200	2	2 400	No	2033/37	New
Reft	RBN	1 255	1	1 255	No	2041	New
South-Ural	RBN	1 255	2	2 510	No	2038/40	New
Siberia	RBN	1 255	2	2 510	No	2041/42	New
Seversk	RBN	1 255	2	2 510	No	2037/39	New
Khabarovsk	VVER-600S	600	2	1 200	No	2041/42	New
Under Construction			7 (1)	5106			
Planned			35 (3)	24 293			

Sources: General Scheme for the Placement of Energy Facilities through 2042, with Rosatom and IAEA-PRIS, 2025

Note: *Keel laying of one barge designed to host two reactors, counted as two reactors under construction.

The document notes that several SMR projects, such as those in Chukotka, Norilsk, the second unit in Yakutsk and even the Baimsky GOK, will only be confirmed after power purchase agreements are signed with end users. In other words, these projects may not move forward, or may proceed only partially, if such agreements are not secured.

273 - Government of Russia, "РАСПОРЯЖЕНИЕ от 30 декабря 2024 г. № 4153-п", 30 December 2024, see <http://static.government.ru/media/files/Rwf9Akjf5FwAnustDEL2m7PEvZ2617k3.pdf>, accessed 24 April 2025.

Nearly half of the new capacity is planned over the next decade at existing sites in western Russia, with new sites in central and eastern regions expected from the 2030s. The focus remains on large VVER reactors (18 units), while the fast reactor fleet is projected to grow from two to about nine units by 2042. Most SMR projects are based on RITM reactors, already used on eight nuclear icebreakers.

Rosatom primarily builds new large nuclear units under the Capacity Supply Agreement (CSA) mechanism. After commissioning, the unit receives increased capacity payments on the wholesale market to ensure accelerated return on investment. For earlier nuclear projects, contracts allowed for cost recovery over 20 years.²⁷⁴

In 2023, according to the newspaper *Kommersant*, Russia's Ministry of Energy began optimizing the capital and operating costs of new nuclear power plants by proposing to extend the duration of existing contracts to 25 years, with a baseline return rate of 10.5 percent. At the same time, it was proposed to limit CAPEX at around RUB184,100/kW (~US\$₂₀₂₁ 2,500/kW), which is reportedly in line with the cost of previous VVER-1200 units, in particular those put into operation at Novovoronezh II in 2016 and 2019,²⁷⁵ and would be close to the latest estimate of the projected cost of the nearly completed Kursk 2-1—RUB182,900/kW (US\$₂₀₂₂ 2,670/kW).²⁷⁶ At the same time, the single-rate price for the Kursk II nuclear power plant under the CSA agreement may amount to around RUB7/kWh²⁷⁷—equivalent to approximately US\$75–102 per MWh, depending on exchange rate fluctuations in recent years.

Reactor Exports

Rosatom is the biggest nuclear power technology provider in the world; it is constructing 27 out of the 63 units under construction worldwide as of 1 July 2025. Of these 27 units, 20 are being built abroad in seven countries—including Mochovce-4, a Russian design completed by a Czech-led consortium in Slovakia—and seven at home, including SMRs. As of mid-2025, Rosatom or one of its subsidiaries is involved as the main contractor or vendor in the following projects abroad which are in various stages of active construction (see *Annex 5* for further references):

- ➔ **Rooppur, Bangladesh.** Construction started on two VVER-1200 reactors at Rooppur in 2017 and 2018, which were expected to begin operation in 2023 and 2024, respectively.²⁷⁸ The first fuel load shipment was delivered in October 2023,²⁷⁹ but the first unit was not launched in either 2023 or 2024. In March 2025, the head of Rosatom stated that commissioning the

²⁷⁴ - Polina Smertina and Tatyana Dyatel, “Курской АЭС-2 включают господдержку”, *Kommersant*, 18 January 2021, see <https://www.kommersant.ru/doc/4652962>, accessed 25 May 2025.

²⁷⁵ - Polina Smertina, “Атом делится на 25 лет”, *Kommersant*, 4 April 2023, see <https://www.kommersant.ru/doc/5913490>, accessed 25 May 2025.

²⁷⁶ - Polina Smertina, “Нынче дорог каждый атом”, *Kommersant*, 23 August 2022, op. cit.

²⁷⁷ - Ibidem.

²⁷⁸ - Rosatom, “First Concrete Poured at the Constructed Rooppur NPP Site (Bangladesh)”, Press Release, 30 November 2017, see <https://rosatomafrika.com/en/press-centre/news/first-concrete-poured-at-the-constructed-rooppur-npp-site-bangladesh/>, accessed 29 July 2023; and Rosatom, “Main construction of the 2nd Unit of Rooppur NPP begins with the ‘First Concrete’ ceremony”, Press Release, 14 July 2018, see <https://rosatom-mena.com/press-centre/news/main-construction-of-the-2nd-unit-of-rooppur-nuclear-power-project-begins-with-the-first-concrete-ce/>, accessed 1 August 2024.

²⁷⁹ - Rosatom, “The First Batch of Nuclear Fuel Has Been Delivered to Rooppur NPP”, Press Release, 5 October 2023, see <https://www.rosatom.ru/en/press-centre/news/the-first-batch-of-nuclear-fuel-has-been-delivered-to-rooppur-npp/>, accessed 8 August 2024.

first unit of the Rooppur nuclear power plant is one of the corporation's key priorities for the current year.²⁸⁰ The project is facing challenges in particular due to underdeveloped local grid infrastructure and accumulated debts resulting from U.S. sanctions on Russia.²⁸¹ See section on **Bangladesh**.

- ➔ **Tianwan and Xudapu, China.** Two VVER-1200s each at Tianwan and Xudapu (or Xudabao) are being built. Construction of the respective first units (Tianwan-7 and Xudapu-3) started in 2021 and that of the second pair (Tianwan-8 and Xudapu-4) in 2022.²⁸² The commissioning of the units is scheduled for 2026–2027 (Tianwan)²⁸³ and 2026–2028 (Xudapu).²⁸⁴ China's projects are the most localized among Rosatom's constructions abroad; the company only designs and supplies core reactor island equipment, while Chinese partners handle all other aspects including project management.²⁸⁵ See **China Focus**.
- ➔ **El Dabaa, Egypt.** Four VVER-1200s are under construction at El Dabaa. This is Rosatom's most recent construction project—all four units began construction from July 2022 onwards, with the latest starting in January 2024. The construction of the four reactors is scheduled to be completed by 2030. The cost is given as US\$30 billion, facilitated by a US\$25 billion loan from Russia.²⁸⁶ See section on **Egypt**.
- ➔ **Kudankulam, India.** Four VVER-1000s (Units 3 to 6) are under construction at Kudankulam. Construction started on the first pair in 2017 and the second pair in 2021. According to the site director's estimates as of March 2025, the commissioning of the first of these units is expected in 2026. In December 2023, Russia and India signed “two important amendments, which will take the Kudankulam nuclear power project forward,”²⁸⁷ but the details are not disclosed, and the meaning remains unclear. According

280 - Daria Bystrova, “Шесть вызовов ближайших шести лет: в «Росатоме» прошел день информирования”, *Страна Росатом*, 10 March 2025, op. cit.; and WNN, “Grid Connections in Turkey and Bangladesh Among Rosatom's 2025 Priorities”, 13 March 2025, see <https://world-nuclear-news.org/articles/first-kwh-from-turkey-and-bangladesh-rosatoms-2025-priorities>, accessed 22 May 2025.

281 - Alexander Nikitin and Dmitry Gorchakov, “Rosatom in the War Years of 2023 and 2024— Main Events, Projects, Decisions, Facts and Problems”, *Bellona*, 18 December 2024, see <https://etc.bellona.org/publication/rosatom-in-the-war-years/>, accessed 25 May 2025.

282 - Rosatom MENA, “Start of New Unit Construction at China's Tianwan and Xudapu Nuclear Power Plants”, Rosatom, 19 May 2021, see <https://www.rosatom-mena.com/press-centre/news/start-of-new-unit-construction-at-china-s-tianwan-and-xudapu-nuclear-power-plants/>; WNISR, “Russian Nuclear Industry Starts Nuclear Reactor Construction in China—Anyways”, 26 February 2022, see <https://www.worldnuclearreport.org/Russian-Nuclear-Industry-Starts-Nuclear-Reactor-Construction-in-China-Anyways.html>; and WNISR, “Second Russian Nuclear Reactor Construction Start in China This Year—Anyways 2”, 20 May 2022, see <https://www.worldnuclearreport.org/Second-Russian-Nuclear-Reactor-Construction-Start-in-China-This-Year-Anyways-2.html>; all accessed 8 August 2024.

283 - ASE Rosatom, “The First Concrete Has Been Laid at Tianwan NPP Power Unit 8 in China”, 28 February 2022, see <https://ase-ec.ru/en/for-journalists/news/2022/feb/the-first-concrete-has-been-laid-at-tianwan-npp-power-unit-8-in-china/>, accessed 28 February 2022.

284 - Rosatom, “Rosatom Ships the Reactor Hall Equipment for Xudapu NPP Unit 4 (China)”, Press Release, as released on *Atom Media*, 14 August 2024, see <https://atommedia.online/en/press-releases/rosatom-otgruzil-oborudovanie-dlya/>, accessed 22 May 2025.

285 - Ibidem.

286 - *Daily News Egypt*, “Dabaa Nuclear Plant Project Progresses According to Schedule: Minister of Electricity”, 14 June 2023, see <https://www.dailynewsegypt.com/2023/06/14/dabaa-nuclear-plant-project-progresses-according-to-schedule-minister-of-electricity/>, accessed 22 August 2023; and Asma Alsharif, “Russia to Lend Egypt \$25 Billion to Build Nuclear Power Plant”, *Reuters*, 19 May 2016, see <https://www.reuters.com/article/us-egypt-russia-nuclear/russia-to-lend-egypt-25-billion-to-build-nuclear-power-plant-idUSKCN0YA1G5/>, accessed 8 August 2024.

287 - Ministry of External Affairs, “Press Conference of EAM Dr. S. Jaishankar with FM Sergey Lavrov of Russia (December 27, 2023)”, Government of India, 27 December 2023, see https://www.mea.gov.in/Speeches-Statements.htm?dtl/37483/Press_Conference_of_EAM_Dr_S_Jaishankar_with_FM_Sergey_Lavrov_of_Russia_December_27_2023; and *The Hindu*, “India, Russia Ink Pacts on Construction of Future Power Units of Kudankulam Nuclear Plant”, 27 December 2023, see <https://www.thehindu.com/news/national/india-russia-ink-pacts-on-construction-of-future-power-units-of-kudankulam-nuclear-plant/article6767964.ece>; both accessed 8 August 2024.

to the roadmap for nuclear cooperation between Russia and India, signed over a decade ago, a total of up to 12 reactors were envisaged to be built in India, including up to six in Kudankulam.²⁸⁸ See section on [India](#).

- ➔ **Bushehr, Iran.** Construction of Bushehr nuclear power plant with two units was initially started in 1976 by the German company KWU-Siemens and was suspended in 1979. In 1995, the Russian company Atomstroyexport was contracted to complete and reconstruct the first unit of Bushehr, equipped with a VVER-1000 reactor. The reactor was connected to the grid in 2011. In 2014, a new US\$10 billion contract was signed for the construction of two additional VVER-1000 units.²⁸⁹ New basemat concrete for the second unit (Bushehr-2) was poured in 2019, and its commercial operation is expected in 2029. Concrete pouring for the third unit was expected in 2024,²⁹⁰ but no official updates have been reported. Russia and Iran are also discussing the possibility of building additional units.²⁹¹ The roadmap signed in 2014 allows for the construction of two more units at the Bushehr site and an additional four units at a new site.²⁹² See section on [Iran](#).
- ➔ **Akkuyu, Türkiye.** Four VVER-1200s are being built at Akkuyu. Construction started on them between 2018 and 2022. This is Rosatom's first project being built under a BOO (Build-Own-Operate) scheme with the plant owned by Rosatom. The first unit was originally scheduled for commissioning in 2023, but due to a range of technical, political, and other reasons, including U.S. financial sanctions and delays in the delivery of Western equipment, in particular from Siemens, after 2022, commissioning has been repeatedly postponed. Unit 1 is currently expected to be commissioned in 2026.²⁹³ See section on [Türkiye](#).

In addition, preparatory work is underway at Hungary's Paks II plant for two VVER-1200s. The European Commission approved the contract in May 2023 despite the ongoing conflict between the E.U. and Russia on energy and the war in Ukraine.²⁹⁴ On 24 June 2024, the E.U. adopted its 14th sanctions package against Russia, which included a full exemption for Hungary's Paks II nuclear project under Article 12h.²⁹⁵ Back in March 2021, prior to the full-scale invasion of

288 - John Chalmers, "Russia Agrees with India to Construct 12 Nuclear Reactors", *Reuters*, 11 December 2014, see <https://www.reuters.com/article/markets/commodities/russia-agrees-with-india-to-construct-12-nuclear-reactors-idUSL3NoTV2PH/>; and *NEI Magazine*, "India and Russia Strengthen Nuclear Co-Operation by Exploring New Projects and Advanced Technologies", 12 July 2024, see <https://www.neimagazine.com/news/india-and-russia-strengthen-nuclear-co-operation-by-exploring-new-projects-and-advanced-technologies/>; both accessed 22 May 2025.

289 - TASS, "Что известно об атомных проектах России за рубежом", 25 March 2024, see <https://tass.ru/info/18916163>, accessed 22 May 2025; and Rosatom, "New Reactor Units for Iran", Newsletter #142, August 2016, see <https://rosatomnewsletter.com/2016/08/26/new-reactor-units-for-iran/>, accessed 9 June 2025.

290 - Judith Perera, "Iran's Nuclear Development", *NEI Magazine*, 9 January 2025, see <https://www.neimagazine.com/analysis/irans-nuclear-development/>, accessed 4 July 2025.

291 - President of Russia, "Press Conference Following Russian-Iranian Talks", The Kremlin, 17 January 2025, see <http://en.kremlin.ru/events/president/news/76126>, accessed 9 June 2025.

292 - Rosatom, "ROSATOM to Build Eight New Reactors in Iran", Newsletter #64, November 2014, see <https://rosatomnewsletter.com/2014/11/12/rosatom-to-build-eight-new-reactors-in-iran/>, accessed 9 June 2025.

293 - *Türkiye Today*, "Russia Signals Investor Confidence in Türkiye's Flagship Nuclear Project", 2 July 2025, see <https://www.turkiyetoday.com/business/russian-signals-investor-confidence-in-turkiyes-flagship-nuclear-project-3203728>, accessed 7 July 2025.

294 - WNN, "EC Outlines Approval Grounds for Paks II Contract Amendments", 30 May 2023, see <https://world-nuclear-news.org/Articles/EC-outlines-approval-grounds-for-Paks-II-contract>, accessed 14 July 2024.

295 - *About Hungary*, "FM: Paks has received a full exemption from EU sanctions", Cabinet Office of the Prime Minister of Hungary, 25 June 2024, see <https://abouthungary.hu/news-in-brief/fm-paks-has-received-a-full-exemption-from-eu-sanctions>, accessed 23 May 2025.

Ukraine, Rosatom had planned to pour first concrete at the Paks II site in 2022.²⁹⁶ However, as of mid-2025, this has still not happened. Rosatom has stated it was “doing everything” to officially start construction before the end of 2025.²⁹⁷ The situation surrounding the project remains rather uncertain, as there are external factors both hindering its progress, e.g., attempts to challenge the project’s legality within the E.U.,²⁹⁸ and supporting its advancement, e.g., the recent easing of U.S. sanctions.²⁹⁹

Rosatom is a subcontractor in Slovakia’s Mochovce-4 project—a Soviet-era VVER unit whose construction began in 1985 and is now set for completion in 2025 by an international consortium. Rosatom provided technical support, while the main equipment came from Czech company Škoda JS. The twin Mochovce-3, connected to the grid in 2023, became the E.U.’s 19th VVER unit based on Russian design.

Most of these projects are long-standing, with contracts signed over seven years ago, and Rosatom has not secured any new foreign nuclear power plant construction contracts in recent years. The only exception is a May 2024 contract with the State Unitary Enterprise “Directorate for the Construction of Nuclear Power Plants” under Uzatom, the Atomic Energy Agency Under the Cabinet of Ministers of the Republic of Uzbekistan, to build six 55-MW SMRs in Uzbekistan,³⁰⁰ where a larger VVER-1200 project had also been under negotiation. While the shift to SMRs was not Rosatom’s original goal, the larger project remains under discussion. Still, the deal marks Rosatom’s first international SMR contract—a significant milestone.³⁰¹

In June 2025, Rosatom was also selected to lead an international consortium for the construction of Kazakhstan’s first nuclear power plant.³⁰² However, the contract has not yet been signed, and it remains unclear which other companies will join the consortium and how roles will be distributed among the partners. Meanwhile, it has been decided that the construction of Kazakhstan’s second nuclear power plant would be entrusted to China.³⁰³

296 - TASS, “В Росатоме заявили, что пандемия не повлияла на график строительства АЭС ‘Аккую’”, 10 March 2021, see <https://tass.ru/ekonomika/10874139>, accessed 23 May 2025.

297 - TASS, “Rosatom Doing Its Best to Start Construction of Paks-2 NPP This Year — CEO”, 21 May 2025, see <https://tass.com/economy/1961365>, accessed 9 June 2025.

298 - Court of Justice of the European Union, “Advocate General Medina Proposes to Set Aside the Judgment of the General Court That Upheld the Commission’s Decision to Approve Aid from Hungary for Two New Nuclear Reactors at Paks”, Press Release No 24/25, 27 February 2025, see <https://curia.europa.eu/jcms/upload/docs/application/pdf/2025-02/cp250024en.pdf>, accessed 9 June 2025.

299 - *Nucleonics Week*, “Lifting of Gazprombank Sanctions May Clear Way for Hungarian Reactor Construction”, Vol. 66, Issue 28, 9 July 2025; and *MTI*, “Az amerikai kormányzat feloldotta a paksi bővítéssel kapcsolatos szankciókat”, as published by Government of Hungary, 29 June 2025, see <https://kormany.hu/hirek/az-amerikai-kormanyzat-feloldotta-a-paksi-bovitessel-kapcsolatos-szankciokat>, accessed 31 July 2025.

300 - Rosatom, “The Russian Federation and Uzbekistan Sign an Agreement on the Construction of a Small Nuclear Power Plant”, Press Release, 27 May 2024, see <https://www.rosatom.ru/en/press-centre/news/-the-russian-federation-and-uzbekistan-sign-an-agreement-on-the-construction-of-a-small-nuclear-powe/>, accessed 1 June 2024.

301 - Rosatom, “First SMRs for Export”, Newsletter #278, June 2024, see <https://rosatomnewsletter.com/2024/06/28/first-smrs-for-export/>, accessed 13 August 2024.

302 - Atomic Energy Agency of Kazakhstan, “Выбран лидер международного консорциума для строительства первой АЭС в Казахстане”, Government of Kazakhstan, 14 June 2025, see <https://betaegov.kz/memleket/entities/atom-energiyas/press/news/details/1017485>, accessed 14 July 2025; and Rosatom, “Rosatom and Agency for Atomic Energy of the Republic of Kazakhstan Approved Roadmap for NPP Construction in Kazakhstan”, Press Release, 20 June 2025, see <https://rosatom.ru/en/press-centre/news/rosatom-and-agency-for-atomic-energy-of-the-republic-of-kazakhstan-approved-roadmap-for-npp-construc/>, accessed 23 June 2025.

303 - Atomic Energy Agency of Kazakhstan, “Китайская CNNC станет лидером консорциума по строительству еще одной АЭС в Казахстане”, Government of Kazakhstan, 14 June 2025, see <https://betaegov.kz/memleket/entities/atom-energiyas/press/news/details/1017542>, accessed 17 July 2025.

Nuclear Interdependencies and Sanctions

Since its full-scale invasion of Ukraine in February 2022, and as of summer 2024, Russia was facing sanctions from forty-five countries—mainly in Europe and North America, but also from countries like Australia, Japan, New Zealand, and South Korea.³⁰⁴ As of mid-2025, further sanctions were under discussion. Ukraine is likely the only country that has sanctioned more than two hundred Rosatom-linked companies (from more than 400) and cut all ties with the corporation. Western countries have taken a more selective approach, targeting mostly military-linked entities and companies directly connected to Russia's occupation of the Zaporizhzhia nuclear power plant, for example, the joint stock company “Operating organization of Zaporizhzhya NPP”, established by Rosenergoatom to manage the occupied nuclear power plant.³⁰⁵

By early 2025, nearly 70 Rosatom-related subsidiaries and individuals were under U.S. sanctions,³⁰⁶ with some also sanctioned by the E.U., U.K., Canada, and others. However, other than the termination of the contract for the Finnish Hanhikivi-1 project, so far, these sanctions have not jeopardized Rosatom's pre-2022 foreign newbuild contracts, even if they have caused some difficulties and delays. Rosatom's strong global presence, the challenge of replacing one of only a handful of nuclear suppliers, as well as dependencies on Russia as a client for Western equipment, appear to have given Rosatom a kind of sanctions immunity. See dedicated chapter on [Russia Nuclear Interdependencies](#) for details.

The European Union

Since 2022, and as of 1 July 2025, the E.U. has adopted 17 sanctions packages against Russia, targeting finance, energy, technology, and trade.³⁰⁷ Measures include disconnecting banks from SWIFT, freezing Central Bank assets, banning imports of oil, coal, gold, and diamonds, and restricting high-tech and dual-use exports. However, despite these restrictions, the E.U. continued to import unsanctioned fossil fuels, such as pipeline gas and LNG, from Russia, amounting to €21.9 billion (US\$23.7 billion) in 2024 according to some estimates, with the volume decreasing by only 1 percent compared to the previous year.³⁰⁸ Half of this amount was accounted for by the five largest buyers—Hungary, Slovakia, Italy, France, and Czechia.³⁰⁹

304 - Peter Piatetsky, “What are countries doing to counter Russia's War?”, *Castellum.AI*, Undated, see <https://www.castellum.ai/insights/which-countries-are-taking-action-on-ukraine>, accessed 14 July 2024.

305 - Office of Foreign Assets Control, “Russia-related Designations and Designations Updates; Belarus Designations; Publication of Russia-related Determination; Issuance of Russia-related General Licenses and Associated Frequently Asked Questions”, Press Release, U.S. Department of the Treasury, 24 February 2023, see <https://ofac.treasury.gov/recent-actions/20230224>, accessed 4 July 2025.

306 - U.S. Department of State, “Sanctions to Degrade Russia's Energy Sector”, Press Release, United States Government, 10 January 2025, see <https://2025.state.gov/office-of-the-spokesperson/releases/2025/01/sanctions-to-degrade-russias-energy-sector/>, accessed 26 May 2025.

307 - Consilium of the European Union, “Russia's War of Aggression Against Ukraine: EU Agrees 17th Package of Sanctions”, Press Release, 20 May 2025, see <https://www.consilium.europa.eu/en/press/press-releases/2025/05/20/russia-s-war-of-aggression-against-ukraine-eu-agrees-17th-package-of-sanctions/>, accessed 23 May 2025.

308 - Vaibhav Raghunandan, Petras Katinas, Isaac Levi, and Luke Wickenden “EU Imports of Russian Fossil Fuels in Third Year of Invasion Surpass Financial Aid Sent to Ukraine”, Centre for Research on Energy and Clean Air, 24 February 2025, Updated 10 April 2025, see <https://energyandcleanair.org/publication/eu-imports-of-russian-fossil-fuels-in-third-year-of-invasion-surpass-financial-aid-sent-to-ukraine/>, accessed 23 May 2025.

309 - Ibidem.

WNISR2024 contained a brief overview of how nuclear equipment and fuel remained largely exempt from E.U. sanctions due to concerns and political pressure from certain Member States—notably France and Hungary³¹⁰—with strong nuclear ties to Russia. Hungary continues work on Paks II, while France appears committed to its nuclear cooperation with Russia, including enriched uranium imports, joint projects with Rosatom like fuel fabrication in Germany, and sales of its Arabelle turbines for VVER reactors.

On 6 May 2025, the European Commission presented its roadmap for reducing reliance on Russian energy supplies, including nuclear supplies.³¹¹ The development of a step-by-step phaseout plan for Russian nuclear imports in cooperation with Member States by the end of 2025 revolves around proposed measures which include:

- ➔ economic incentives and tariffs to make the purchase of Russian enriched uranium less attractive;
- ➔ a ban on prolongations and new contracts with Russian suppliers (the Euratom Supply Agency that must counter-sign any such contract will not do so anymore).

The introduction of this roadmap—covering issues omitted from the E.U.’s 17 previous sanctions packages—is a positive step. However, much depends on the still-unspecified details. There are concerns about continued cooperation with Rosatom through loopholes such as licensed fuel production in the E.U. (e.g., Framatome’s Lingen facility, see [Framatome and the Lingen VVER Fuel Manufacturing Plant Project](#)³¹²). It also remains unclear how the measures will be adopted amid opposition from Member States like Hungary and France.

One of the E.U.’s main dependencies on Russia in the nuclear sector is the use of Russian nuclear fuel for 19 VVER reactors operating in five countries: the Czech Republic, Hungary, Slovakia, Bulgaria, and Finland. As shown in WNISR2024, according to the Norwegian organization Bellona’s analysis based on Eurostat data, purchases of such fuel nearly doubled in the first year (2023) after the start of the all-out war with Ukraine, as operators sought to stockpile supplies amid increasing uncertainty. However, these purchases significantly declined from 635 tons (€718 million or US\$₂₀₂₃ 776 million) in 2023 to 438 tons (€527 million or US\$₂₀₂₄ 572.8 million) in 2024, although this still exceeds the pre-war level of around 300 tons per year.³¹³ The 2023 total of 635 tons includes 62.3 tons supplied to Bulgaria, according to Eurostat, but data on Bulgaria’s imports in other years is missing, suggesting the database may be incomplete.

By 2024, all five countries using Russian nuclear fuel had signed contracts with alternative suppliers (Westinghouse and/or Framatome), and in Bulgaria and Finland, non-Russian fuel

³¹⁰ - Victor Jack, “French-Russian Nuclear Relations Turn Radioactive”, *Politico*, 20 April 2023, see <https://www.politico.eu/article/french-russian-nuclear-relations-radioactive-rosatom-sanctions/>, accessed 21 July 2024; and Henry Foy, “Why Hungary is again blocking the latest round of Russia sanctions”, *The Financial Times*, 15 February 2024, see <https://www.ft.com/content/53f2e696-5ff2-4be9-bcfo-f6a144fbd8ff>, accessed 29 May 2024.

³¹¹ - European Commission, “Roadmap Towards Ending Russian Energy Imports”, Communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Roadmap, 12 May 2025, see <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52025DC0440R%2801%29&qid=1747125158211>, accessed 24 May 2025.

³¹² - Dmitry Gorchakov, “This German Town Could Decide the Future of EU Reliance on Russian Nuclear Fuel”, *The Moscow Times*, 30 December 2024, see <https://www.themoscowtimes.com/2024/12/30/this-german-town-could-decide-the-future-of-eu-reliance-on-russian-nuclear-fuel-a87489>, accessed 25 May 2025.

³¹³ - Alexander Nikitin and Dmitry Gorchakov, “Rosatom in the War Years of 2023 and 2024—Main Events, Projects, Decisions, Facts and Problems”, December 2024, Bellona, op. cit.; and Eurostat, “EU Trade Since 1988 by HS2-4-6 and CN8”, Updated 16 July 2025, see https://ec.europa.eu/eurostat/databrowser/view/ds-045409__custom-17371491/default/table?lang=en, accessed 14 August 2025.

was already being loaded into reactors that year.³¹⁴ (See [Russia Nuclear Interdependencies](#)). On 30 May 2025, the first batch of Westinghouse fuel was also delivered to Temelín in the Czech Republic.³¹⁵

*France remains virtually the only buyer in the E.U.
of Russian enriched uranium*

Imports of enriched uranium from Russia likewise fell from 253 tons (€430 million³¹⁶ or US\$₂₀₂₃ 465 million) in 2023 to 147 tons (€170 million or US\$₂₀₂₄ 185 million) in 2024, with France remaining virtually the only buyer.³¹⁷ That material was delivered either directly to France or to Framatome’s fuel manufacturing facility in Lingen, Germany.

The United States

For several decades, the U.S. has remained one of the main buyers of Russian enriched uranium, sourcing up to a third of its needs from Russia.³¹⁸ In 2023, amid ongoing uncertainty, purchases even reached their highest level since 2013—over 700 tons worth US\$1.2 billion.³¹⁹

A new law banning the import of uranium from Russia was passed in May 2024 and came into effect on 11 August 2024.³²⁰ Given the significance of Russian supply, a caveat allows for waivers until the end of 2027, if the U.S. Department of Energy judges that no alternative supply is available. The legislation also unlocks \$US2.7 billion in federal support for domestic enrichment.³²¹

In response, in mid-November 2024, the Russian government imposed a temporary ban on enriched uranium exports to the U.S. until the end of 2025 and revoked existing export licenses. However, like the U.S. ban, this restriction can be bypassed through the issuance of special one-time licenses. As a result, enriched uranium deliveries from Russia to the U.S. resumed in early 2025.³²²

³¹⁴ - Dmitry Gorchakov, “This German Town Could Decide the Future of EU Reliance on Russian Nuclear Fuel”, *The Moscow Times*, 30 December 2024, op. cit.

³¹⁵ - Marek Sviták, “První nové jaderné palivo Westinghouse dorazilo do České republiky”, Press Release, Temelín Nuclear Power Plant, CEZ Group, 23 May 2025, see <http://www.cez.cz/cs/pro-media/tiskove-zpravy/prvni-nove-jaderne-palivo-westinghouse-dorazilo-do-ceske-republiky-220823>, accessed 9 June 2025.

³¹⁶ - Eurostat, “EU Trade Since 1988 by HS2-4-6 and CN8”, Updated 16 July 2025, see <https://ec.europa.eu/eurostat/databrowser/bookmark/7964fbf5-f9d6-44ac-9b0c-e3ece145b000?lang=en>, accessed 14 August 2025.

³¹⁷ - Alexander Nikitin and Dmitry Gorchakov, “Rosatom in the War Years of 2023 and 2024—Main Events, Projects, Decisions, Facts and Problems”, December 2024, Bellona, op. cit.

³¹⁸ - Dmitry Gorchakov, “This German Town Could Decide the Future of EU Reliance on Russian Nuclear Fuel”, *The Moscow Times*, 30 December 2024, op. cit.

³¹⁹ - Comtrade, “Trade Data”, United Nations, 2025, see <https://comtradeplus.un.org/TradeFlow>, last accessed 9 June 2025.

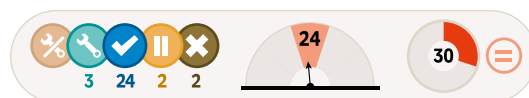
³²⁰ - U.S. Government, “Public Law 118–62—Prohibiting Russian Uranium Imports Act—An Act to Prohibit the Importation Into the United States of Unirradiated Low-Enriched Uranium That Is Produced in the Russian Federation, and for Other Purposes.”, 13 May 2024, see <https://www.congress.gov/118/plaws/publ62/PLAW-118publ62.pdf>, accessed 8 August 2024.

³²¹ - Jennifer T. Gordon, “The US is Banning the Import of Russian Nuclear Fuel. Here’s Why That Matters.”, Atlantic Council, 16 May 2024, see <https://www.atlanticcouncil.org/blogs/new-atlanticist/the-us-is-banning-the-import-of-russian-nuclear-fuel-heres-why-that-matters/>, accessed 16 July 2024.

³²² - Dmitry Gorchakov, “Enriched Uranium Fuels Russia’s War Machine. But the U.S. Still Imports It”, *The Moscow Times*, 13 March 2025, see <https://www.themoscowtimes.com/2025/03/13/enriched-uranium-fuels-russias-war-machine-but-the-us-still-imports-it-a88274>, accessed 25 May 2025.

Nevertheless, by the end of 2024, exports of enriched uranium from Russia to the U.S. had nearly halved compared to the previous year—down to 335 tons worth US\$624 million.³²³ Judging by a series of measures and executive orders issued by the Trump administration in May 2025 aimed at supporting the U.S. nuclear industry, the current administration appears set to continue efforts to reduce dependence on Russian supplies.³²⁴ For further details on U.S. policy, see [United States Focus](#).

SOUTH KOREA FOCUS



Republic of Korea (hereafter, South Korea) became a nuclear-operating country in 1977, when its first commercial reactor, Kori-1, was connected to the grid. The first reactor was a Westinghouse-designed Pressurized Water Reactor (PWR, WH 60), marking the country's dependence on foreign technology during the initial phase.

During the 1980s and 1990s, South Korea pursued an aggressive technology transfer (import) strategy, culminating in the development of its own standardized reactor designs. The OPR-1000 was developed drawing on the System 80 design of Combustion Engineering (C-E), a U.S.-based nuclear engineering company, through a formal technology transfer agreement.³²⁵ C-E was acquired by Westinghouse in 2000, but the collaboration laid the foundation for Korea's reactor localization. This evolution continued with the APR-1400, which further built upon the System 80+ framework and integrated significant domestic design innovations.

By 2007, South Korea surpassed Germany in nuclear electricity generation, rising from sixth to fifth place globally. Following the Fukushima events in 2011, Japan significantly curtailed its nuclear operations, and in 2012, South Korea temporarily became the fourth-largest nuclear power producer in the world. However, this position was overtaken by China in 2015, as the country rapidly expanded its nuclear fleet. Since then, South Korea has remained in fifth place globally in terms of both operating capacity and annual nuclear electricity generation. As of 1 July 2025, South Korea's installed nuclear capacity exceeds that of the 15 smallest nuclear fleets in the world combined.

To date, two reactors have been closed: Kori-1 in 2017 and Wolsong-1 in 2019. The two oldest reactors in the country (Kori-2 and Kori-3) were shut down in April 2023 and September 2024, respectively, after their operating licenses expired. As they are expected to restart, they are considered in LTO, leaving 24 reactors in operation. In addition to Saeul-3 and -4 (formerly known as Shin-Kori-5 and -6), under construction since 2017 and 2018, respectively, construction started in May 2025 at Shin Hanul-3. This places South Korea among a small number of countries that are not only maintaining but also expanding their nuclear fleet.

Among the 31 countries with operating reactors, South Korea stands out for its highly standardized fleet, high load factors, and centralized management through Korea

³²³ - Ibidem; and Comtrade, "Trade Data", 2025, op. cit.

³²⁴ - The White House, "Reinvigorating the Nuclear Industrial Base", Executive Order, U.S. Presidency, 23 May 2025, see <https://www.whitehouse.gov/presidential-actions/2025/05/reinvigorating-the-nuclear-industrial-base/>, accessed 9 June 2025.

³²⁵ - Mark Holt, "U.S. and South Korean Cooperation in the World Nuclear Energy Market: Major Policy Considerations", Congressional Research Service, 25 June 2013.

Hydro & Nuclear Power (KHNP), a subsidiary of state-owned Korea Electric Power Corporation (KEPCO).

In 2009, South Korea became a nuclear-exporting country by securing a contract to construct and operate four APR-1400 reactors at the Barakah site in the United Arab Emirates (UAE). While the Barakah project in the UAE remained its only full-scale export deal for over a decade, on 4 June 2025 South Korea finalized a contract to supply two APR-1000 reactors for the Dukovany expansion project in the Czech Republic. If successfully completed, this would mark South Korea's first entry into the European nuclear market.

Policy Overview: From Nuclear Expansion to Political Uncertainty

From the second half of 2024 to the first half of 2025, South Korea underwent a dramatic political upheaval with significant implications for its energy policy landscape. Since 2022, under the Yoon Suk-yeol administration, the country had enhanced pro-nuclear policies, integrating nuclear power into national energy, industrial, and export strategies. However, on 3 December 2024 then-President Yoon declared an unconstitutional and unlawful emergency martial law, sparking widespread public backlash and cross-party condemnation. The National Assembly impeached him on 14 December 2024, and the Constitutional Court upheld the impeachment on 4 April 2025, permanently removing Yoon from office. This abrupt change created a sudden rupture in nuclear-policy leadership, introducing considerable uncertainty about the future direction of South Korea's nuclear program.

Yoon's rise to power was significantly aided by his vocal criticism and political attacks on the nuclear phaseout policy pursued by former President Moon Jae-in, which played a major role in mobilizing conservative support and shaping Yoon's pro-nuclear platform.³²⁶ Once elected, Yoon strongly reversed course on the nuclear phaseout, prioritizing nuclear energy expansion instead.

A key expression of President Yoon's pro-nuclear agenda was the 11th Basic Plan for Long-term Electricity Supply and Demand (BPE), which was formally established by the Ministry of Trade, Industry and Energy (MOTIE) on 21 February 2025 and later revised and re-announced on 13 March 2025.³²⁷ The 11th BPE proposed a long-term electricity mix in which nuclear power would supply about 32 percent of electricity by 2030 and just over 35 percent by 2038, up from 31.7 percent in 2024 (see Table 9). This includes plans for two new 1400-MW (APR-1400) reactors and four SMRs totaling 0.7 GW (four 170 MW i-SMRs³²⁸), although the i-SMR still

³²⁶ - Ser Myo-ja, "Yoon Incinerates Moon's Anti-Nuclear Energy Policy", *The JoongAng*, 6 July 2021, see <https://koreajoongangdaily.joins.com/2021/07/06/national/politics/Yoon-Seokyoul-nuclear-phaseout-Wolsong1/20210706183300295.html>, accessed 22 August 2025.

³²⁷ - MOTIE, "제11차 전력수급기본계획(2024-2038) 수정 공고", Ministry of Trade, Industry and Energy, Government of South Korea, 13 March 2025, see <https://www.motie.go.kr/kor/article/ATCLcoib2801b/70152/view>, accessed 20 May 2025.

³²⁸ - KHNP, "한국수력원자력-한국원자력연구원 SMR 협력 MOU 체결", Press Release, Korea Hydro & Nuclear Power, 23 August 2024, see https://khnp.co.kr/main/selectBbsNttView.do%3BWCN_EXHP%3D0Zn5oQ1P3VR4CnlbVwDVfiUPsZvcsojAqiarKadkiitVX8C6kWWQ%21-774723050?bbsNo=71&integrDeptCode=&key=2289&nttNo=57661&pageIndex=19&searchCnd=a1l&searchCtgry=&searchKrwD=&utm, accessed 2 June 2025.

remains at the Research and Development (R&D) phase and has not received standard design approval yet.³²⁹

Table 9 · Power Generation by Source and Share Forecast

	Unit	Nuclear	Coal	LNG	Renewable Energy	New Energy	Clean Hydrogen & Ammonia	Other	Total
Actual Electricity Mix in 2024	TWh	188.8	167.2	167.2	53.3	9.5	-	9.6	595.6
	Share	31.7%	28.1%	28.1%	8.9%	1.6%	-	1.6%	100%
11th Basic Plan on Electricity Supply and Demand - Electricity Mix Targets									
2030 Target	TWh	204.2	110.5	161.0	120.9	18.7	15.5	11.8	642.6
	Share	31.8%	17.2%	25.1%	18.8%	2.9%	2.4%	1.8%	100%
2038 Target	TWh	248.3	70.9	74.3	205.7	26.4	43.9	34.9	704.5
	Share	35.2%	10.1%	10.6%	29.2%	3.8%	6.2%	5.0%	100%

Sources: KEPCO and MOTIE, 2025³³⁰

In addition to newbuilds, the Yoon administration institutionalized long-term reactor operation. Amendments to the Enforcement Decree of the Nuclear Safety Act (effective from late 2022) allowed operators to apply for lifetime extensions five to ten years before license expiry, streamlining the process and aligning it with industry planning cycles.³³¹ The nuclear industry presumed all existing reactors would be extended,³³² provided the independent Nuclear Safety and Security Commission (NSSC) grants permission.

However, with the impeachment and removal of President Yoon, the direction of nuclear policy has entered a new phase of uncertainty. The incoming President Lee Jae-myung from the Democratic Party of Korea, who took office in early June 2025, has not yet provided detailed clarification on how he will approach nuclear policymaking.

During a pre-electoral televised debate, Lee stated:

While we cannot completely eliminate nuclear energy overnight, the era of building more reactors should come to an end. (...)

We need to act urgently to strengthen our renewable base—not just for the environment, but for our economy to survive global RE100 [100% Renewable Energy] standards. (...)

³²⁹ - Although SMRs remain in the R&D phase, their inclusion in the administrative plan (the 11th BPE) is highly unusual. MOTIE has stated that the government aims to commercialize SMRs domestically by 2035, assuming the completion of safety review, standard design approval, and construction licensing in the early 2030s. While the plan text refers to the deployment of one demonstration SMR unit with a 0.7 GW capacity in 2035–2036, the facility planning table lists the commissioning of two units each in 2034 and 2035. In the case of the i-SMR under joint development by Korean Hydro & Nuclear Power (KHNP) and the Korea Atomic Energy Research Institute (KAERI), each reactor module has a capacity of 170 MW and up to four can be installed together, yet the plan refers to this configuration as a single reactor. Furthermore, the capacity is listed as 175 MW instead of the announced 170 MW, indicating possible inconsistencies in how this not-yet-existent power source has been incorporated into national planning.

³³⁰ - KEPCO, “2025년도판 한국전력통계(제94호)”, 30 May 2025, Korea Electric Power Company, see <https://www.kepcoco.kr/home/customer/library/electricity-statistics/kepcoco-stats/boardView.do>, accessed 28 July 2025; and MOTIE, “제11차 전력수급기본계획 (2024-2038) 수정 공고”, Ministry of Trade, Industry and Energy, Government of South Korea, 13 March 2025, op. cit.

³³¹ - 김정수, “원안위, 원전 수명연장 위한 안전성보고서 제출시기 5년 앞당겨”, *The Hankyoreh*, 15 September 2022, see <https://www.hani.co.kr/arti/society/environment/1058801.html>, accessed 21 May 2025; and Law Viewer, “Enforcement Decree of the Nuclear Safety Act”, last amended 1 August 2023, see https://elaw.klri.re.kr/eng_mobile/viewer.do?hseq=63367&type=part&key=18, accessed 27 July 2025.

³³² - 조재희, “[단독] 월성 2·3·4호기도 수명 연장... ‘文정부 탈원전 대못 뺄기로’”, *The Chosun Daily*, 1 April 2024, see <https://www.chosun.com/economy/industry-company/2024/04/01/RE2FDVXMNZD7HCGWOXN35QUTHY/>, accessed 22 May 2025.

Nuclear energy may appear cheap, but when you account for what happens if something goes wrong, it becomes one of the most expensive options.³³³

These and similar remarks suggest a cautious, pragmatic stance—neither fully endorsing nor rejecting nuclear energy outright. In contrast, the conservative candidate Kim Moon-soo from the People Power Party, who placed second in the presidential election, had pledged to increase nuclear’s share to 60 percent³³⁴—35 percent from large reactors and 25 percent from SMRs. However, his final published campaign manifesto lowered the target to 35 percent.³³⁵

It is difficult to understand what such percentage-based nuclear targets mean in terms of actual reactor capacity. To achieve the 35-percent nuclear share by 2050 proposed in Kim Moon-soo’s revised manifesto, South Korea would need to construct an additional 24 large-scale 1400-MW reactors³³⁶—on top of all currently operating, under construction, and planned units—even if the lifespan of each reactor were extended twice. This appears to represent an impossible target from a purely industrial point of view, considering past and present experience.

As of 1 July 2025, it remains unclear whether the 11th BPE could and would be implemented as outlined. The newly launched Lee Jae-myung administration has not announced any specific vision or clear plans regarding policy directions for power generation, including nuclear power. President Lee promised during his presidential campaign to merge the Ministry of Trade, Industry and Energy’s department of energy affairs with the Ministry of Environment’s department of climate crisis response into a new integrated “Ministry of Climate and Energy.”³³⁷ As such, it is expected that the incoming government’s power policy will take shape during the process of establishing the new ministry and appointing its minister.

Operating Fleet

As of 1 July 2025, South Korea operates 26 commercial nuclear reactors at five sites: Kori, Saeul, Hanul, Wolsong, and Hanbit. Including two reactors currently in LTO, the total operating capacity stands at approximately 24 GW. The reactor fleet is highly standardized, with 23 of the 26 units based on variations of the Pressurized Water Reactor (PWR) technology, while only three units—Wolsong-2, -3, and -4—use the Canadian CANDU pressurized heavy water reactor (PHWR) technology.

333 - Bahk Eun-ji, “Presidential Candidates Clash Over Nuclear Policy, Health Insurance in Televised Debate”, *The Korea Times*, 23 May 2025, see <https://www.koreatimes.co.kr/southkorea/20250523/presidential-candidates-clash-over-nuclear-policy-health-insurance-in-televised-debate>, accessed 26 May 2025.

334 - Ibidem.

335 - 안상민, “‘원전 35%도 현실성 없다’ 에너지전환포럼, 원전공약 분석 결과 발표”, *전기신문*, 27 May 2025, see <https://www.electimes.com/news/articleView.html?idxno=355602>, accessed 22 August 2025.

336 - The projected total electricity generation for 2050 is based on the 1,257.7 TWh figure assumed in the carbon neutrality scenario established by the South Korean Government in 2021. The estimate assumes an 85 percent capacity factor for nuclear power.

337 - Ahn So-young, “[세종총향계] 기후에너지부 신설 현실화... 기대와 우려 공존하는 산업부·환경부”, *The Chosun Daily*, 6 June 2025, see https://biz.chosun.com/policy/policy_sub/2025/06/06/QBVTELBS2FDB3NZ6VSKMEZLVN1/, accessed 26 July 2025.

Reactors Under Construction and Planned

Three reactors—Saeul-3 and Saeul-4 as well as Shin-Hanul-3—remain under construction as of 1 July 2025.

The two Saeul APR-1400 reactors, located in Ulsan, were first included in the 4th BPE, established in December 2008. At that time, the reactors were scheduled for completion by December 2018 (Saeul-3) and December 2019 (Saeul-4).³³⁸ The construction licenses for both units were granted on 27 June 2016. First concrete was poured for Saeul-3 in April 2017 and for Saeul-4 in September 2018.³³⁹ As of the most recent 11th BPE, the expected completion dates for the two reactors are now set for February 2026 (Saeul-3) and November 2026 (Saeul-4).³⁴⁰

In addition to Saeul-3 and Saeul-4, two more reactors have received construction permits: Shin-Hanul-3 and Shin-Hanul-4, both also based on the APR-1400 design. The NSSC granted construction licenses for both units on 12 September 2024. According to a press release from KHNP, construction on Shin-Hanul-3 has officially begun on 20 May 2025 with the first concrete pour for foundations of the reactor building.³⁴¹ KHNP President Whang Joo-ho stated that “we will do our utmost to ensure the safe construction of Shin-Hanul Units 3 and 4 and to achieve the goal of delivering the project *on time and within budget*, thereby enhancing the reputation of K-Nuclear in the global market.”³⁴²

Given that all eight reactors—Shin-Kori-2, Shin-Wolsong-1, Shin-Wolsong-2, Saeul-1, Saeul-2, Shin-Hanul-1, and Shin-Hanul-2—that were connected to the grid in South Korea since 2012, along with the four Barakah units in the UAE, were increasingly delayed from their original timelines, the promise of being “on time” appears very optimistic.

The construction of two additional large-scale APR-1400 reactors was introduced in the 11th BPE, scheduled for completion in June 2037 and June 2038 respectively, though no sites have yet been designated for them. The same plan also outlines the expected completion of four 175-MW SMRs in September and December 2034 and in March and June 2035. If all of these plans are realized and the lifespans of existing reactors are extended, the number of operating reactors in South Korea would increase from 26 (with the restart of Kori-2 and Kori-3) to 36, and the total installed nuclear capacity would expand from approximately 26 GW to 35 GW by 2038.

338 - Ministry of Knowledge Economy, “The 4th Basic Plan of Long-Term Electricity Supply and Demand (2008-2022)”, Government of South Korea, as translated and released by Korea Power Exchange, December 2008, see https://www.kpx.or.kr/boardDownload.es?bid=ATT&list_no=7222000017129071087642&seq=2, accessed 26 July 2025.

339 - KHNP, “Nuclear Power Construction—Saeul #3,4”, Updated 31 March 2025, see <https://cms.khnp.co.kr/eng/contents.do?key=525>, accessed 10 April 2025.

340 - Ibidem; and MOTIE, “제11차 전력수급기본계획(2024-2038) 수정 공고”, 13 March 2025, op. cit.

341 - KHNP, “한국수력원자력, 신한울3호기 최초 콘크리트 타설”, Press Release, 20 May 2025.

342 - Ibidem.

Small Modular Reactors (SMRs)

SMRs have emerged in recent years as a topic of significant public interest in South Korea. According to a search on Big Kinds,³⁴³ a news database provided by the Korea Press Foundation, covering over 100 national and regional news outlets of various kinds, the number of news articles mentioning SMRs increased steadily from 5,576 in 2022 to 6,408 in 2023, reaching 7,717 in 2024. Media coverage has primarily focused on investment and industrial strategy aspects.

Media focus on SMRs is partly due to the participation of KHNP in the government-led innovative SMR (i-SMR) development project, jointly promoted by the Ministry of Trade, Industry and Energy and the Ministry of Science and ICT (MSIT), with the Korea Atomic Energy Research Institute (KAERI) as a partner. The i-SMR is currently under development with the goal of obtaining standard design approval in 2028.³⁴⁴ Reportedly, KHNP has conducted preliminary preparations in the first half of this year to select a construction site for the i-SMR and plans to launch a site-solicitation process in the second half.³⁴⁵

In addition, major South Korean conglomerates are involved in U.S.-based projects—such as Doosan Enerbility, Samsung C&T Corporation, and GS Energy in NuScale or SK Group and HD Hyundai with TerraPower—as investors, equipment and service providers, or future strategic partners.³⁴⁶ KHNP is also reported to be investing in SMRs by purchasing shares in the special purpose company (SPC) established by SK Group to acquire the latter's stake in TerraPower.³⁴⁷ According to the minutes of KHNP's 5th Board of Directors meeting held on 28 August 2024, the draft Plan for Acquiring Shares in a U.S. Fourth-Generation SMR Developer was presented.³⁴⁸ The proposal was conditionally approved, with the rationale detailed and supplemented and the plan revised to proceed with the project after confirming economic viability through alternative methods of corporate valuation.³⁴⁹ However, as of the first half of 2025, the finalization of KHNP's acquisition of a stake in TerraPower had not been confirmed. These developments have contributed to the high level of media interest in SMRs.

In fact, South Korea invested several hundred billion won (several hundred million U.S. dollars) over the past decades in the development of the 100-MW SMART (System-integrated Modular Advanced Reactor) design. A standard design certification for the original SMART reactor was completed in 2012, and a revised version, SMART100, received standard design approval

343 - See Big Kinds, Homepage, Korea Press Foundation, see <https://www.bigkinds.or.kr/>.

344 - Innovative Small Modular Reactor Development Agency, "About Us—Milestone", Undated, see <https://ismr.or.kr/eng/sub/milestone>, accessed 27 August 2025.

345 - 김인애, "한수원 SMR 건설 선점 경쟁 뛰어들어, 황주호 혁신기술로 수출 확대 드라이브", *The Business Post*, 13 March 2025, see https://www.businesspost.co.kr/BP?command=article_view&num=386902, accessed 25 June 2025.

346 - HD Hyundai, "HD Hyundai and TerraPower Strengthen Collaboration to Accelerate Natrium Commercialization", 12 March 2025, see <https://esg.hd.com/en/news/902>; and SK, "SK Invests in Bill Gates' TerraPower to Accelerate Transition to Net Zero", 15 August 2022, see <https://eng.sk.com/news/sk-invests-in-bill-gates-terrapower-to-accelerate-transition-to-net-zero>; both accessed 26 July 2025.

347 - 김인애, "한수원 SMR 건설 선점 경쟁 뛰어들어, 황주호 혁신기술로 수출 확대 드라이브", *The Business Post*, 13 March 2025, see https://www.businesspost.co.kr/BP?command=article_view&num=386902, accessed 25 June 2025.

348 - KHNP, "공공기관 경영정보 공개시스템", as released on All Public Information In-One (ALIO) Portal, Government of South Korea, 16 October 2024, see <https://www.alio.go.kr/item/itemReport.do?seq=2024101702886555&disclosureNo=2024101702886555>, both accessed 27 August 2025.

349 - KHNP, "미국 4세대 SMR 개발사 지분인수", 27 March 2025, see <https://www.khnp.co.kr/main/selectBbsNttView.do?key=171&bbsNo=198&nttNo=64229>, accessed 31 August 2025.

from the Nuclear Safety and Security Commission in 2024.³⁵⁰ Despite these milestones and prolonged R&D efforts, to date, not a single SMART reactor has been sold and built domestically or abroad.

The nuclear power issue appeared in South Korea's highly contentious political discourse following the declaration of emergency martial law by then-President Yoon on 3 December 2024. In a presidential address, delivered on 12 December after the martial law announcement, Yoon attempted to justify the unconstitutional measure by accusing the opposition of threatening democracy, national interests, and security through a wide range of traitorous, corrupt, and criminal actions, including that of undermining “national growth engines.” He stated:

The main opposition party is going so far as to shut off the Republic of Korea's economic growth engines. This becomes evident when you look at the Democratic Party's cutbacks in next year's budget.

The financing for supporting the nuclear power ecosystem has been reduced. The funds allocated for the export of nuclear power plants to the Czech Republic have been slashed by 90 percent. The budget for developing next-generation nuclear plants has been virtually eliminated.³⁵¹

However, these claims were demonstrably false. According to major media outlets' analyses, the 2025 nuclear-related budget proposed by the MOTIE, consisting of 24 items totaling KRW488.9 billion (US\$₂₀₂₄358.6 million), was passed without any reductions by the National Assembly on 10 December 2024. While there is no specific budget item titled “Czech nuclear export support,” the general nuclear export assistance program (Overseas Electricity Market Entry Support Project) received KRW18.3 billion (US\$₂₀₂₄13.4 million) and was approved without cuts.³⁵²

Yoon's reference to “next-generation nuclear development” appears to relate to SMR-related funding. The KRW5.4 billion (~US\$₂₀₂₄4 million) allocated for the SMR Component Manufacturing Support Center and the KRW32.9 billion (US\$₂₀₂₄42million) for the i-SMR (Innovative SMR) R&D program were both passed in full. Separately, the MSIT also allocated KRW53 billion (US\$₂₀₂₄38.9 million) to its own innovative SMR development program, which likewise passed without amendment.³⁵³

The only nuclear-related item that saw a 90-percent reduction, as Yoon claimed, was not related to the APR-1000 model intended for export to the Czech Republic, rather, it was the Public-Private Partnership Program for Advanced Reactor Export Infrastructure, overseen by the MSIT, which focused on the basic design of an experimental next-generation Sodium-cooled

350 - 이병구, “韓 수출형 원자로 ‘SMART100’ 5년 만에 표준설계인가”, *Dong-A Science*, 26 September 2024, see <http://m.dongascience.com/news.php?idx=67636>, accessed 25 June 2025; and NSSC, “NSSC Held 201st Meeting of Commission”, 26 September 2024, see https://www.nssc.go.kr/en/cms/PR_BBS_CON/BoardView.do?SITE_NO=3&BOARD_SEQ=1&BBS_SEQ=46337&MENU_ID=90&CONTENTS_NO=1, accessed 27 July 2025.

351 - Choi He-suk, “Full text of South Korean President Yoon Suk Yeol's address to the nation on Thursday”, *The Korea Herald*, 12 December 2024, see <https://www.koreaherald.com/article/10016987>, accessed 26 July 2025.

352 - 김규남, “‘야당이 원전 예산 삭감’ 윤석열 주장은 거짓말...‘불법 계엄’ 정당화 시도”, *The Hankyoreh*, 12 December 2024, see <https://www.hani.co.kr/arti/society/environment/1172761.html>, accessed 25 June 2025.

353 - Ibidem.

Fast Reactor (SFR). This project's budget was reduced from KRW7 billion (US\$₂₀₂₄5.1 million) to KRW0.7 billion (US\$₂₀₂₄0.5 million) after bipartisan agreement citing public controversy.³⁵⁴

Further, in June 2025, the Czech Minister of Industry and Trade stated:

The political situation in South Korea sometimes raised concerns in our country that it might jeopardize the nuclear tender. That is one of the reasons why, during our visit to South Korea in February [2025], we met not only with representatives of the government, but also with the then opposition Democratic Party. We were convinced that this was not the case. During meetings in both Korea and Prague, the then Korean opposition confirmed to me that it fully supports nuclear power and the project for new nuclear power plants in Dukovany.³⁵⁵

These developments illustrate that nuclear in general and SMRs in particular have become a highly visible and politically charged topic in South Korea, reaching into debates over constitutional legitimacy and the national budget.

The Czech Dukovany Nuclear Contract

WNISR2024 covered in some detail the KHNP/KEPCO–Westinghouse Part-810 export-control dispute—dismissed by a U.S. court on 18 September 2023, with an appeal filed on 16 October 2023—which formed a backdrop to the 2025 Dukovany contract.

On 4 June 2025, just one day after South Korea's presidential election, the Czech government and KHNP signed the final contract for the construction of two nuclear reactors at the Dukovany site.³⁵⁶ The offer has been confirmed at around CZK200 billion (US\$9.1 billion) per unit; though KHNP had earlier noted that “the final contract amount may vary depending on the outcome of the contract negotiations,” no updated amount was communicated.³⁵⁷ This marks South Korea's second-ever nuclear reactor export—coming 16 years after the country's first deal was signed with the UAE in 2009. Despite persistent efforts by the government and industry, no further exports had been secured until the Czech deal. Czech Prime Minister Petr Fiala personally announced the signing, calling it a “strategic investment” that would strengthen the country's energy security. The timing of the contract—following the lifting of a court injunction and coinciding with Korea's political transition—drew attention both domestically and internationally.³⁵⁸

354 - Ibidem.

355 - Ministry of Industry and Trade, “EPC Contract for Completion of Dukovany Has Been Signed. Minister of Industry and Trade, Lukáš Vlček Will Visit Korea Again in July”, Press Release, Government of the Czech Republic, 4 June 2025, see <https://mpo.gov.cz/en/guidepost/for-the-media/press-releases/epc-contract-for-completion-of-dukovany-has-been-signed--minister-of-industry-and-trade--lukas-vlcek-will-visit-korea-again-in-july--287912/>, accessed 26 July 2025.

356 - Government of the Czech Republic, “Smlouva mezi Elektrárnou Dukovany II a KHNP na výstavbu dvou nových jaderných bloků v Dukovanech podepsána”, 4 June 2025, see <https://vlada.gov.cz/cz/media-centrum/aktualne/smlouva-mezi-elektrarnou-dukovany-ii-a-khnp-na-vystavbu-dvou-novych-jadernych-bloku-v-dukovanech-podepsana-220044/>, accessed 4 June 2025.

357 - Ibidem; and KHNP, “KHNP is Ready to Support to Secure the Energy Needs of the Czech Republic”, Press Release, 17 July 2024, see <https://www.khnp.co.kr/eng/selectBbsNttView.do?key=565&bbsNo=84&nttNo=56342>, accessed 11 August 2024.

358 - Jan Lopatka, “Czechs Sign \$18 Billion Nuclear Power Plant Deal with KHNP After Court Injunction Lifted”, *Reuters*, 4 June 2025, see <https://www.reuters.com/business/energy/czech-court-rules-18-bln-nuclear-power-plant-deal-with-khnp-can-go-ahead-2025-06-04/>, accessed 26 June 2025; and 조재희 and 조재현, “[단독] 25조 체코 원전 최종 계약... UAE 이후 16년만의 수주”, *The Chosun Daily*, 4 June 2025, see <https://www.chosun.com/economy/industry-company/2025/06/04/ADQLQIS7WJHN3B7LKSDYW5SYJ4/>, accessed 18 June 2025.

The Czech nuclear project centers on building two APR-1000 reactors at the existing Dukovany nuclear power plant site and is aimed at replacing aging Soviet-era reactors and reducing the country's dependence on coal and Russian energy technologies. In addition to KHNP, a consortium of Czech firms, including the national energy utility České Energetické Závody (ČEZ), will participate in project execution. The Czech government has emphasized the importance of partnering with a supplier from a democratic country that meets NATO and E.U. standards, a point that worked in favor of KHNP against competitors such as China's CGN and Russia's Rosatom, who were excluded early in the process.³⁵⁹

The path to the final contract was complex and extended over several years. In March 2022, the Czech government officially launched the tender for Dukovany Unit 5, with options to build Unit 6 as well. KHNP submitted its bid in November 2022, competing against France's Électricité de France (EDF) and the Canadian-U.S. Westinghouse-Bechtel consortium. In July 2024, the Czech government confirmed KHNP as the preferred bidder, citing its competitive pricing, safety standards, and experience in exporting nuclear technology.³⁶⁰ This decision faced intense scrutiny, including legal and political objections from rival bidders (see [past WNISR editions](#) and section on the [Czech Republic](#)).

Legal hurdles escalated in May 2025, when a Czech court decided to temporarily forbid ČEZ to finalize the agreement with KHNP, pending its appraisal of the case brought by EDF against the Czech authority, which had twice dismissed the company's claims of unlawful irregularities in the contract's awarding process.³⁶¹ A few days earlier, the European Commission had also pleaded to the Czech government for a halt to the signature of the contract, to allow for a review in response to a leaked document showing "significant indications" that KHNP may have received subsidies from the South Korean state "that are liable to distort the internal market", in violation of E.U. regulations.³⁶² However, on 4 June 2025, the Czech Supreme Administrative Court lifted the preliminary injunction imposed by the regional court, claiming notably that the Brno court had failed to take KHNP's interest into account, thus, clearing the way for the contract to be signed.³⁶³ On the same day, the state-owned project company Elektrárna Dukovany II and KHNP formalized the agreement by signing an Engineering, Procurement and Construction (EPC) contract.

The Dukovany project is based on the APR-1000 design, a European-compliant variant of the APR-1400 reactor, which has already been built in South Korea and the UAE. Although

359 - *Euractiv*, "Czech Company Launches Long-Awaited Nuclear Tender Process", 18 March 2022, see https://www.euractiv.com/section/politics/short_news/czech-company-launches-long-awaited-nuclear-tender-process/, accessed 26 June 2025.

360 - Government of the Czech Republic, "The Government Has Decided on a Preferred Supplier for the New Nuclear Power Source at Dukovany", Press Release, 17 July 2024, see <https://vlada.gov.cz/en/media-centrum/aktualne/the-government-has-decided-on-a-preferred-supplier-for-the-new-nuclear-power-source--negotiations-on-the-construction-of-two-units-at-dukovany-will-be-214609/>, accessed 22 July 2024.

361 - Regional Court of Brno, "TISKOVÁ ZPRÁVA Ve Věci Elektrárna Dukovany II", Ministry of Justice, Government of the Czech Republic, 6 May 2025, see <https://msp.gov.cz/documents/d/krajsky-soud-v-brne/tiskova-zprava-elektrarna-dukovany-ii-pdf>, accessed 9 May 2025.

362 - Stéphane Séjourné, "Request for Immediate Action to Suspend Contract Signature for the New Nuclear Reactors of Dukovany and Temelin, Czechia", Executive Vice-President, Prosperity and Industrial Strategy, European Commission, addressed to Lukáš Vlček, Minister of Industry and Trade, Government of the Czech Republic, as released by *Euractiv*, 2 May 2025, see <https://www.euractiv.com/section/eet/news/commission-misled-press-over-french-pressure-on-czech-nuclear-deal/>, accessed 12 May 2025.

363 - Czech Republic's Supreme Administrative Court, "Nejvyšší správní soud zrušil předběžné opatření ve věci výstavby jaderných bloků v elektrárně Dukovany", Press Release, 4 June 2025, see <https://www.nssoud.cz/aktualne/tiskove-zpravy/detail/nejvyssi-spravni-soud-zrusil-predbezne-opatreni-ve-veci-vystavby-jadernych-bloku-v-elektrarne-dukovany>, accessed 4 June 2025.

KHNP has not yet constructed an APR-1000 domestically, the design has received certification from the European Utility Requirements (EUR) organization, strengthening its credibility for deployment in the European Union. The APR-1000 design includes additional safety features to the APR-1400 design such as double containment, a core catcher, and enhanced cooling systems to meet European safety standards.

Export Ambitions:

The Risks of Low Bidding and the ‘On Time, On Budget’ Model

In 2009, KEPCO signed a US\$20 billion contract as the lead of a consortium to build four APR-1400 nuclear reactors in the UAE.³⁶⁴ Under this contract, KHNP was responsible for reactor operations and technical provision, Doosan Enerbility for the main equipment, and Samsung C&T and Hyundai Engineering & Construction for construction. In March 2024, the fourth unit of the Barakah nuclear power plant began supplying electricity to the UAE grid, marking the full operation of the plant.

However, contrary to the often-used slogan ‘on time and on budget’ frequently cited by KEPCO and KHNP, the Barakah project experienced years of delays similar to many other new nuclear projects worldwide.³⁶⁵ For instance, Unit 1 was originally scheduled to begin commercial operation in 2017 according to a plan released in 2014,³⁶⁶ but it did not commence commercial operation until 2021³⁶⁷. Similarly, Unit 4 was delayed from its initial target of 2020 to 2024.

There has been no transparent, comprehensive report on the causes of these delays, but there are indications that the KEPCO-led consortium, including KHNP, may have been at least partly responsible. At the time of the UAE export deal, South Korea had not yet completed or operated a single APR-1400 reactor domestically. The Shin-Kori-3 (now Saeul-1), whose construction began in 2008, was the first APR-1400 reactor built in South Korea. In 2013, a major safety and corruption scandal erupted, and a government investigation reportedly found “277 faked certificates for parts used in 20 operating reactors, as well as 2,010 false documents at eight plants that were offline or under construction.”³⁶⁸ Furthermore, falsified test reports for control cables in several Korean reactors, including Shin-Kori-3 and -4, led to the replacement of over 900 kilometers of installed cable, which likely contributed to delays at both Shin-Kori and Barakah.³⁶⁹

364 - ENEC, “Prime Contractor”, Undated, see <https://www.enec.gov.ae/barakah-plant/prime-contractor/>, accessed 27 July 2025.

365 - He-rim Jo, “KHNP Vows Cost-Effective Nuclear Build, Eyes European Markets”, *The Korea Herald*, 9 May 2024, see <https://www.koreaherald.com/article/10483489>; and *NEI Magazine*, “Korea Anticipates Revival Of Its Domestic Nuclear Industry”, 23 July 2024, see <https://www.neimagazine.com/news/korea-anticipates-revival-of-its-domestic-nuclear-industry/>; both accessed 27 August 2025.

366 - ENEC, “Unit 1 of Power Plant More Than 57% Complete”, Press Release, Emirates Nuclear Energy Company, 17 September 2014, see <https://www.enec.gov.ae/news/latest-news/unit-1-of-enecs-barakah-power-plant-now-more-than-57-complete/>, accessed 26 June 2025.

367 - ENEC, “Unit 1 of Barakah Plant Started Commercial Operations”, Press Release, 6 April 2021, see <https://www.enec.gov.ae/news/latest-news/unit-1-of-barakah-plant-started-commercial-operations/>, accessed 30 June 2021.

368 - Sonal Patel, “S. Korea Indicts 100 in Nuclear Graft Scandal, Considers Drastic Cut in Future Nuclear Power Share”, *POWER Magazine*, 17 October 2013, see <https://www.powermag.com/s-korea-indicts-100-in-nuclear-graft-scandal-considers-drastic-cut-in-future-nuclear-power-share/>, accessed 27 July 2025.

369 - Ibidem.

Additional issues, such as coolant leakage from pressurizer safety valves in Shin-Kori-4 and voids found in the concrete containment buildings of Barakah Units 2 and 3, further complicated the timeline.³⁷⁰

In May 2025, it was reported that unresolved cost-assessment disputes between KEPCO and its own subsidiary KHNP over the Barakah project had escalated to international arbitration.³⁷¹ On 7 May 2025, KHNP initiated arbitration proceedings at the London Court of International Arbitration over additional construction costs, claiming around US\$1.1 billion according to KEPCO filings.³⁷² Given that such arbitration processes typically take two to three years, both parties now face increased financial uncertainties.

Industry observers in South Korea point to the core cause of these disputes: the Korean export strategy based on fixed-price bidding, also known as the “On Time, On Budget” model.³⁷³ While attractive for winning contracts, this model is highly vulnerable to cost overruns and penalty risks when unforeseen construction delays occur.³⁷⁴ Large infrastructure projects are inherently subject to commodity price volatility and timeline extensions, increasing the likelihood of disputes. Because the nuclear contract terms were not publicly disclosed—KEPCO and the UAE signed a non-disclosure agreement (see [WNISR2023](#))—and due to limited alternative sources of information on cost increases, it is difficult to assess how much construction costs have increased or how much actual profit has fallen. However, a delay of three to four years inevitably raises questions about who bears the added cost—KEPCO or KHNP, but in any case the Korean side. However, Hwang Joo-ho, president of KHNP, was quoted as saying that “when we built the Barakah NPP in the UAE, some of the increase in cost was due to the fact that we had to add new work (that was not in the contract) at the request of the client.”³⁷⁵

In fact, KEPCO reportedly has “consistently faced legal disputes with partners and subsidiaries” per *Business Korea*, including an arbitration case over additional costs that arose from project delays in the construction of Barakah filed by construction partners Hyundai E&C and Samsung C&T in July 2017,³⁷⁶ with a claim for an additional KRW600 billion (US\$₂₀₁₇530 million). However, the arbitration resulted in a payout of only KRW20–30 billion (US\$₂₀₁₉17–26 million).³⁷⁷

370 - 남지원, “냉각재 누설 해결 못한 채...신고리 4호기 ‘졸속’ 승인 논란”, *경향신문*, 17 February 2019, see <https://www.khan.co.kr/article/201902072108005>, accessed 27 August 2025; and ENEC, “Quality Assurance in Action at Barakah Nuclear Energy Plant”, 4 December 2018, see <https://www.enec.gov.ae/news/announcements/quality-assurance-in-action-at-barakah-nuclear-energy-plant/%20and%20provided/>, accessed 27 July 2025.

371 - 주재현, “‘26조’ 채코 계약 위기인데...K원전 집안싸움 ‘국제증재’로”, *서울경제/Sedaily*, 7 May 2025, see <https://www.sedaily.com/NewsView/2GSPFWBY8T/GC0119>, accessed 26 June 2025.

372 - KEPCO, “Form 6-K—Report on Legal Proceedings”, filed with the U.S. Securities and Exchange Commission, 7 May 2025, see <https://www.sec.gov/Archives/edgar/data/887225/000119312525114525/d880274d6k.htm>, accessed 27 July 2025.

373 - 주재현, “‘26조’ 채코 계약 위기인데...K원전 집안싸움 ‘국제증재’로”, *서울경제*, 7 May 2025, op. cit.

374 - The French integrated nuclear consortium went technically bankrupt and was dismantled in particular due to a similar “turnkey” construction project, Olkiluoto-3 in Finland, that turned out taking 13 years more than planned and almost four times as expensive as “sold for”.

375 - Yu Junho, “‘아빠와 아들 간에도 돈은 정확해야’...국제망신 지적에도 소신 밝힌 한수원”, *Maeil Business Newspaper*, 10 May 2025, see <https://www.mk.co.kr/news/economy/11313096>, accessed 27 July 2025.

376 - Jung Suk-ye, “‘Nuclear Family Feud’: Team Korea Engages in Legal Battles with Partners and Subsidiaries”, *Business Korea*, 26 February 2025, see <https://www.businesskorea.co.kr/news/articleView.html?idxno=236191>, accessed 27 July 2025.

377 - 옥기원, “[단독] UAE 원전 이익률 1.6%뿐...채코 원전 경제성도 빨간불”, *The Hankyoreh*, 24 October 2024, see <https://www.hani.co.kr/arti/society/environment/1164066.html>, accessed 26 June 2025.

EDF had also argued that the level of the fixed price for the Czech project—below €90/MWh (US\$102.2/MWh)³⁷⁸—constitutes dumping and would only be possible because the Korean government subsidizes the cost gap. Korean nuclear industry officials rejected the assertion, attributing the cost advantage to Korea’s robust supply chain and project management capabilities.³⁷⁹

Since 2013, KEPCO has disclosed some cumulative revenue and profit data related to the UAE project in its annual business reports. Although these figures cover various domestic and international construction projects, they primarily reflect the Barakah project.³⁸⁰ KEPCO reported cumulative profit from the UAE project at KRW1.33 trillion (US\$₂₀₁₉ 1.1 billion) in 2019 (after the completion of Units 1 and 2), but this dropped to KRW72.1 billion (~US\$₂₀₂₄ 53 million) by the end of 2024. Given the reported total contract revenue of KRW22.3 trillion (US\$₂₀₂₄ 16.35 billion), the implied cumulative profit margin stands at just 0.32 percent—a dramatic drop from the 10 percent margin initially anticipated in 2009.³⁸¹

Moreover, the profit margin may decrease further or disappear altogether due to unresolved cost-sharing issues between KEPCO and KHNP. As of the end of 2024, KEPCO set aside KRW154.6 billion (US\$₂₀₂₄ 113 million) as a “provision for liabilities” in its financial statement, indicating that cost disputes over the Barakah project are already reflected in its accounting. According to a media story citing KEPCO’s audit report, the company acknowledged that negotiations were ongoing with KHNP over extension-related costs and delay penalties and that a potential outflow of economic resources was expected. KEPCO noted that the amount recorded was based on auditor-approved figures and could change depending on future negotiations. If costs incurred during construction are not settled between KEPCO and KHNP—under the so-called “Team Korea”—KEPCO could reportedly face additional losses of up to KRW1.46 trillion (US\$1 billion).³⁸²

South Korea’s low-price bidding strategy is often cited as a major factor behind diminishing returns. KEPCO’s US\$20 billion bid for Barakah in 2009 was substantially lower than those from AREVA and GE-Hitachi, which played a decisive role in securing the contract. However, completing the project within such tight cost constraints—especially amid delays—makes significant profits unlikely if not leading to significant losses.

Adding to the challenge, Korean firms reportedly earned less because Westinghouse took over significant portions of the core equipment supply for the Barakah project. According to a report submitted to lawmaker Kim Sung-hwan’s office and seen by Korean-daily *The Hankyoreh*, Doosan supplied 51 percent of the primary system equipment (by value), while Westinghouse supplied 41 percent, and KEPCO E&C 7 percent.³⁸³ Toshiba, then-owner of Westinghouse,

378 - Contexte, “EDF et Westinghouse déposent des recours contre l’appel d’offres nucléaire tchèque remporté par le Coréen KHNP”, 28 August 2024, see https://www.contexte.com/actualite/energie/edf-et-westinghouse-deposent-des-recours-contre-lappel-doffres-nucleaire-tcheque-remporte-par-le-coreen-khnp_199875.html, accessed 4 November 2024.

379 - 주재현, “‘26조’ 체코 계약 위기인데...K원전 집안싸움 ‘국제중재’로”, *서울경제*, 7 May 2025, see <https://www.sedaily.com/NewsView/2GSPFWBY8T/GC0119>, accessed 26 June 2025.

380 - 옥기원, “[단독] UAE 원전 이익률 1.6%뿐...체코 원전 경제성도 빨간불”, *The Hankyoreh*, 24 October 2024, op. cit.

381 - 옥기원, “UAE 원전 이익률 0%대...‘정산 분쟁’에 조 단위 손실까지 우려”, *The Hankyoreh*, 13 March 2025, see <https://www.hani.co.kr/arti/society/environment/1186658.html>, accessed 30 May 2025.

382 - Ibidem.

383 - 옥기원, “[단독] UAE 원전 이익률 1.6%뿐...체코 원전 경제성도 빨간불”, *The Hankyoreh*, 24 October 2024, op. cit.

also supplied over half of the secondary systems (turbine generators). Westinghouse further received US\$1.3 billion for licensing and technical support. Altogether, it is estimated that Westinghouse secured about 16 percent of the total project value, or around KR3.9 trillion (US\$2.84 billion).³⁸⁴ An industry insider claimed that after KEPCO signed a cooperation agreement with Westinghouse in March 2010, Korean firms saw their share of the supply chain significantly reduced.³⁸⁵

Professor Park Jong-woon of Dongguk University's Department of Energy and Electrical Engineering warned that the APR-1000 model planned for construction in the Czech Republic would require major design modifications compared to the APR-1400 used in Korea.

Prof. Park noted that “If South Korea, which has no experience in inland nuclear power plant construction,³⁸⁶ is forced to pursue ‘low-cost orders’ and ‘on-time delivery’ and fails to meet the completion period, it will suffer losses such as huge delay compensation.”³⁸⁷

KEPCO's Continued Financial Crisis³⁸⁸

Korea Electric Power Corporation (KEPCO) was established on 1 January 1982 under the Korea Electric Power Corporation Act, with the purpose of developing electric power resources and conducting generation, transmission, transformation, distribution, and related businesses. On 1 April 2007, it was designated as a market-oriented public corporation under the Act on the Management of Public Institutions. KEPCO was listed on the Korea Exchange in August 1989 and on the New York Stock Exchange in October 1994.

As of the second quarter of 2025, KEPCO's ownership structure remains majority-controlled by the South Korean government: the Korea Development Bank—wholly owned by the government—holds 32.9 percent, while the government directly holds 18.2 percent, together amounting to 51.1 percent.

WNISR covered KEPCO's financial problems in its 2023 and 2024 editions and the crisis continues. KEPCO's total debt at the end of 2024 stood at KRW120 trillion (US\$₂₀₂₄ 88 billion) on a standalone basis and at KRW205 trillion (US\$₂₀₂₄ 150 billion) on a consolidated basis for KEPCO Group whose revenues stood at KRW93.4 trillion (US\$₂₀₂₄ 69 billion) and the profit level at KRW8.4 trillion (US\$₂₀₂₄ 6.2 billion).

384 - Ibidem.

385 - Ibidem; also Westinghouse, “Westinghouse Electric Company vs. Korea Electric Power Corp. and Korea Hydro & Nuclear Power Co. Ltd.—Complaint”, Case 1:22-cv-03228-APM, in the U.S. District Court for the District of Columbia, as released by *POWER Magazine*, filed 21 October 2022, see <https://www.powermag.com/wp-content/uploads/2022/11/westinghousecomplaintkhnp-oct21.pdf>, accessed 26 August 2025.

386 - All of the nuclear plants in South Korea and the only foreign project implemented so far, the Barakah plant in the UAE, are on the seacoast.

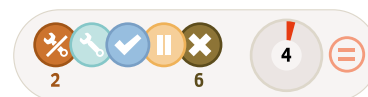
387 - 옥기원, “[단독] UAE 원전 이익률 1.6%뿐...체코 원전 경제성도 빨간불”, *The Hankyoreh*, 24 October 2024, op. cit.

388 - The Data Analysis, Retrieval, and Transfer System (DART) is Korea's corporate filings repository. Through DART, KEPCO's and KHNP's periodic reports are publicly accessible, and the summary financial statements provide consolidated and standalone figures for total debt, revenue, and operating profit from 2009 to 2024; see DART, Homepage, 2025, see <https://dart.fss.or.kr/main.do>, accessed 31 August 2025; see also KEPCO, “Korea Electric Power Corporation and Its Subsidiaries—Consolidated Financial Statements—For Each of the Two Years in the Period Ended December 31, 2024 (With Independent Auditor's Report Thereon)”, May 2025.

In South Korea, which imports most of its fossil fuels, the share of coal, gas, and oil in power generation was 66 percent in 2009 and still accounted for close to 60 percent in 2024. This heavy reliance on imports means that when global fossil fuel prices rise and the government does not allow equivalent increases in electricity tariffs, KEPCO inevitably records operating losses. To cover these losses, the company issues bonds, leading to further growth in total debt. When international fossil fuel prices surged due to Russia's invasion of Ukraine in 2022, KEPCO's debt rose sharply. The Korean government ultimately raised electricity tariffs in 2023, and thereafter KEPCO's debt level stabilized.³⁸⁹

According to KHNP's filings, from 2009 to 2024 the company has never recorded an operating deficit. However, KHNP's debt steadily increased from KRW13.5 trillion (US\$₂₀₀₉10.5 billion) in 2009 to KRW47 trillion (US\$₂₀₂₄34.5 billion) in 2024. With KEPCO Group's extraordinary debt exceeding KRW200 trillion (US\$145 billion) and KHNP's debt exceeding KRW47 trillion (US\$34.2 billion), the burden of financing the infrastructure investments required for the energy transition poses a significant challenge. Moreover, this massive debt load constrains KEPCO's and KHNP's ability to raise capital for any new investments or business ventures.

TAIWAN FOCUS



About a decade ago, 2025 was designated as the target year for achieving Taiwan's Nuclear-Free Homeland policy. As scheduled, Taiwan's last operating reactor—Maanshan-2 at the Third Nuclear Power Plant in Hengchun, Pingtung—was closed on 17 May 2025. Beginning with that date, Taiwan officially entered a “nuclear-free” era.³⁹⁰

Compared to Germany, which completed its nuclear phaseout in 2023, the case of Taiwan attracted little attention from international media. However, like in Germany, challenges to the policy have emerged in Taiwan.

First, current domestic politics are unfavorable to the nuclear phaseout decision. Pro-nuclear opposition parties have secured a majority in the Legislative Yuan, the country's parliament, and continue to advocate for restarting the operation of the Maanshan reactors. Some industrial leaders and economic advisors to President Lai have also publicly expressed support for nuclear energy.

Second, international and geopolitical factors have led to the perception of indirect costs of phasing out nuclear power. To reduce its trade deficit, the United States has pressured Taiwan to increase energy imports such as natural gas from the U.S., but it has also offered nuclear technology.

Third, public resistance to nuclear power has decreased, and confidence in nuclear energy has remained relatively high in recent years. At the same time, widespread biased information

³⁸⁹ - Ibidem; and Charles Lee, “South Korea Raises Electricity Rates for Industrial Use, While Freezing Bills for Households”, S&P Global, 23 October 2024.

³⁹⁰ - Lin Chin-Hua and Jonathan Chin, “Nation's Last Remaining Nuclear Reactor Shut Down”, *Taipei Times*, with *Central News Agency*, 18 May 2025, see <https://www.taipeitimes.com/News/front/archives/2025/05/18/2003837074>, accessed 25 May 2025; and Taipower, “Taipower's Maanshan Nuclear Power Plant Unit 2 Ceases Operation as 40-Year License Expires Diversified Dispatch with Gas and Renewables to Secure Stable Supply”, 17 May 2025, see <https://www.taipower.com.tw/2764/2804/2805/63562/normalPost>, accessed 25 July 2025.

targeting renewable energy has significantly fueled public opposition to the construction of energy facilities such as offshore wind turbines or large solar plants.

Another critical challenge is the decommissioning of nuclear plants and construction of waste disposal facilities. The outdoor dry storage facility at the Second Nuclear Power Plant in Kuosheng, New Taipei City, was originally scheduled for completion in 2017, but construction was delayed because the Soil and Water Conservation Plan was not approved by the New Taipei City Government. In August 2024, the municipal government finally approved Taipower's revised plan, and construction started on 31 December 2024. The removal of used fuel from the plant's pool is expected to start as early as 2027 pending license approval.³⁹¹ In addition, in May 2025, the dry storage facility was licensed for the Chinshan nuclear plant, also located in New Taipei City.³⁹²

In May 2024, the Ministry of Economic Affairs established the Office for Radioactive Waste Disposal.³⁹³ National Chengchi University Professor Tu Wen-ling was appointed as its director in April 2025; the office is tasked to release a legislative draft for a high-level radioactive waste disposal facility by the end of 2025.³⁹⁴

National Politics: Toward a Restart of Nuclear Plants?

After Democratic Progressive Party (DPP) candidate William Lai won the presidential election in January 2024, Chinese Nationalist Party (KMT) legislators renewed calls for scrapping the nuclear phaseout strategy.³⁹⁵ On assuming the presidency on 20 May 2024, Lai made a pledge to carry on the energy policy of President Tsai Ing-wen, his predecessor (see section on [Energy Policy](#)).

Soon after his appointment by Lai, Premier Cho Jung-tai reaffirmed that the new government “has no plans” to extend Maanshan's operational lifetime.³⁹⁶ However, he has also indicated on several occasions the government's openness to “new nuclear power” after 2030, if safety concerns associated with nuclear technology were resolved.³⁹⁷ A few weeks later, the National

391 - Taiwan Power Company, “Key Decommissioning Work at Kuosheng Nuclear Power Plant Officially Begins; Outdoor Dry Storage for Spent Nuclear Fuel Breaks Ground”, as published by the Ministry of Economic Affairs, 31 December 2024, see https://www.moea.gov.tw/MNS/english/news/News.aspx?kind=6&menu_id=176&news_id=119042, accessed 15 June 2025.

392 - 劉千綾, “核一室外乾貯運轉執照獲准 台灣核電除役新里程碑”, *Central News Agency*, 1 May 2025, see <https://www.cna.com.tw/news/afe/202505010149.aspx>, accessed 24 July 2025.

393 - Department of Energy, “經濟部主管法規共用系統-最新訊息內容, Ministry of Economic Affairs, Government of Taiwan, 10 May 2024, see <https://law.moea.gov.tw/NewsContent.aspx?id=134782>, accessed 15 June 2025.

394 - International College of Innovation, “ICI Dean Wen-Ling Tu Appointed Director of the Ministry of Economic Affairs' Office for Radioactive Waste Disposal, Leading Legislative Efforts on High-Level Radioactive Waste Management”, National Chengchi University, 15 April 2025, see <https://ici.nccu.edu.tw/news/uncategorized/ici-dean-wen-ling-tu-appointed-director-of-the-ministry-of-economic-affairs-office-for-radioactive-waste-disposal-leading-legislative-efforts-on-high-level-radioactive-waste-management/>, accessed 15 June 2025; and 曾智怡, “經部核廢處置辦公室主任底定 政大教授杜文苓擔重任”, *Central News Agency*, 11 April 2025, see <https://www.cna.com.tw/news/afe/202504110210.aspx>, accessed 25 May 2025.

395 - Hsin-han Lin and Jonathan Chin, “KMT Seeks to Scrap Rules on Nuclear Power Extensions”, *Taipei Times*, 24 January 2024, see <https://www.taipeitimes.com/News/taiwan/archives/2024/01/24/2003812551>, accessed 30 May 2024.

396 - Pei-ju Teng, Chien-ling Liu and Cheng-hsiang Fan, “Premier Rules Out Extending Life of Taiwan's Last Operational Nuclear Plant”, *Focus Taiwan/Central News Agency*, 6 July 2024, see <https://focustaiwan.tw/business/202406070015>, accessed 25 May 2025.

397 - *Liberty Times Net*, “總統府氣候變遷委員會7/25登場 卓榮泰：對新核能採開放態度”, 17 July 2024, see <https://news.ltn.com.tw/news/politics/breakingnews/4739361>, accessed 25 May 2025.

Climate Change Response Committee established under the direct authority of President Lai included both proponents and opponents of nuclear electricity.³⁹⁸

During the Committee's first meeting, President Lai stated

Twenty-plus years ago, back when I was a member of the Legislative Yuan, working across party lines I co-sponsored a draft version of the Basic Environment Act. The Act has come to be known as Taiwan's "environmental constitution," and it is the first law in Taiwan to incorporate the concept of a "nuclear-free homeland." Article 23 of the Act reads that the government shall formulate a plan to progressively achieve the goal of a nuclear-free homeland.

Although the DPP was the ruling party at that time within the executive branch, we did not have a legislative majority. The fact that we were able to get the Basic Environment Act passed by reaching a consensus between the ruling and opposition parties is proof that the concept of a nuclear-free homeland is not just an ideological stance of the DPP.³⁹⁹

Lai and the new cabinet continue however to face difficulties in stopping KMT legislators' attempts to reverse the nuclear phaseout as DPP no longer holds a majority in the Legislative Yuan; the KMT is currently the biggest party by one seat over the DPP, and it has additional support from two independent lawmakers and the Taiwan People's Party (TPP) with eight seats, making that a total of 62 seats for the opposition against 51 for the DPP.⁴⁰⁰

During Tsai Ing-wen's eight-year administration, a fierce debate erupted between the DPP and KMT over several large-scale power outages, with the KMT blaming the government's nuclear phaseout policy.⁴⁰¹ Indicators like the System Average Interruption Duration Index (SAIDI) do not suggest any correlation with the closure of nuclear power plants. For example, between 2018 and 2020, the SAIDI was higher than in 2023 and 2024.⁴⁰² Nevertheless, in July 2024 (still under the Tsai administration), the KMT proposed an amendment to the Nuclear Reactor Facilities Regulation Act to extend the operating lifetime of nuclear reactors by 20 years to 60 years, but the amendment did not garner sufficient support during the standing committee's review.⁴⁰³

The KMT has found a new window of opportunity with its current majority in the Legislative Yuan. In March 2025, KMT and TPP lawmakers jointly proposed draft amendments to relax the deadline for license renewal applications and to extend the reactor operational limit to

398 - Paul Jobin, "The National Committee on Climate Change: Also a Security Issue", *Taiwan Insight*, University of Nottingham, 28 August 2024, see <https://taiwaninsight.org/2024/08/28/the-national-committee-on-climate-change-also-a-security-issue/>, accessed 25 May 2025.

399 - Office of the President, "President Lai Presides Over First Meeting of National Climate Change Committee", Government of Taiwan, 8 August 2024, see <https://english.president.gov.tw/News/6793>, accessed 15 June 2025.

400 - Alison Hsiao, "No Party Gets Legislative Majority; Small TPP to Play Key Role", *Focus Taiwan/Central News Agency*, 13 January 2024, see <https://focustaiwan.tw/politics/202401130019>; and 鍾麗華, "總統府氣候變遷委員會7/25登場 卓榮泰: 對新核能採開放態度", *Liberty Times Net*, 17 July 2024, see <https://news.ltn.com.tw/news/politics/breakingnews/4739361>; both accessed 25 May 2025.

401 - Erin Hale, "Taiwan's Tsai Faces Hot Summer Votes Over Pork and Nuclear Power", *Nikkei Asia*, 15 June 2021, see <https://asia.nikkei.com/politics/taiwan-s-tsai-faces-hot-summer-votes-over-pork-and-nuclear-power>; and M. Chuang, "MOEA, Taipower Submit Blackout Report 303", *Public Television System*, 7 March 2022, see <https://news.pts.org.tw/article/570573>; both accessed 12 August 2025.

402 - Taipower, "Major Operating Performance Indicators in the Past 10 Years", Taiwan Power Company, 10 July 2025, see <https://www.taipower.com.tw/2764/2826/2835/2841/25121/>, accessed 22 August 2025.

403 - 林靜梅 and 林志堅, "藍委擬修《核管法》 提5版本盼核電延役", 公視新聞網, 10 July 2024, see <https://news.pts.org.tw/article/704203>, accessed 25 May 2025.

60 years, theoretically paving the way for restarting the Maanshan plant.⁴⁰⁴ In response to a KMT legislator's question, Minister of Economic Affairs Kuo Jyh-huei stated that Taiwan would need to acquire new fuel elements to continue operations, a process that would take at least 16 to 18 months.⁴⁰⁵ Although DPP legislators repeatedly raised concerns over unresolved nuclear waste and safety issues, they were ultimately outnumbered by the opposition,⁴⁰⁶ and the amendment passed on 13 May 2025—just four days before the scheduled closure of Maanshan Unit 2.⁴⁰⁷ The actual implementation of this amendment still requires additional procedures and safety checks proposed by Taipower, and no final decision has been made regarding the need for further Environmental Impact Assessments (EIAs).

The proposed restart also raised another issue rooted in the legacy of nuclear development in Taiwan. As the retiring reactors were constructed under the KMT's authoritarian regime prior to the 1980s, they were exempt from EIAs. As a result, there is no legal precedent for how to conduct an EIA for the reactivation of closed reactors. The day after the amendment passed, Minister of Environment Peng Chi-ming stated before the Legislative Yuan's Committee on Social Welfare and Environmental Hygiene that he found no existing legal framework to guide such reactivation. DPP legislator Lin Shu-fen supplemented that reactivation should follow the existing regulations for infrastructure development projects; consequently, not only is it required to conduct an evaluation of the cost, but also an environmental impact assessment.⁴⁰⁸ Since the plant's license has expired and there is no direct capacity for operation, if a restart is requested, inspections and evaluations will be carried out but the Nuclear Safety Commission could reject the restart application for safety concerns.⁴⁰⁹

Pro-nuclear lobbying had experienced a major setback in December 2021, when a proposal to resume the construction of two reactors at the Fourth Nuclear Power Plant in Lungmen was rejected in a referendum, indicating popular support for a nuclear-free policy at the time.⁴¹⁰ Regardless of the vote's outcome though, the plant was unlikely to be completed or become operational due to the dire state of the project (see past *WNISR* editions).

More recently, some business leaders and KMT politicians have promoted the idea of deploying Small Modular Reactors (SMRs) “in every administrative region of Taiwan.”⁴¹¹ Environmental organizations such as Green Citizens' Action Alliance (GCAA) and Citizen of the Earth,

404 - Legislative Yuan, 立法院第114卷第33期 (5326), Parliament of Taiwan, released 23 April 2025, see <https://ppg.ly.gov.tw/ppg/publications/official-gazettes/114/33/01/details>, accessed 15 June 2025.

405 - Jake Chung, “Legislators Pass Nuclear Power Bill”, *Taipei Times*, 14 May 2025, see <https://www.taipeitimes.com/News/front/archives/2025/05/14/2003836840>, accessed 25 May 2025.

406 - 李蘇竣, “藍白聯手通過《核管法》初審 九版本擬放寬核電換照年限”, Environmental Information Center, 31 March 2025, see <https://e-info.org.tw/node/241028>, accessed 25 May 2025.

407 - Legislative Yuan, “立法院第 11 屆第 3 會期第 11 次會議紀錄”, Parliament of Taiwan, 立法院公報, Vol. 114, No. 44, May 2025, see https://ppg.ly.gov.tw/ppg/PublicationBulletinDetail/download/communique1/final/pdf/114/44/LCIDC01_1144405_00001.pdf, accessed 15 June 2025.

408 - 陳昭宏, “「核電延役免環評」彭啟明也覺奇怪 立委呼籲環境部修法”, Environmental Information Center, 14 May 2025, see <https://e-info.org.tw/node/241283>, accessed 21 August 2025.

409 - James Thompson and Ya-Yen Tsao, “EXPLAINER/Taiwan's Aug. 23 Nuclear Power Referendum”, *Focus Taiwan/Central News Agency*, 11 August 2025, see <https://focustaiwan.tw/politics/202508110015>, accessed 11 August 2025.

410 - Ben Blanchard, “Taiwan Referendums Fail in Major Setback for Opposition”, *Reuters*, 18 December 2021, see <https://www.reuters.com/markets/commodities/taiwan-opposition-hopes-boost-contentious-referendums-2021-12-18/>, accessed 25 May 2025.

411 - Jason Pan, “KMT Backs Terry Gou's Taiwan-Wide Nuclear Plan”, *Taipei Times*, 5 June 2023, see <https://www.taipeitimes.com/News/taiwan/archives/2023/05/06/2003799264>, accessed 25 May 2025.

Taiwan, have argued that in addition to further worsening the problem of nuclear waste,⁴¹² SMRs would be too slow and too expensive to efficiently address the climate crisis.⁴¹³

The latest initiative from the KMT-TPP coalition to reverse the nuclear phaseout is a referendum scheduled for 23 August 2025 on the following question: “Do you agree that the Third Nuclear Power Plant [Maanshan] should continue operating, provided that the competent authority confirms there are no safety concerns?”⁴¹⁴ The question is confusing: since the plant has already been closed, it cannot “continue operating”; it can only be *restarted*. On the same day another vote is to be held to decide on the recall of seven KMT lawmakers, following a first vote on 26 July 2025 for 24 KMT lawmakers. This recall movement results from the national mobilization of civil society organizations, started in May 2024, to reverse the balance of power at the Legislative Yuan on the claim that the KMT-TPP coalition is threatening the island’s sovereignty by making excessive concessions to Beijing.⁴¹⁵

International Political Pressure

Another major factor influencing Taiwan’s nuclear phaseout policy is its diplomatic environment and geopolitical concerns, particularly the relationship with its most important ally, the United States. Following his inauguration, U.S. President Donald Trump swiftly initiated a trade war by imposing tariffs on many countries. In response, the U.S.’ East Asian allies—Japan, South Korea, and Taiwan—swiftly signed agreements to access liquefied natural gas (LNG) from a future project in Alaska.⁴¹⁶ On 20 March 2025, Raymond F. Greene, the director of the American Institute in Taiwan (AIT, the *de facto* embassy), mentioned that the U.S. could provide Taiwan with “the full range of energy solutions from geothermal to nuclear to advanced grid technologies” and declared that the Trump administration was “especially eager to share [...] LNG resources with close partners.”⁴¹⁷

Tung Tzu-hsien, a pro-nuclear businessman and member of President Lai’s National Climate Change Committee, quickly reacted to Greene’s remarks, arguing that Taiwan should revise its nuclear regulatory laws to accommodate the expansion of its energy portfolio.⁴¹⁸

412 - 吳柏軒, “綠盟: 全球再生能源超越核電、SMR比傳統更多核廢料”, *Liberty Times Net*, 29 March 2023, see <https://news.ltn.com.tw/news/life/breakingnews/4254756>, accessed 25 May 2025.

413 - Jake Chung, “Taiwan’s Nuclear Energy Policy Needs Clarity: Group”, *Taipei Times*, 20 February 2025, see <https://www.taipeitimes.com/News/front/archives/2025/02/20/2003832177>, accessed 21 August 2025.

414 - Kuo Chien-shen, Chang Hsiung-feng and Sunny Lai, “Maanshan Nuclear Plant Restart Referendum Proposal Clears Legislature”, *Central News Agency*, 20 May 2025.

While almost three quarters of the votes were in favor of restart, the proposal was rejected because the favorable votes did not reach the legal quorum of one quarter of the total number of eligible voters; see CNA, “Referendum on Extending No. 3 Nuclear Power Plant Operation Defeated”, 23 August 2025, see <https://focustaiwan.tw/politics/202508230015>, accessed 2 September 2025.

415 - Teng Pei-ju, “Taiwan’s Recall Movement: Power Play or Popular Outrage?”, *Focus Taiwan/Central News Agency*, 27 March 2025, see <https://focustaiwan.tw/politics/202503270021>, accessed 1 July 2025.

416 - River Akira Davis, “Trump’s Tariff Threats Revive Interest in \$44 Billion Alaska Gas Project”, *The New York Times*, 27 February 2025, see <https://www.nytimes.com/2025/02/27/business/trump-tariffs-alaska-lng-japan.html>; and Wen-Yee Lee, Yimou Lee, and Florence Tan, “Aiming for Energy Security, Taiwan Seeks to Invest in Alaska LNG Project”, *Reuters*, 20 March 2025, see <https://www.reuters.com/business/energy/taiwans-cpc-seeks-invest-project-buy-alaska-lng-2025-03-20/>, both accessed 16 June 2025.

417 - American Institute in Taiwan, “AIT Director Raymond Greene’s Remarks at the American Chamber of Commerce in Taiwan 2025 Hsieh Nian Fan Banquet”, American Institute in Taiwan, 20 March 2025, see <https://www.ait.org.tw/ait-dir-greenes-remarks-at-the-amcham-2025-hsieh-nian-fan/>, accessed 25 May 2025.

418 - 吳家豪, “合立言談核能 董子賢: 是MAGA很好的推銷員”, *Central News Agency*, 25 March 2025, see <https://www.cna.com.tw/news/aie/202503250312.aspx>, accessed 25 May 2025.

Regarding potential products, AIT officials provided a comprehensive list without limiting it to specific items. In an interview, Greene added SMRs and services related to nuclear waste management to his proposed energy package.⁴¹⁹ Although the policy remains ambiguous, Lai's government's reluctance is palpable. On 17 April 2025, KMT legislator Chen Ching-hui questioned Environment Minister Peng Chi-ming about the possibility of Taiwan purchasing SMRs from the U.S. as a “bargaining chip” in tariff negotiations. Peng responded that he had not been involved in such discussions but emphasized the high cost, potential supply chain issues, and technological challenges of SMRs, all of which require public dialogue. He also cautioned that Taiwan's aging nuclear plants lack environmental impact assessments, raising safety concerns. Peng reiterated the government's openness to discussion but stressed that Taiwan lacks the regulatory mechanisms, technical capacity, and social consensus for restarting nuclear power, calling it a complex and lengthy process.⁴²⁰

Energy Policy

Public opposition to nuclear power in Taiwan reached a new high immediately after the Fukushima disaster was triggered in March 2011.⁴²¹ Sending shock waves through Taiwan, the event increased public acceptance for a nuclear phaseout and an energy transition. Having returned to power in 2016, the DPP announced the New Energy Policy aimed at establishing “a low carbon, sustainable, stable, high-quality and economically efficient energy system” through an energy transition and energy industry reform.⁴²² On 12 January 2017, the Electricity Act Amendment completed its third reading in the legislature, ushering Taiwan's energy transition, including the nuclear phaseout.⁴²³

During the second term of Tsai's presidency (2020–24), Taiwan aspired to become a leading country of renewable energy in the Asia-Pacific region.⁴²⁴ The island's renewable energy potential is significant, and in 2021, the Global Wind Energy Council estimated Taiwan's offshore wind technical potential to be as high as 494 GW.⁴²⁵ In 2019, the government set the goal to install 5.7 GW of offshore wind capacity by the end of 2025.⁴²⁶ In May 2021, the target was increased to 15 GW with annual deployment of 1.5 GW over the decade. The target has

419 - Tzou Jiing-wen, Huang Ching-hsuan and Esme Yeh, “US Will Make Taiwan Stronger: Greene”, *Taipei Times*, 11 March 2025, see <https://www.taipetimes.com/News/front/archives/2025/03/11/2003833222>, accessed 24 July 2025.

420 - Legislative Yuan, “立法院公報第114卷第38期委員會紀錄”, Parliament of Taiwan, 7 May 2025, see https://ppg.ly.gov.tw/ppg/PublicationOfficialGazettes/download/communique1/final/pdf/114/38/LCIDCo1_1143801.pdf, accessed 24 July 2025.

421 - Ho Ming-sho, “The Fukushima Effect: Explaining the Resurgence of the Anti-Nuclear Movement in Taiwan”, *Environmental Politics*, 2 November 2014.

422 - Ministry of Economic Affairs, “Taiwan's New Energy Policy”, Government of Taiwan, April 2017.

423 - Bureau of Energy, “電業法修正案三讀通過 經長：綠電先行，邁向2025非核家園的里程碑”, Ministry of Economic Affairs, Government of Taiwan, 12 January 2017, see https://www.twtpo.org.tw/activity_show.aspx?category_id=70&cat_id=72&id=3160, accessed 25 May 2025.

424 - Energy Taiwan, “2020 Energy Taiwan Commenced as Taiwan Become Hot Spot for Global Green Energy Investment”, *Energy Trend*, 15 October 2020, see <https://www.energytrend.com/news/20201015-19621.html>, accessed 25 May 2025.

425 - Global Wind Energy Council, “Offshore Wind Technical Potential in Taiwan”, June 2021, see https://marketintelligence.gwec.net/wp-content/uploads/2021/06/Taiwan_Offshore-Wind-Technical-Potential_GWEC-OREAC.pdf, accessed 10 August 2025.

426 - Ministry of Economic Affairs, “展綠、增氣、減煤、非核”, Government of Taiwan, 2019, see https://www.moea.gov.tw/MNS/populace/Policy/Policy.aspx?menu_id=32800&policy_id=9 accessed 8 August 2025; and Executive Yuan, “Wind Power Program Key to Achieving Nuclear-Free Homeland”, Press Release, 16 May 2019, see <https://english.ey.gov.tw/Page/61BF20C3E89B856/0a648ac9-8aa6-4a58-a2d1-10a544ee2da0>, accessed 21 August 2025.

been confirmed in 2023.⁴²⁷ Nevertheless, targets for end-2025 placed solar capacity at 20 GW and combined renewable energy generation at 20 percent of the power mix.⁴²⁸

These goals remained ambitious, especially since until a significant boost in 2022, the development of renewable energy had been slow. In 2022, the installed renewable energy capacity reached 14.1 GW, representing 23 percent of installed capacity, and renewable power generation increased by 36 percent to reach 23.9 TWh, contributing 8.3 percent of the total electricity production. The year 2022 marked the first time that the share of renewable energy—including geothermal, biomass, waste, and hydro—in total electricity production slightly surpassed nuclear power (8.3 percent versus 8.2 percent), with a 163-percent increase in offshore wind power generation compared to the previous year and a 57-percent increase in total wind production.⁴²⁹

The trend continued in 2024 with the share of renewable energy in total electricity production reaching 11.7 percent—compared to nuclear power’s 4.2-percent contribution—mainly generated by solar at 5 percent and wind at 4 percent (onshore and offshore combined). Solar production was up 18.5 percent while wind power generation jumped 68.5 percent compared to the previous year. The installed capacity of renewable energies reached 21 GW up from 18 GW in 2023.⁴³⁰ The deployment acceleration has also been noted by investors. Taiwan again moved up two places in the Ernst & Young’s “Renewable Energy Country Attractiveness Index 2023” to rank 24th in 2023,⁴³¹ and it maintained that position in 2024.⁴³²

However, as of mid-2025, Taiwan remains a fair step away from its goals—solar PV capacity is at 14.8 GW, wind at 4 GW, and the contribution of renewables to total power generation stands at 13 percent,⁴³³ compared to the respective targets of 20 GW, 4.7 GW and 20 percent. The country remained heavily dependent on imported fossil fuels in 2024 with an overall primary energy dependence rate of 95.2 percent. In electricity generation, LNG and coal combined made up over 80 percent in 2024. LNG-generated electricity shot up from less than 40 TWh in 2004 (and less than 20 TWh in 2000) to 122.5 TWh in 2024, contributing the largest portion of total electricity generation at 42.4 percent, now above coal’s 39.2 percent (see [Figure 41](#)).⁴³⁴

427 - Bureau of Energy, “Taiwan’s Offshore Wind Market Matures, Continually Attracting International Developers”, Ministry of Economic Affairs, Government of Taiwan, 10 April 2023, see <https://ncsd.ndc.gov.tw/Fore/nsdn/archives/news/detail?id=2114ebe2-da26-45dc-9882-2d1fd9dcb6d>, accessed 25 May 2025.

428 - Energy Administration, “Energy Transition Promotion Scheme—Promote Green Energy, Increase Nature Gas, Reduce Coal-fired, Achieve Nuclear-free”, Ministry of Economic Affairs, Government of Taiwan, Undated, see https://www.moea.gov.tw/MNS/english/Policy/Policy.aspx?menu_id=32904&policy_id=19, accessed 25 May 2025; and Energy Administration, “經濟成長力道強 2025 年再生能源裝置量目標不變”, Ministry of Economic Affairs, 3 January 2023, see https://www.moeaea.gov.tw/ecw/populace/news/News.aspx?kind=9&menu_id=4360&news_id=24010, accessed 21 August 2025.

429 - Bureau of Energy, “Energy Statistics Handbook 2022”, Ministry of Economic Affairs, Government of Taiwan, 21 June 2023, see https://www.esist.org.tw/publication/handbook/handbook_2023/2023EnergyStaHandBook.pdf, accessed 25 May 2025.

430 - Energy Administration, “Energy Statistics Handbook 2024”, Ministry of Economic Affairs, Government of Taiwan, 2025, see <https://www.esist.org.tw/attachments/handbook/2024/ebook/2024EnergyStaHandBook.pdf>, accessed 10 August 2025.

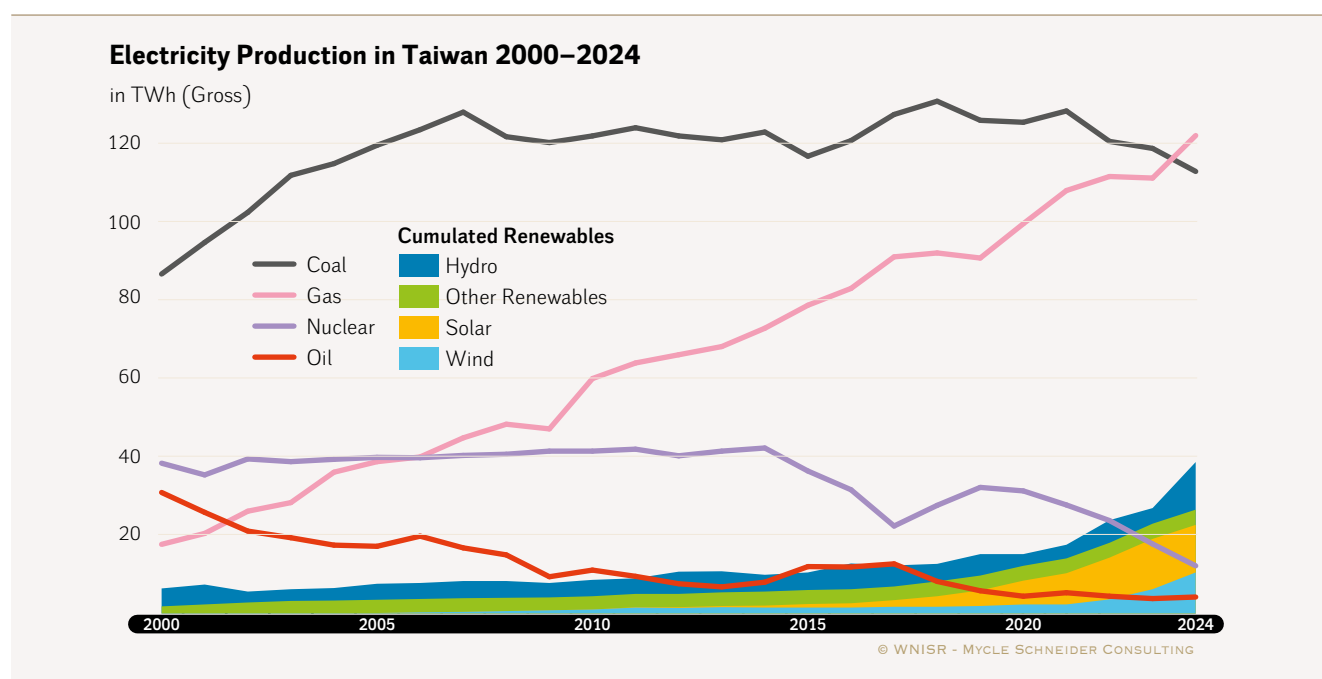
431 - EY, “Renewable Energy Country Attractiveness Index (RECAI)—62nd Edition”, Ernst & Young, November 2023, see <https://www.ey.com/content/dam/ey-unified-site/ey-com/en-gl/insights/energy-resources/documents/ey-recal-62-v9-final.pdf>, accessed 31 May 2024.

432 - EY, “Renewable Energy Country Attractiveness Index (RECAI)—63rd Edition”, Ernst & Young, June 2024, see <https://www.ey.com/content/dam/ey-unified-site/ey-com/en-gl/insights/energy-resources/documents/ey-gl-recal-63-report-06-2024.pdf>, accessed 25 May 2025.

433 - Energy Administration, Homepage, Ministry of Economic Affairs, Government of Taiwan, see <https://www.esist.org.tw/>, accessed 21 August 2025.

434 - Energy Administration, Ministry of Economic Affairs, “Energy Statistics Handbook 2024”, Ministry of Economic Affairs, 2025, op. cit.

Figure 41 - Electricity Production in Taiwan, 2000–2024



Source: MOEA, Energy Handbook, Various Years

Despite not being able to participate in the Paris Agreement and COP negotiations, in April 2021 the Taiwanese government unilaterally pledged to achieve Net-Zero by 2050, announcing that it would draft regulations to that end and accelerate the implementation of existing targets.⁴³⁵ In 2023, Taiwan promulgated the Climate Change Response Act, which replaced the former Greenhouse Gas Reduction and Management Act of 2015, making legally binding the goal of Net-Zero by 2050.⁴³⁶ On 29 August 2024, Taiwan's Ministry of Environment finalized three regulations for the carbon tax system, officially launching the carbon pricing era. Carbon fees will begin in 2025, based on that year's emissions, with payments collected from 2026 onward. The system allows emitters time to plan and meet 2030 reduction targets through voluntary reduction plans.⁴³⁷

Per capita energy consumption has hardly gone down over the past decade, while per capita electricity consumption increased by 14 percent over the decade 2013–2022, decreased slightly by 1.2 percent in 2023, and went back up in 2024 by 2.6 percent year-on-year.⁴³⁸ Peak load experienced the strongest growth rate at 19.5 percent over that decade to exceed 40 GW for the

⁴³⁵ - Office of the President of Taiwan, "President Tsai Addresses COP26 Taiwan Day Event", 7 November 2021, see <https://english.president.gov.tw/NEWS/6186>, 25 May 2025.

⁴³⁶ - Climate Change Administration, "Foundations of Climate Legislation", Ministry of Environment, Government of Taiwan, Updated 29 March 2025, see <https://www.cca.gov.tw/en/affairs/response-policies/climate-legislation/2025.html>, accessed 16 June 2025.

⁴³⁷ - Climate Change Administration, "核心業務—碳費專區", Ministry of Environment, Government of Taiwan, 9 August 2025, see <https://www.cca.gov.tw/affairs/carbon-fee-fund/2301.html>, accessed 9 August 2025.

⁴³⁸ - Bureau of Energy, "Energy Statistics Handbook 2022", Ministry of Economic Affairs, 21 June 2023, op. cit.; and Energy Administration, "Energy Statistics Handbook 2024", Ministry of Economic Affairs, Government of Taiwan, 2025, op. cit.

first time in 2022.⁴³⁹ Hitting a new record in July 2024 at 41.4 GW, it has since remained just below that, reaching 40.9 GW on 2 July 2025.⁴⁴⁰

The previous government's strategy aimed to “promote green energy, increase natural gas, reduce coal-fired power, and achieve nuclear-free.”⁴⁴¹ This implies that Taiwan would have continued to see a substantial increase in natural gas consumption aiming to provide 50 percent of gross electricity production in 2025, compared to 42.4 percent achieved in 2024.⁴⁴²

In March 2022, Taiwan's Pathway to Net-Zero Emissions in 2050 was unveiled.⁴⁴³ The strategy was based on a NT\$900 billion (US\$₂₀₂₂32.4 billion) budget to 2030, of which NT\$210.7 billion (~US\$₂₀₂₂7.6 billion) were allocated to “renewables and hydrogen”, and another NT\$207.8 billion (~US\$₂₀₂₂7.5 billion) were to be invested in “grid and energy storage”. The associated goals included a total of 40 GW of combined wind and solar capacity by 2030, and by 2050, an installed capacity of 40–80 GW in solar and 40–55 GW of offshore wind, for a combined share of more than 60 percent.

Under the presidency of William Lai, the new DPP government is expected to follow the preceding administration's footsteps for the energy transition, but tensions in national and international politics might render implementation more challenging. Another problem is the gap between the reality of nuclear energy and its public representations as shown in a series of surveys such as Academia Sinica's Taiwan Social Change Survey Programme.⁴⁴⁴

Public Attitudes and Misinformation

The Fukushima disaster of 2011 had a strong impact on public opinion in Taiwan.⁴⁴⁵ However, according to a 2024 analysis, in recent years, the percentage of respondents who agreed or strongly agreed that nuclear power plants posed a high risk which was nearing 80 percent in 2017 dropped to 64.3 percent in 2019, 66.5 percent in 2021, and 62.6 percent in 2022.⁴⁴⁶

Meanwhile, although in 2017, the share of nuclear power had already fallen to less than 10 percent—the first time in over four decades—a large proportion of citizens believed that nuclear energy was Taiwan's primary source of electricity. In a 2018 survey conducted by the

439 - Eric Chang, “Taiwan Electricity Use Surpasses 40 GW for First Time”, *Taiwan News*, 21 July 2022, see <https://www.taiwannews.com.tw/news/4602212>, accessed 25 May 2025.

440 - Taipower, “Estimated Peak Percent Operating Reserve of Today”, 9 August 2025, see https://www.taipower.com.tw/do06/loadGraph/loadGraph/load_reserve_E.html, accessed 9 August 2025.

441 - Energy Administration, “Energy Transition Promotion Scheme—Promote Green Energy, Increase Nature Gas, Reduce Coal-fired, Achieve Nuclear-free”, Ministry of Economic Affairs, Undated, see https://www.moea.gov.tw/MNS/english/Policy/Policy.aspx?menu_id=32904&policy_id=19, accessed 25 May 2025.

442 - Energy Administration, “Energy Statistics Handbook 2024”, 2025, op. cit.

443 - Climate Change Administration, “Net Zero Roadmap”, Undated, Ministry of Energy, Government of Taiwan, see <https://www.cca.gov.tw/en/climatetalks/net-zero-roadmap/1891.html>, accessed 16 June 2025.

444 - Thung-Hong Lin, Keng-Ming Hsu and Hsin-Huang Michael Hsiao, “減碳社會學 台灣淨零轉型的民意與挑戰”, 巨流圖書公司, 2024; and 蕭新煌, 許耿銘 and 林宗弘, “2024台灣減碳與非核民意的疑點”, 自由時報, 19 January 2025, see <https://talk.ltn.com.tw/amp/article/paper/1688091>, accessed 25 May 2025; also Fu Yang-Chih, “2019 Taiwan Social Change Survey (Round 7, Year 5): Technology and Risk Society (C00351_2)”, Survey Research Data Archive, Academia Sinica, November 2020, see https://doi.org/10.6141/TW-SRDA-C00351_2-1, accessed 24 June 2025.

445 - Ming-Sho Ho, “The Fukushima effect: explaining the resurgence of the anti-nuclear movement in Taiwan”, *Environmental Politics*, 2014, see <https://doi.org/10.1080/09644016.2014.918303>, accessed 10 August 2025.

446 - Thung-Hong Lin, Keng-Ming Hsu, and Hsin-Huang Michael Hsiao, “Sociology of Decarbonization: The Public Opinion and Challenges of Taiwan's Net-Zero Transition”, *Chuliu Book Co.*, 2024, pp. 27–28.

Risk Society and Policy Research Center, National Taiwan University, although 82 percent of respondents expressed concern about the development of Taiwan's energy policy, only 32 percent correctly identified coal-fired power as Taiwan's primary source of electricity and 44 percent believed that nuclear power contributed the largest share.⁴⁴⁷ This view persists: in a poll conducted by Pearson on behalf of media portal *Tai Sounds*, in April 2024 more than half of respondents (53.4 percent) still considered nuclear power one of Taiwan's top three sources of electricity.⁴⁴⁸ Another survey conducted at the end of 2024, highlighted a strong risk perception of global warming, yet fewer than 20 percent of respondents correctly identified nuclear power's low share (below 10 percent), while nearly 25 percent of college-educated respondents believed it accounted for over 51 percent of Taiwan's electricity mix.⁴⁴⁹

The general misconception regarding nuclear, partly rooted in education during the peak of nuclear energy, has led to an overestimation of nuclear power's significance in the supply mix. Misinformation from pro-nuclear advocates and the media has further undermined public confidence in Taiwan's nuclear-free policy,⁴⁵⁰ leaving public opinion evenly split (~50 percent support/opposition). According to research projects supported by Academia Sinica from 2017 to 2024, notably, women, less-educated citizens, and the DPP supporters were more likely to favor a nuclear-free homeland, while men, higher-educated individuals, and the KMT supporters prioritized decarbonization and energy security over nuclear risks—resulting in a prevailing sense of “nuclear-free anxiety.”⁴⁵¹

Misperceptions about nuclear waste management are also widespread. According to the 2019 Taiwan Social Change Survey (Round 7) led by researchers at Academia Sinica, on behalf of the National Science Council, which focused on technology and risk, only less than 12 percent of respondents were aware that Taiwan's high-level radioactive nuclear waste (spent fuel) was currently stored at nuclear power plants.⁴⁵² Interestingly, the survey also found that supporters of the statement “we shall keep using nuclear energy,”—53 percent in this survey—did not demonstrate better knowledge of nuclear waste management than those in favor of a nuclear phaseout; in both categories, only 14 percent had the right answer.⁴⁵³

Taiwan has recently been targeted by foreign disinformation campaigns aimed at undermining its energy policy. As a recent study on climate and energy misinformation in Taiwan highlights, disinformation about nuclear power has become a significant force shaping public discourse,

447 - Risk Society and Policy Research Center, “Taiwan Risk Society Forum: How Can We Rebuild Social Trust In Energy Transition After Taiwan's Referendum?”, National Taiwan University, 17 December 2018, see https://rsprc.ntu.edu.tw/web/research/research_study_list_in.jsp?lang=en&rp_id=RP1749181972938, accessed 16 June 2025.

448 - 洪敏隆, “【電價態度調查4-3】近3成以為核電是台灣主要供電來源 綠能核能兩派對如何穩定供電沒交集”, *Tai Sounds*, 6 May 2024, see <https://www.taisounds.com/specialtopic/content/115/123200>, accessed 25 May 2025.

449 - 蕭新煌, 許耿銘 和 林宗弘, “2024台灣減碳與非核民意的疑點”, 自由時報, 19 January 2025, op. cit.

450 - Ming-Sho Ho, “Aiming for Achilles' Heel: A relational explanation of the ascendancy of pro-nuclear activism in Taiwan, 2013–2020”, *Social Movement Studies*, 2 November 2023.

451 - 蕭新煌, 許耿銘 和 林宗弘, “2024台灣減碳與非核民意的疑點”, 自由時報, 19 January 2025, see <https://talk.ltn.com.tw/amp/article/paper/1688091>, accessed 25 May 2025.

452 - The respondents were given two options, onsite or on Orchid Island (Lanyu) in Taitung County: 41 percent thought it was on the island and 47 percent did not know with only 12 percent knowing the right answer.

453 - Yang-Chih Fu, “2019 Taiwan Social Change Survey (Round 7, Year 5): Technology and Risk Society (C00351_2)”, Survey Research Data Archive, Academia Sinica, 2020, see https://doi.org/10.6141/TW-SRDA-C00351_2-1, accessed 25 May 2025.

particularly amid Taiwan's efforts to phase out nuclear energy under the 2025 Nuclear-Free Homeland Plan.⁴⁵⁴

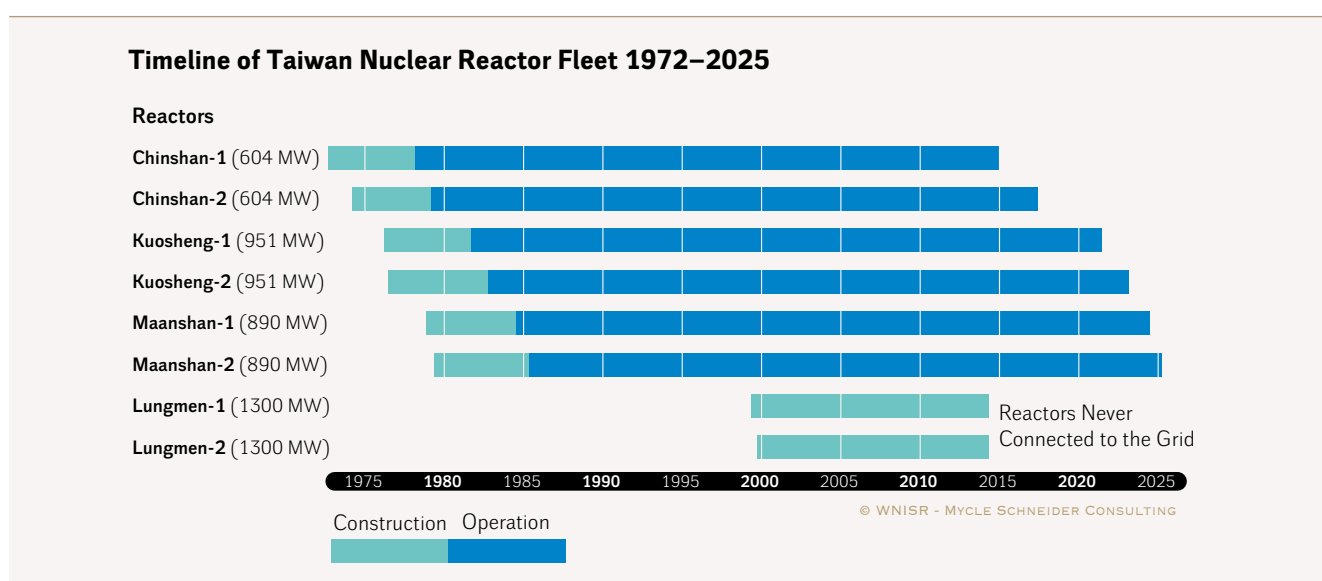
Reactor Closures and Spent-Fuel Management

As reported in previous *WNISR* editions, Taipower announced the closure of Chinshan-1 on 5 December 2018. The reactor had not generated power since the end of 2014. Chinshan-2 had been off-grid since June 2017, but was not officially closed until 15 July 2019, when its 40-year operating license expired.

On 1 July 2021, Taipower stated that due to lack of spent-fuel storage-capacity, Kuosheng-1 was closed six months ahead of schedule.⁴⁵⁵ The closure of the reactor, located on the northern coast, only 22 km away from Taipei, was originally slated for 27 December 2021, the day its operating license expired.⁴⁵⁶ Kuosheng-2 ceased operating on 14 March 2023.

Finally, the remaining two PWRs at Maanshan closed on 26 July 2024 and 17 May 2025, respectively. In line with the nuclear phaseout and current regulation, the application to disconnect the units from the grid had been submitted in July 2021.⁴⁵⁷ (See *Figure 42*.)

Figure 42 · Histogram of Taiwan Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2025

⁴⁵⁴ - John Chung-En Liu and Chia-Fen Lee, "Climate and Energy Misinformation in Taiwan", Department of Sociology, and International Degree Program in Climate Change and Sustainable Development, National Taiwan University, in *Frontiers in Communication*, 10 January 2025, see <https://www.frontiersin.org/articles/10.3389/fcomm.2024.1531126/full>, accessed 25 May 2025.

⁴⁵⁵ - Taipower, "核二1號機燃料池滿今提前停機 台電：歲修機組陸續歸隊與民營電廠機組加入，持續確保供電無虞", 1 July 2021, Taiwan Power Company, see <https://www.taipower.com.tw/2289/2323/2324/7730/normalPost>, accessed 25 May 2025.

⁴⁵⁶ - WNN, "Early Shutdown for Taiwanese reactor", *World Nuclear News*, 1 July 2021, see <https://www.world-nuclear-news.org/Articles/Early-shutdown-for-Taiwanese-reactor>, accessed 25 May 2025.

⁴⁵⁷ - NEI Magazine, "Taipower Applies to Close Down Maanshan NPP", 29 July 2021, see <https://www.neimagazine.com/news/taipower-applies-to-close-down-maanshan-npp-8946136>, accessed 25 May 2025.

Despite the fact that the spent-fuel pools of the Chinshan and Kuosheng power plants have been filling up, the government made little effort to arrange dry cask storage for the high-level radioactive waste and little more than 1 percent of the fuel has been taken out of the pools (see Table 10). Successive governments paid little attention to intermediate storage and final disposal of spent fuel.⁴⁵⁸ In 2023, GCAA and other environmental groups lobbied in vain to legislate on the issue.⁴⁵⁹

Table 10 · Spent Fuel at Taiwan's Nuclear Power Plant Sites

Site / Unit	Grid Connection/ Closure	Spent Fuel at Taiwan's Nuclear Sites (in Numbers of Fuel Assembly)			
		Reactor Core	Spent-Fuel Pool	Dry Storage Facility	Total
Chinshan-1	1977/2014	54	3,056	280	6,874
Chinshan-2	1978/2017	408	3,076		
Kuosheng-1	1981/2021	624	4,808	NA	10,868
Kuosheng-2	1982/2023	624	4,812		
Maanshan-1	1984/2024	0	1,879	NA	3,785
Maanshan-2	1985/2025	0	1,906		

Source: IAEA-PRIS (grid connection years) and Nuclear Safety Commission, 2025⁴⁶⁰

Reactor closures, in general, have not ushered in the actual technical decommissioning phase, the bulk of which would come only after the spent-fuel assemblies have been unloaded from the cores and pools and placed in dry cask facilities.

The operating license for Unit 1 of the First Nuclear Power Plant (Chinshan) expired in December 2018, leading to its official closure. To prepare for decommissioning of Chinshan-1, Taipower proposed a plan to establish a dry cask storage facility, adopting a system certified by the U.S. Nuclear Regulatory Commission (NRC). The associated Soil and Water Conservation Plan was approved by the New Taipei City Government in 2010 and completed in 2013. However, following the completion, Taipower submitted 13 applications for subsequent detailed design modifications for review, all of which were rejected by the government of New Taipei City.⁴⁶¹ In April 2014, the city's government formally rejected the entire project and refused to grant approval. During this period, New Taipei City was governed by Mayor Eric Chu, KMT, who is current chairman of the party.⁴⁶²

Following a decade long legal battle, on 16 March 2023, the Taipei High Administrative Court ruled in favor of Taipower, ordering the New Taipei City Government to approve Taipower's

458 - NSC, "Spent Fuel Storage Status", Spent Fuel Dry Storage Regulations, Nuclear Safety Commission, 29 July 2025, see <https://www.nusc.gov.tw/english/Fuel-Cycle-and-Materials-Regulation/Spent-Fuel-Storage-Status-175.html>, accessed 9 August 2025.

459 - François Bougon, "À Taiwan, la sortie du nucléaire laisse des traces", *Mediapart*, 8 May 2023, see <https://www.mediapart.fr/journal/international/080523/taiwan-la-sortie-du-nucleaire-laisse-des-traces>, accessed 25 May 2025.

460 - NSC, "Spent Fuel Storage Status (July 2025)", Nuclear Safety Commission, Updated 29 July 2025, see <https://www.nusc.gov.tw/english/Fuel-Cycle-and-Materials-Regulation/Spent-Fuel-Storage-Status-175.html>, accessed 21 August 2025.

461 - 黃怡菁 and 郭俊麟, "核一核廢暫存計畫 遭新北市退件13次", 公視新聞網, 23 May 2018, see <https://news.pts.org.tw/article/394777>, accessed 21 August 2025.

462 - 陳冠廷, "綠新北議員籲朱立倫 擋下核1乾貯場", *Newtalk*, 17 April 2014, see <https://newtalk.tw/news/view/2014-04-17/46425>, accessed 9 August 2025.

dry storage plan.⁴⁶³ The municipal government ultimately approved the dry cask storage facility at Chinshan in May 2024,⁴⁶⁴ followed by the approval of the dry cask storage facility at Kuosheng in August 2024.⁴⁶⁵ (See **Taiwan** in **Decommissioning Status Report**).

In 2023, a new independent body, the Nuclear Safety Commission (NSC), replaced the former nuclear regulator, the Atomic Energy Commission (AEC).⁴⁶⁶ While scaled down from second-level to a third-level agency, the NSC shifted focus from nuclear development to monitoring and regulating nuclear decommissioning, as stipulated by the Nuclear Safety Commission Organization Act, the legal framework for NSC's establishment.⁴⁶⁷ According to the Act, the new commission shall oversee and implement waste management, which will be a major challenge in the coming decades.

UKRAINE FOCUS



For the first time, a country with a developed nuclear power sector has been subjected to a full-scale military attack and has remained at war for more than three years. Russia's full-scale invasion of Ukraine in February 2022—the largest military conflict in Europe since World War II—has created fundamentally new challenges for the international nuclear safety and security system. Previously unthinkable scenarios have become routine: shelling of operating nuclear power plants and nuclear facilities, disruptions in power and water supply to nuclear reactors, and even the seizure and occupation of nuclear sites. Throughout the war, however, nuclear power plants have remained the backbone of Ukraine's electricity system.

Over the past 10 years—both before and after the 2022-invasion—nuclear power has consistently accounted for around 50 percent of Ukraine's total electricity generation. However, due to partial destruction of the energy infrastructure and a decline in consumption, the country's overall electricity output dropped by around 35 percent between 2021 and 2024. In 2024, Ukrainian reactors produced only 53 TWh (gross)—about the same as in 2023 but almost 40 percent lower than the pre-war level of 86.2 TWh⁴⁶⁸ in 2021—primarily due to the seizure and shutdown of the six reactors at the Zaporizhzhia nuclear plant.

Ukraine has 15 operable reactors (two VVER-440s and 13 VVER-1000s) with a total installed capacity of 13.1 GW. These include six units at Zaporizhzhia that, since March 2022, have been occupied by the Russian army assisted by technical experts from Rosatom. The six reactors

⁴⁶³ - 李蘇竣, “核一乾貯場卡關10年 法院判台電勝訴 新北市應核准水保計畫”, Environmental Information Center, 17 March 2023, see <https://e-info.org.tw/node/236319>, 21 August 2025.

⁴⁶⁴ - 林靜梅 和 彭耀祖, “台電與新北市府達成和解 核一乾式儲存場卡關11年解套”, 公視新聞網, 2 May 2024, see <https://news.pts.org.tw/article/693289>, accessed 25 May 2025; and 林靜梅, 莊志成, “”, 公視新聞網, 10 May 2024, see <https://news.pts.org.tw/article/694552>, accessed 21 August 2025.

⁴⁶⁵ - Taipower, “Key Decommissioning Work at Kuosheng Nuclear Power Plant Officially Begins; Outdoor Dry Storage for Spent Nuclear Fuel Breaks Ground”, 31 December 2024, op. cit.

⁴⁶⁶ - Nuclear Safety Commission, “Nuclear Safety Commission Established as an Independent, Professional, and Impartial Organization to Enhance Nuclear Safety Regulation in Taiwan”, 6 October 2023, see <https://www.nusc.gov.tw/english/newsdetail/pressrelease/242.html>, accessed 10 August 2025.

⁴⁶⁷ - Laws & Regulations Database, “Nuclear Safety Commission Organization Act”, Ministry of Justice, promulgated 21 June 2023, see <https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=J0000101>, accessed 10 August 2025.

⁴⁶⁸ - Energy Institute, “Statistical Review of World Energy 2025”, 2025, see https://www.energyinst.org/_data/assets/excel_doc/0006/1656348/Statistical-Review-of-World-Energy-Data.xlsx, accessed 28 June 2025.

have been shut down since September 2022 and are considered in LTO. The country also has four closed RBMK reactors at the Chornobyl nuclear power plant, including Unit 4, which underwent a disastrous accident in 1986.

As of 1 July 2025, the mean age of Ukraine's reactor fleet, including reactors in LTO, is 36.4 years. Only three reactors are younger than 30 years. All others have been granted lifetime extensions for 10 or 20 years, as described in [WNISR2024](#).

Newbuild Projects

In April 2023, the Cabinet of Ministers approved a new Energy Strategy for Ukraine until 2050.⁴⁶⁹ In December of the same year, at the COP28 conference, Ukraine presented the report Clean Energy Roadmap: From Reconstruction to Decarbonization in Ukraine.⁴⁷⁰ Linked to the goals of Ukraine's energy strategy and developed with the support of the United States, the report presented scenarios for the development of a low-carbon energy system in Ukraine. According to the proposed scenarios, the country's nuclear energy production should increase by at least 2.5 times by 2050 compared to the current level, accounting for between one-third and 60 percent of electricity generation, depending on the scenario, and up to half of total primary energy production. The remainder should come almost entirely from renewable energy sources.

In January 2024, Ukraine's then-Minister of Energy German Galushchenko⁴⁷¹ announced that the country would begin construction during the year of four nuclear units at Khmelnytskyi (also spelled Khmel'nitsky, including by the IAEA), where two reactors are already operating.⁴⁷² As described in [past WNISR editions](#), Ukraine has a long history of attempting to complete two abandoned VVER-1000 reactors—Units 3 and 4 of the Khmelnytskyi nuclear power plant—whose construction originally started nearly 40 years ago. These efforts were revived in response to the loss and destruction of a significant share of Ukraine's generating capacity following Russia's full-scale invasion. According to Galushchenko, "Completing the construction of the Khmelnytskyi NPP [Nuclear Power Plant] is a strategic task for Ukraine."⁴⁷³

However, the feasibility of completing these units largely depends on the potential purchase of key equipment—primarily reactor vessels and steam generators, originally intended for Bulgaria's unfinished Russian-designed Belene nuclear power plant. In July 2023, the National Assembly of Bulgaria mandated the Ministry of Energy to enter into negotiations with Ukraine

469 - Cabinet of Ministers, "Розпорядження від 21 квітня 2023 р. № 373-р—Про схвалення Енергетичної стратегії України на період до 2050 року", Government of Ukraine, 21 April 2023, see <https://www.kmu.gov.ua/npas/pro-skhalennia-enerhetychnoi-stratehii-ukrainy-na-period-do-2050-roku-373r-210423>, accessed 26 April 2024.

470 - Nazar Kholod, Oleksandr Diachuk et al., "Clean Energy Roadmap: From Reconstruction to Decarbonization in Ukraine—Report for COP28", Pacific Northwest National Laboratory, Institute for Economics and Forecasting, National Academy of Sciences of Ukraine, Argonne National Laboratory, DiXi Group, Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, commissioned by the Ministry of Energy, Government of Ukraine, December 2023, see https://www.researchgate.net/publication/383263587_Clean_Energy_Roadmap_From_Reconstruction_to_Decarbonization_in_Ukraine, accessed 15 July 2025.

471 - On 17 July 2025, he was appointed Minister of Justice.

472 - Ministry of Energy, "Після будівництва нових блоків Хмельницька АЕС стане найпотужнішою в Європі – Герман Галушенко", Government of Ukraine, 29 January 2024, see <https://mev.gov.ua/novyna/pislya-budivnytstva-novykh-bloktiv-khmelnytska-aes-stane-naypotuzhnishoyu-v-yevropi-herman>, accessed 14 August 2025.

473 - Ministry of Energy, "Міненерго вітає рішення Парламенту щодо першого кроку в добудові Хмельницької АЕС", Government of Ukraine, 11 February 2025, see <https://www.mev.gov.ua/novyna/minenerho-vitaye-rishennya-parlamentu-shchodo-pershoho-kroku-v-dobudovi-khmelnytskoyi-aes>, accessed 12 June 2025.

but requested not to sell the equipment below the initial purchase price of ~€600 million (US\$₂₀₂₃ 649 million).⁴⁷⁴ Discussions dragged on, and on 11 September 2024, the Bulgarian parliament granted a 180-day extension of the negotiation deadline.⁴⁷⁵

On 11 February 2025, the Verkhovna Rada of Ukraine approved a draft law allowing the Ukrainian nuclear operator Energoatom to purchase equipment from Bulgaria for the completion of the two units at Khmelnytskyi.⁴⁷⁶ The law was signed by President Volodymyr Zelenskyy on 13 March 2025. According to proponents of the project, this purchase represents the fastest way to acquire two large nuclear units, which would significantly reduce power shortages in the country. They claim the reactors could be completed within three to four years.⁴⁷⁷ The Ministry of Energy had indicated in February 2025, that construction work was 80 percent complete at Unit 3 and 25 percent at Unit 4.⁴⁷⁸

However, critics of the project, as cited in WNISR2024, emphasized concerns that remain relevant a year later. They noted that the equipment is not complete and that, so far, no agreements to manufacture the missing equipment exist. They also pointed out that there was no law authorizing the construction of Units 3 and 4, no design, no safety report, and no construction license. This remains valid as of mid-2025.

In February 2025, Energoatom commissioned an update of the project's feasibility study.⁴⁷⁹ The work was supposed to be completed within four months (by early June), and the Ministry of Energy called on Energoatom to accelerate this work in accordance with the decision of the Verkhovna Rada,⁴⁸⁰ however no public information on the results had been released as of 1 July 2025.

In April 2025, senior officials in the Bulgarian government announced that the country would not proceed with the sale of Belene reactor equipment to Ukraine.⁴⁸¹ The decision was

474 - National Assembly of Bulgaria, “Решение за възлагане на министъра на енергетиката да проведе преговори с министъра на енергетиката на Украйна или негов представител с цел продажба на оборудване, предназначено за проекта АЕЦ ‘Белене’”, 6 July 2023, see <https://www.parliament.bg/bg/desision/ID/164938>, accessed 12 June 2025.

475 - Krassen Nikolov, “Bulgaria Gives Ukraine More Time to Buy its Russia-Made Nuclear Reactors”, *Euractiv*, 12 September 2024, see <https://www.euractiv.com/section/politics/news/bulgaria-gives-ukraine-more-time-to-buy-its-russia-made-nuclear-reactors/>, accessed 26 May 2025; and National Assembly of Bulgaria, “The National Assembly Extended by 180 Days the Deadline for Negotiations with Ukraine for the Sale of Equipment Intended for the Belene NPP Project”, 11 September 2024, see <https://www.parliament.bg/en/news/ID/6104>, accessed 12 June 2025.

476 - Yuliia Dysa and Pavel Polityuk, “Ukraine Backs Purchase of Soviet-Designed Nuclear Reactors from Bulgaria”, *Reuters*, 11 February 2025, see <https://www.reuters.com/business/energy/ukraine-backs-purchase-soviet-designed-nuclear-reactors-bulgaria-2025-02-11/>, accessed 26 May 2025; and Ministry of Energy, “Міненерго вітає рішення Парламенту щодо першого кроку в будові Хмельницької АЕС”, February 2025, op. cit.

477 - Grace Symes and Phil Chaffee, “Bulgaria: Sofia Cancels Sale of Belene Equipment to Ukraine”, *Energy Intelligence*, 25 April 2025, see <https://www.energyintel.com/00000196-687d-d910-afb7-ef7fdbd60000>, accessed 26 May 2025.

478 - Ministry of Energy, “Міненерго вітає рішення Парламенту щодо першого кроку в будові Хмельницької АЕС”, 11 February 2025, op. cit.

479 - Юрий Николов and Анна Сорока, “«Енергоатом» за 28 млн замовив переоцінку будови Хмельницької АЕС, яку підтримав Зеленський: скільки коштуватиме хапок?”, *Наши Деньги*, 7 February 2025, see <https://nashigrosni.org/2025/02/07/enerhoatom-za-28-mln-zamovyv-pereotsinku-dobudovy-khmel-nyts-koi-aes-iaku-pidtrymav-zelens-kyy-skil-ky-koshtuvatyme-khapok/>, accessed 14 July 2025; and Prozorro, “Будівництво енергоблоків № 3 та № 4 Хмельницької АЕС. Техніко-економічне обґрунтування. Коригування кошторисної вартості”, Government of Ukraine, 4 February 2025, see <https://prozorro.gov.ua/en/tender/UA-2025-02-04-004858-a>, accessed 14 August 2025.

480 - Ministry of Energy, “Міненерго вітає рішення Парламенту щодо першого кроку в будові Хмельницької АЕС”, Government of Ukraine, 11 February 2025, see <https://www.mev.gov.ua/novyna/minenerho-vitaye-rishennya-parlamentu-shchodo-pershoho-kroku-v-dobudovi-khmelnytskyoi-aes>, accessed 12 June 2025.

481 - Olena Hrazhdan, “Bulgaria Decides Against Selling Nuclear Reactors to Ukraine”, *Kyiv Post*, 15 April 2025, see <https://www.kyivpost.com/post/50845>, accessed 26 May 2025.

reportedly driven by a renewed interest in keeping the equipment for potential use at Bulgaria's own nuclear facilities, such as Kozloduy. Given Bulgaria's political instability and history of inconsistent nuclear policy, the situation remains fluid; the decision may still be revised, though there is also a possibility that the deal will not move forward.

According to the IAEA, Khmelnytskyi-3 and -4 are officially under construction, but WNISR removed them from the construction list as no active work has been reported in some four decades despite all attempts to revive the project. The last time the government attempted to restart construction of the plant, the total cost of completing Khmelnytskyi Units 3 and 4 was estimated at UAH₂₀₁₇ 72.3 billion (~US\$₂₀₁₇ 2.7 billion).⁴⁸² But there has been no independent evaluation of the cost estimate.

In June 2022 Energoatom and Westinghouse signed an agreement to construct up to nine AP-1000 units in Ukraine.⁴⁸³ In January 2023, the Cabinet of Ministers approved the launch of a feasibility study for constructing two such reactors—Khmelnytskyi-5 and -6—by 2032, with an expectation that they would cost around US\$5 billion each.⁴⁸⁴ The proposed timeline and cost seem excessively optimistic, especially considering that the forerunner Vogtle plant in the U.S. took over a decade to complete at more than triple the cost projected for Ukraine.

In April 2024, it was announced that a “symbolic cubic meter” of concrete for Unit 5 had been poured at Khmelnytskyi in the presence of U.S. and Ukrainian officials as well as the CEOs of Westinghouse and Energoatom.⁴⁸⁵ Bridget Brink, then-U.S. Ambassador to Ukraine,⁴⁸⁶ reiterated at the ceremony that these units would be the first of nine AP-1000 reactors to be built in Ukraine in cooperation with Westinghouse.

But similar to Units 3 and 4, work on Khmelnytskyi Units 5 and 6 remains effectively inactive with no formal feasibility study, safety report, or construction license. The symbolic ceremony held in April 2024 cannot be considered the actual start of construction, as it involved concreting of a drainage channel rather than the nuclear island itself.⁴⁸⁷ Thus, by mid-2025,

482 - Cabinet of Ministers, “Про схвалення техніко-економічного обґрунтування ‘Будівництво енергоблоків №№ 3, 4 Хмельницької АЕС’ (м. Нетішин, вул. Енергетиків) (Коригування)”, Document 579-2018-р, Parliament of Ukraine, 26 July 2018, as amended 18 December 2024, see <https://zakon.rada.gov.ua/go/579-2018-%D1%80>, accessed 12 June 2025.

483 - Westinghouse, “Energoatom and Westinghouse Reaffirm Clean Energy Partnership, Announce Expanded Cooperation on Westinghouse-supplied VVER Fuel and AP1000® Plants to be Built in Ukraine”, Press Release, 3 June 2024, see <https://westinghousenuclear.com/news/energoatom-and-westinghouse-reaffirm-clean-energy-partnership>, accessed 1 July 2024.

484 - Ukrainian Energy, “The Government Makes a Decision to Build Two AP1000 Power Units at Khmelnytskyi NPP”, 20 January 2023, see <https://ua-energy.org/en/posts/20-01-2023-fcb4edf0-01a2-4c5a-8c1a-6b66691d742f>, accessed 1 July 2024; and Ministry of Energy, “На Хмельницькій АЕС побудують нові енергоблоки за американською технологією AP1000®, - Герман Галущенко”, Government of Ukraine, 20 January 2023, see <https://www.kmu.gov.ua/news/na-khmelnytskii-aes-pobuduiut-novi-enerhobloky-za-amerykanskoju-tehnolohiieiu-ap1000-herman-halushchenko>; also Cabinet of Ministers of Ukraine, “Про організаційні заходи щодо будівництва енергоблоків Хмельницької АЕС”, Order №52-р, 20 January 2023, see <https://zakon.rada.gov.ua/laws/show/52-2023-%D1%80/ed20230120#Text>; both accessed 12 June 2025.

485 - Petro Kotin, “Today, the World Is Returning to Nuclear Energy. And Ukraine Can Be at the Forefront”, Energoatom, 19 September 2024, see <https://energoatom.com.ua/en/news/sogodni-svit-povertayetsya-do-yadernoyi-energetiki-i-ukrayina-mozhe-buti-v-avangardi>; and Energoatom, “At the Khmelnytsky NPP, a Project on the Construction of Units 5 and 6 Using the American Westinghouse Technology Started”, 15 April 2024, see <https://energoatom.com.ua/en/news/na-hmelnickij-aes-startuvav-proyekt-z-budivnictva-energhoblokv-5-6-za-amerikanskoyu-tehnologiyeyu-westinghouse>; both accessed 12 June 2025.

486 - She resigned in April 2025 in protest over President Trump's Ukraine policy; see Bridget Brink, “I Was U.S. Ambassador to Ukraine. I Resigned Because of Trump's Foreign Policy. | Opinion”, *Detroit Free Press*, 16 May 2025, see <https://www.freep.com/story/opinion/contributors/2025/05/16/trump-ukraine-policy-russia-ambassador-resign/83648993007/>, accessed 6 August 2025.

487 - Energoatom, “At the Khmelnytsky NPP, a Project on the Construction of Units 5 and 6 Using the American Westinghouse Technology Started”, 15 April 2024, op. cit.

despite the stakeholders' intentions and high-profile announcements, not a single new unit can be considered in active construction.

Further, Energoatom has shown interest in deploying Small Modular Reactors (SMRs) and entered cooperation agreements with various potential technology providers and partners, such as NuScale, Holtec, Rolls-Royce, and Hyundai E&C, since 2021.⁴⁸⁸ In September 2023, Energoatom and Westinghouse signed a Memorandum of Understanding (MoU) on the development and deployment of an AP300, a yet-uncertified SMR design. The MoU established a joint working group to develop licensing, contracting, and local supply chains. Westinghouse is hoping that design certification could take place by 2027 and construction could start in 2030.⁴⁸⁹ As Westinghouse has not even submitted an official application for design certification to the U.S. regulator, the timeline appears optimistic, even under new government pressure on the regulator to accelerate procedures.⁴⁹⁰

Reducing Russia Dependencies

Ukraine is the VVER-reactor country that has advanced the furthest in moving away from dependence on Russian nuclear technologies and supplies (see [Annex 3: Fuel Supply for Soviet-designed Reactors in the E.U. and Ukraine](#)). In 2001, Westinghouse began the development of VVER-1000 fuel manufacturing following a government agreement between Ukraine and the U.S. on energy cooperation and safety. In 2008, Energoatom and Westinghouse signed the first contract for fuel delivery; in 2018, the contract was extended to 2025.⁴⁹¹

By the time Russia invaded it in 2022, Ukraine had already transitioned six of its VVER reactors partially or fully to Westinghouse fuel. Four of those reactors were at the Zaporizhzhia site. In June 2022, the contract with Westinghouse was expanded to cover all operational Ukrainian units, stipulating a full transition to Westinghouse fuel.⁴⁹²

In September 2023, the first VVER-440 fuel assemblies delivered by Westinghouse were loaded at the Rivne plant,⁴⁹³ and in March 2024, VVER-1000 fuel assemblies were delivered to Khmelnytskyi⁴⁹⁴.

488 - Petro Kotin, "Energoatom Is Deploying Small Modular Reactor Technologies in Ukraine", CEO of Energoatom, 22 November 2024, see <https://energoatom.com.ua/en/news/energoatom-rozgotaye-tehnologiyi-malih-modulnih-reaktoriv-v-ukrayini>; and Hyundai E&C, "Hyundai E&C to Expand Cooperation in the Nuclear Power Plant Project with Energoatom", Press Release, 5 December 2023, see https://en.hdec.kr/en/company/press_view.aspx?CompanyPressSeq=362; both accessed 13 June 2025.

489 - Westinghouse, "Westinghouse and Ukraine's Energoatom Pursuing Deployment of AP300™ Small Modular Reactor to Meet Climate, Energy Security Goals", Press Release, 12 September 2023, see <https://info.westinghousenuclear.com/news/westinghouse-and-ukraines-energoatom-pursuing-deployment-of-ap300-small-modular-reactor-to-meet-climate-energy-security-goals>, accessed 5 August 2024.

490 - U.S. NRC, "Westinghouse AP300", United States Nuclear Regulatory Commission, Updated 18 April 2025, see <https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/pre-application-activities/westinghouse.html>, accessed 14 August 2025.

491 - Bellona Foundation, "The Russian Nuclear Industry During Wartime, 2022 And Early 2023", 2023, see <https://network.bellona.org/content/uploads/sites/4/2024/04/The-Russian-nuclear-industry-during-wartime-2022-and-early-2023.pdf>, accessed 24 April 2025.

492 - Westinghouse, "Energoatom and Westinghouse Reaffirm Clean Energy Partnership, Announce Expanded Cooperation on Westinghouse-supplied VVER Fuel and AP1000® Plants to be Built in Ukraine", Press Release, 3 June 2024, see <https://info.westinghousenuclear.com/news/energoatom-and-westinghouse-reaffirm-clean-energy-partnership>, accessed 1 July 2024.

493 - Westinghouse, "Westinghouse Delivers First VVER-440 Fuel Assemblies to Energoatom", Press Release, 12 September 2023, see <https://info.westinghousenuclear.com/news/westinghouse-delivers-first-vver-440-fuel-assemblies-to-energoatom>, accessed 17 November 2023.

494 - Energoatom, "The First Batches of Westinghouse Nuclear Fuel Delivered to Khmelnytsky NPP", 8 March 2024, see <https://energoatom.com.ua/en/news/na-hmelnicku-aes-zavezli-pershi-partiyi-yadernogo-paliva-westinghouse>, accessed 4 September 2024.

After terminating its contracts with Russia's Rosatom, Ukraine's Energoatom signed agreements with Western suppliers covering the entire nuclear fuel supply chain. In 2023, Canada's Cameco was contracted to supply natural uranium and conversion services for Ukraine's entire nuclear fleet through 2035.⁴⁹⁵ In autumn 2023, a contract was signed with the British-Dutch-German company Urenco for uranium enrichment services until 2035, with an extension option through 2043.⁴⁹⁶ In March 2025, a similar agreement was signed with France's Orano, covering services through 2040.⁴⁹⁷

Ukraine has demonstrated that even under wartime conditions, it is possible to transition from Russian supplies to Western sources while keeping 60 percent of its nuclear fleet operational. This experience is highly relevant for all countries relying on Russian nuclear supplies but are aiming to transition to other sources (see [Russia Nuclear Interdependencies](#)).

Power Sector Under War Conditions

Since the beginning of the full-scale Russian invasion, Ukraine's electricity sector has faced major disruptions. According to a United Nations Development Programme (UNDP) report,⁴⁹⁸ in the early months of the invasion significant degradation was caused by the temporary occupation of parts of the country, the reduction in industrial activity, and the relocation of millions of people to safer regions or abroad. The situation worsened in October 2022, according to the report, when Russia began systematic missile and drone attacks on Ukraine's energy infrastructure. These attacks left around 12 million people without electricity, disrupted water and heating supplies, and caused widespread hardship during sub-zero winter conditions.

According to the UNDP assessment, in the first 14 months since the start of the invasion, Ukraine's total operational generation capacity decreased by more than half—from 37.6 GW at the beginning of 2022 to 18.3 GW as of 30 April 2023. The analysis found that

At the end of April 2023, there was not a single TPP [Thermal Power Plant] or HPP [Hydroelectric Power Plant] in Ukraine that was not damaged to some extent due to military activities and missile attacks on energy infrastructure facilities. (...) In the transmission network, 42 out of 94 crucial high-voltage transformers have been damaged or destroyed.⁴⁹⁹

Due to the complete shutdown of Zaporizhzhia, operable nuclear capacity declined by 44 percent from 13.8 GW to 7.7 GW. Available hydro capacity dropped by 29 percent from 6.6 GW to 4.7 GW and renewable capacity decreased by 24 percent from 8.1 GW to 6.2 GW,

⁴⁹⁵ - Cameco, "CCO and Energoatom Agree on Commercial Terms to Supply Ukraine's Full Natural UF6 Needs through 2035", Press Release, 8 February 2023, see <https://www.cameco.com/media/news/cco-and-energoatom-agree-on-commercial-terms-to-supply-ukraines-full-natural-uf6-needs>, accessed 27 May 2025.

⁴⁹⁶ - Energoatom, "Energoatom and Urenco Continue Cooperation in the Field of Nuclear Fuel", 23 July 2024, see <https://energoatom.com.ua/en/news/energoatom-ta-urencoprodozhuyut-spivpracyu-u-galuzi-yadernogo-paliva>, accessed 13 June 2025.

⁴⁹⁷ - Orano, "Enrichment: Orano and Energoatom Sign an Agreement to Supply Enrichment Services to Ukraine's Nuclear Power Plants", 6 March 2025, see <https://www.orano.group/en/news/news-group/2025/march/enrichment-orano-and-energoatom-sign-an-agreement-to-supply-enrichment-services-to-ukraine-s-nuclear-power-plants>, accessed 27 May 2025.

⁴⁹⁸ - UNDP, "Towards a Green Transition of the Energy Sector in Ukraine—Update on the Energy Damage Assessment", United Nations Development Programme, June 2023, see <https://www.undp.org/sites/g/files/zskgke326/files/2023-06/undp-ua-energy-damage-assessment.pdf>, accessed 28 May 2025.

⁴⁹⁹ - Ibidem.

“as a large number of wind and solar power plants located in southern Ukraine are currently in areas under the temporary military control of the Russian Federation, are damaged or are in the combat zone,” the UNDP assessment found. For the mid-term, the UNDP analysts see a chance to accelerate the energy transition as “the loss of obsolete coal-fired generation opens an opportunity for their replacement using greener alternatives and decentralizing generation capacities.”⁵⁰⁰

According to a joint report by the World Bank, the Ukrainian government, the European Commission, and the U.N., in the course of 2024, Ukraine’s energy infrastructure sustained additional damage due to 13 massive, targeted attacks. As of 31 December 2024, despite improved preparedness for attacks compared to the previous year and the restoration of several gigawatts of capacity, the overall installed generation capacity available for use dropped to 15 GW, which is significantly lower than the 18–19 GW needed for peak demand, especially in winter.⁵⁰¹

Total electricity generation in 2024 dropped to 101 TWh, which is about 3 percent less than the previous year and less than two thirds of the pre-war year 2021 (156.5 TWh).⁵⁰²

Under such conditions, electricity imports from E.U. countries have become extremely important, especially for balancing the power system. In March 2022, Ukraine disconnected its power grid from Russia and subsequently synchronized with the E.U. grid.⁵⁰³ Starting in 2023, Ukraine shifted from being a net exporter to a net importer of electricity, importing a record 4.4 TWh in 2024—mainly from Hungary and Slovakia.⁵⁰⁴ The growth in imports was also made possible by infrastructure repairs, which increased import capacity from 1.7 GW to 2.1 GW by December 2024,⁵⁰⁵ though this was still insufficient to make up for the Ukrainian power deficit of almost 2.3 GW in summer 2024⁵⁰⁶ and an estimated 3–4 GW during peak winter demand.

Up to November 2024, the G7+ Ukraine Energy Coordination Group says it “mobilized more than US\$ 5 billion in support of Ukraine’s energy sector.”⁵⁰⁷ International support for Ukraine’s

500 - Ibidem.

501 - World Bank Group, Government of Ukraine, European Commission and United Nations, “Ukraine - Fourth Rapid Damage and Needs Assessment (RDNA4)—February 2022 – December 2024”, as release by the United Nations Development Programme, 25 February 2025, see <https://www.undp.org/ukraine/publications/ukraine-fourth-rapid-damage-and-needs-assessment-rdna4-february-2022-december-2024-english>, accessed 28 May 2025.

502 - Energy Institute, “Statistical Review of World Energy 2025”, 2025.

503 - Anna Blaustein, “How Ukraine Unplugged from Russia and Joined Europe’s Power Grid with Unprecedented Speed”, *Scientific American*, 23 March 2022, see <https://www.scientificamerican.com/article/how-ukraine-unplugged-from-russia-and-joined-europes-power-grid-with-unprecedented-speed/>, accessed 1 July 2024; and ENTSO-E, “Continental Europe Successful Synchronisation with Ukraine and Moldova Power Systems”, Press Release, European Network of Transmission System Operators for Electricity, 16 March 2022, see <https://www.entsoe.eu/news/2022/03/16/continental-europe-successful-synchronisation-with-ukraine-and-moldova-power-systems/>, accessed 27 July 2024.

504 - Shcherbak Iryna, “Ukraine’s Record Imports and Minimal Exports of Electricity Over the Past Decade Were Recorded in 2024”, DiXi Group, 22 January 2025, see <https://dixigroup.org/en/ukraines-record-imports-and-minimal-exports-of-electricity-over-the-past-decade-were-recorded-in-2024/>, accessed 26 May 2025.

505 - World Bank Group, Government of Ukraine, European Commission and United Nations, “Ukraine - Fourth Rapid Damage and Needs Assessment (RDNA4)—February 2022 – December 2024”, 25 February 2025, op. cit.

506 - IEA, “Ukraine’s Energy Security and the Coming Winter—An Energy Action Plan for Ukraine and Its Partners”, International Energy Agency, September 2024, see <https://www.iea.org/reports/ukraines-energy-security-and-the-coming-winter>, accessed 13 June 2025.

507 - Directorate-General for Energy, “Statement of the G7+ Ukraine Energy Coordination Group and the Government of Ukraine Promoting Sustainable Green Recovery of Ukraine’s Energy System”, European Commission, 15 November 2024, see https://energy.ec.europa.eu/news/statement-g7-ukraine-energy-coordination-group-and-government-ukraine-promoting-sustainable-green-2024-11-15_en, accessed 28 May 2025.

energy sector focuses on restoring infrastructure, expanding decentralized renewables, and strengthening cross-border links—aligned with the EU Clean Energy Package and climate goals. It also emphasizes better protection of facilities to reduce humanitarian and environmental risks.

At the same time, according to estimates from a joint assessment by the World Bank, the Ukrainian government, the European Commission, and the United Nations, as of the end of 2024, the amount needed to restore Ukraine’s energy sector is about US\$68 billion.⁵⁰⁸

Russian Attacks on Nuclear Facilities

On the first day of Russia’s invasion of Ukraine on 24 February 2022, Russian troops entered the Chernobyl Exclusion Zone from Belarus, advancing along the shortest route toward Kyiv, and seized the Chernobyl nuclear power plant. By 31 March 2022, Russian forces had withdrawn from the area⁵⁰⁹ as part of a large-scale retreat following the failed attempt to capture the Ukrainian capital.

A week after the invasion began, Russian forces from the southern group, advancing from Crimea (occupied since 2014), approached Europe’s largest nuclear power plant, Zaporizhzhia, and on 4 March 2022, they seized the facility.⁵¹⁰ According to the IAEA, representatives of State Atomic Energy Corporation Rosatom arrived at the Zaporizhzhia site “a few days after the Russian military took control.”⁵¹¹ The IAEA also noted that within a few months an “increasing number of Russian technical staff” from Rosatom and its subsidiary Rosenergoatom “has been observed at the site.”

In August 2022, the IAEA reported the first serious shelling of the plant;⁵¹² since then, such attacks have continued intermittently. For more than three years now, the plant has been located directly on the frontlines, which run along the banks of the Kakhovka Reservoir (which was destroyed in the summer of 2023).

On 1 September 2022, IAEA Director General Rafael Grossi visited the station for the first time during the war and established the presence of the IAEA Support and Assistance Mission to Zaporizhzhya (ISAMZ) at the facility.⁵¹³ Since then, representatives of the agency have maintained a continuous presence at the site. However, the IAEA complained that the Mission

508 - World Bank Group, Government of Ukraine, European Commission and United Nations, “Ukraine - Fourth Rapid Damage and Needs Assessment (RDNA4)—February 2022 – December 2024”, 25 February 2025, op. cit.

509 - Charles Digges, “Rosatom’s Role in the War in Ukraine”, Bellona, 2023, see <https://network.bellona.org/content/uploads/sites/4/2024/04/Rosatoms-role-in-the-war-in-Ukraine-1.pdf>, accessed 29 May 2025.

510 - *Deutsche Welle*, “Russia Seizes Ukraine Nuclear Plant”, 3 April 2022, see <https://www.dw.com/en/ukraine-nuclear-plant-fire-extinguished-russia-seizes-site/a-61008531>, accessed 29 May 2025.

511 - IAEA, “Nuclear Safety, Security and Safeguards in Ukraine—February 2022–February 2023”, 3rd Summary Report, International Atomic Energy Agency, 2023, see <https://www.iaea.org/sites/default/files/documents/nuclear-safety-security-and-safeguards-in-ukraine-feb-2023.pdf>, accessed 29 May 2025.

512 - IAEA, “Update 93 – IAEA Director General Statement on Situation in Ukraine”, Press Release 132/2022, 23 August 2022, see <https://www.iaea.org/newscenter/pressreleases/update-93-iaea-director-general-statement-on-situation-in-ukraine>, accessed 29 May 2025.

513 - IAEA, “Update 97 – IAEA Director General Statement on Situation in Ukraine”, Press Release 136/2022, 3 September 2022, see <https://www.iaea.org/newscenter/pressreleases/update-97-iaea-director-general-statement-on-situation-in-ukraine>, accessed 29 May 2025; and IAEA, “Two Years of IAEA Continued Presence at the Zaporizhzhya Nuclear Power Plant”, 4 September 2024, see <https://www.iaea.org/newscenter/pressreleases/iaea-report-highlights-two-years-of-efforts-to-prevent-an-accident-at-ukraines-zaporizhzhya-nuclear-power-plant>, accessed 13 June 2025.

“continued to face some restrictions in obtaining timely and appropriate access to all areas of relevance to nuclear safety and security and in having open discussions with all relevant staff” at the site.⁵¹⁴

In September 2022, the remaining operating reactor units were put in cold shutdown mode.

The same month, President Putin formally declared that the regions of Luhansk, Donetsk, Kherson, and Zaporizhzhia were part of Russia.⁵¹⁵ In October 2022, Putin signed a decree that transferred the power plant to Russian ownership with station management being entrusted to Rosenergoatom. Rosenergoatom established a Joint Stock Company “Operating Organization of Zaporizhzhia NPP”, to operate the plant.⁵¹⁶ The IAEA has acknowledged that it has no authority to enforce any of the resolutions that have been passed by the United Nations calling on Russia to withdraw from the power plant.⁵¹⁷

The most significant threats to radiation and nuclear safety during the occupation of the Zaporizhzhia plant have been linked to the following safety and security risks (for details and further references, see *Nuclear Power and War in WNISR2022*):

- ➔ **The loss of power** necessary to ensure the operation of active safety systems—primarily for cooling nuclear fuel in the reactor cores and storage facilities—to prevent a meltdown accident. Since the end of 2022, the situation with Zaporizhzhia’s grid connection has remained fragile—qualified as “extremely vulnerable” by IAEA’s Rafael Grossi in mid-June 2025⁵¹⁸—and virtually unchanged: with periodic outages, it has been connected to the Ukrainian power system by only one or two lines compared to ten before the occupation. On 4 July 2025, the station was once again (for the ninth time since the occupation began) completely disconnected from the power grid, relying solely on backup diesel generators for over three and a half hours.⁵¹⁹ In the case of an operating reactor, a station blackout followed by the failure of emergency power generators to start up almost certainly leads to a meltdown accident within about one hour.
- ➔ **The loss of water supply** needed to cool the nuclear fuel inside the reactor cores and in the spent fuel pools. At Zaporizhzhia, this risk exacerbated after the destruction of the Russian-controlled Kakhovka Hydroelectric Power Plant dam and the draining of the Kakhovka Reservoir.⁵²⁰ For Zaporizhzhia, this meant the loss of the ultimate heat sink. However, given that all reactors at the plant are shut down, the demand for water is significantly lower

514 - IAEA, “Nuclear Safety, Security and Safeguards in Ukraine—Report by the Director General”, GOV/2025/11, February 2025, see <https://www.iaea.org/sites/default/files/documents/gov2025-11.pdf>, accessed 29 May 2025.

515 - President of Russia, “Signing of Treaties on Accession of Donetsk and Lugansk People’s Republics and Zaporozhye and Kherson Regions to Russia”, The Kremlin, 30 September 2022.

516 - President of Russia, “Executive Order on the Specifics of Legal Regulation for the Use of Nuclear Energy in the Zaporozhye Region”, The Kremlin, 5 October 2022; and Rosenergoatom, “Запорожской АЭС будет управлять новая российская эксплуатирующая организация”, 5 October 2022, see https://rosenergoatom.ru/zhurnalistam/news/42089/?sphrase_id=151925, accessed 13 June 2025.

517 - *Ukrinform*, “IAEA Has No Powers to Force Russia to Leave ZNPP - Grossi”, 20 June 2024, see <https://www.ukrinform.net/rubric-economy/3876778-iaea-has-no-powers-to-force-russia-to-leave-znpp-grossi.html>, accessed 20 June 2024.

518 - IAEA, “Update 296 – IAEA Director General Statement on Situation in Ukraine”, Press Release 46/2025, 12 June 2025, see <https://www.iaea.org/newscenter/pressreleases/update-296-iaea-director-general-statement-on-situation-in-ukraine>, accessed 13 June 2025.

519 - IAEA, “Update 300 – IAEA Director General Statement on Situation in Ukraine”, Press Release 63/2025, 4 July 2025, see <https://www.iaea.org/newscenter/pressreleases/update-300-iaea-director-general-statement-on-situation-in-ukraine>, accessed 15 July 2025.

520 - Jonathan Yerushalmy, “Nova Kakhovka Dam: Everything You Need to Know About Ukraine’s Strategically Important Reservoir”, *The Guardian*, 6 June 2023, see <https://www.theguardian.com/world/2023/jun/06/nova-kakhovka-dam-everything-you-need-to-know-about-ukraines-strategically-important-reservoir>, accessed 29 May 2025.

than during normal operation, and the loss of the reservoir does not pose an immediate threat to the plant.⁵²¹ Later, the IAEA communicated that 11 dedicated wells were drilled on the plant's territory to improve water availability for cooling purposes.⁵²² Nevertheless, the water access situation remains volatile.

- ➔ **Deliberate attacks or accidental shelling** of Zaporizhzhia as well as the other nuclear power plant sites. Russia has been actively fortifying the Zaporizhzhia site, mining its perimeter, digging trenches, and stationing troops both in and around the facility—effectively turning it into a fortified military position.⁵²³ The facility is also being used to shield Russian firing positions and to launch attacks on Ukrainian territory, as noted in a December 2024 McKenzie Intelligence Services (MIS) report commissioned by Greenpeace Ukraine.⁵²⁴
- ➔ **Lack of appropriate personnel needed to run a nuclear facility.** Qualification and staffing levels of current Zaporizhzhia plant personnel are uncertain.⁵²⁵ In addition, reportedly, Ukrainian staff has been subjected to violence, severe psychological pressure, and, in some cases, torture.⁵²⁶ Research undertaken by the Ukrainian NGO Truth Hounds documents cases of systematic detention, mistreatment, and torture of citizens associated with the plant, which it says, “likely constitute war crimes and crimes against humanity.”⁵²⁷
- ➔ **Equipment degradation** at Zaporizhzhia resulting from a combination of shortages of staff that carries out maintenance and inspection activities,⁵²⁸ onsite military activity, poor maintenance, and improper operation. During two winters, Russia kept one or two units in hot shutdown—a non-standard, resource-intensive mode that increased safety risks and contributed to equipment failures, including damage to steam generators, according to Energoatom.⁵²⁹ In April 2024, the last reactor was placed in cold shutdown.⁵³⁰ One notable case of infrastructure damage was the August 2024 fire in a cooling tower that caused

521 - François Diaz-Maurin, “Ukrainian dam is destroyed; nuclear plant lives in a ‘grace period’”, *Bulletin of the Atomic Scientists*, 6 June 2023, see <https://thebulletin.org/2023/06/ukrainian-dam-is-destroyed-nuclear-plant-lives-in-a-grace-period/>, accessed 29 May 2025.

522 - IAEA, “Update 184 - IAEA Director General Statement on Situation in Ukraine”, Press Release 102/2023, 22 September 2023, see <https://www.iaea.org/newscenter/pressreleases/update-184-iaea-director-general-statement-on-situation-in-ukraine>, accessed 29 May 2025; and IAEA, “Update 235 - IAEA Director General Statement on Situation in Ukraine”, Press Release 58/2024, 27 June 2024, see <https://www.iaea.org/newscenter/pressreleases/update-235-iaea-director-general-statement-on-situation-in-ukraine-o>, accessed 13 June 2025.

523 - Bellona, “Bellona’s Nuclear Digest, August 2023”, 26 September 2023, see <https://bellona.org/news/nuclear-issues/2023-09-bellonas-nuclear-digest-august-2023>, accessed 15 July 2025.

524 - Greenpeace Ukraine, “Russian Military Escalates Operations at Zaporizhzhia Nuclear Plant, Heightening Nuclear Risks”, 10 December 2024, see <https://www.greenpeace.org/ukraine/en/news/3122/russian-military-escalates-operations-at-zaporizhzhia-nuclear-plant-heightening-nuclear-risks/>, accessed 29 May 2025.

525 - IAEA, “Update 227 - IAEA Director General Statement on Situation in Ukraine”, Press Release 45/2024, 9 May 2024, see <https://www.iaea.org/newscenter/pressreleases/update-227-iaea-director-general-statement-on-situation-in-ukraine>, accessed 27 July 2024.

526 - Marc Santora, “Torture and Turmoil at Ukrainian Nuclear Plant: An Insider’s Account”, *The New York Times*, 28 March 2023, see <https://www.nytimes.com/2023/03/28/world/europe/ukraine-zaporizhzhia-nuclear-plant-grossi.html>, accessed 29 May 2025.

527 - Truth Hounds, “In a Nuclear Prison: How Rosatom Turned Europe’s Largest Nuclear Power Plant into a Torture Chamber and How Can the World Stop It”, September 2023, see <https://truth-hounds.org/en/cases/in-a-nuclear-prison-how-rosatom-turned-europes-largest-nuclear-power-plant-into-a-torture-chamber-and-how-can-the-world-stop-it/>, accessed 21 July 2024.

528 - IAEA, “Update 154 - IAEA Director General Statement on Situation in Ukraine”, Press Release 25/2023, 21 April 2023, see <https://www.iaea.org/newscenter/pressreleases/update-154-iaea-director-general-statement-on-situation-in-ukraine>, accessed 27 July 2024.

529 - Energoatom, “Due to the Criminal Actions of the Ruscists, a Primary-to-Secondary Reagent Leak Continues at the Zaporizhzhia NPP Power Unit 5”, 20 November 2023, see <https://energoatom.com.ua/en/news/cherez-zlochinni-diyi-rashistiv-na-energobloci-5-zaporizkoyi-aes-prodovzhuyetsya-vitok-reagentiv-z-pershogo-kontura-v-drugij>, accessed 13 June 2025.

530 - IAEA, “Update 223 - IAEA Director General Statement on Situation in Ukraine”, Press Release 36/2024, 13 April 2024, see <https://www.iaea.org/newscenter/pressreleases/update-223-iaea-director-general-statement-on-situation-in-ukraine>, accessed 31 May 2025; and IAEA, “Nuclear Safety, Security and Safeguards in Ukraine—Report by the Director General”, GOV/2025/11, February 2025, op. cit.

serious harm, due to which, according to IAEA's Rafael Grossi, the tower might have to be demolished.⁵³¹

Since early 2023, Rosatom representatives have repeatedly declared intentions to restart reactors at Zaporizhzhia. Beyond the potential danger of operating any nuclear reactor in a war zone (see above), the further degraded conditions under military occupation, severely restricted access to reliable power and water supply as well as the ongoing hostilities around the plant, restarting units at the Zaporizhzhia site would bring risk levels to different dimensions as described in detail in a 2024 Bellona Foundation report.⁵³² Such a decision could only be made at the highest political level in Russia. Meanwhile, technical preparations are underway; as of mid-2025, preparations in the form of grid-related activities have been observed in the occupied territories.⁵³³ Moreover, statements by the head of Rosatom indicate preparations for the construction of a floating pumping station with a capacity of 80,000 m³ per hour.⁵³⁴

It should be stressed that while the situation at Zaporizhzhia is exacerbated by the military occupation and the plant's proximity to the frontlines, the other three operational nuclear power plants in Ukraine—comprising a total of nine reactors—are exposed to similarly serious fundamental safety and security risks. The potential of a dangerous event at an operating reactor is significantly higher than at a unit in cold shutdown.

Although these other plants have not come under direct attack during the war, they still face serious risks due to missile overflights and strikes on critical substations in the power grid. Such incidents have already forced reactors to reduce output, undergo emergency shutdowns, or disconnect entirely from the grid. Since autumn 2024, following an agreement with Ukrainian President Volodymyr Zelenskyy, the IAEA has also undertaken the task of inspecting key substations in Ukraine's energy system that are critical for nuclear safety.⁵³⁵

In addition to the threats facing Ukrainian nuclear power plants, as mentioned above, ongoing hostilities and Russian attacks across Ukraine pose risks to other nuclear facilities, in particular:

- ➔ The Kharkiv research reactor has been subjected to repeated shelling leading to structural damage, loss of external power, and serious concerns about the security of nuclear materials and the safety of the facility.⁵³⁶

531 - IAEA, "Update 248 – IAEA Director General Statement on Situation in Ukraine", Press Release 82/2024, 5 September 2024, see <https://www.iaea.org/newscenter/pressreleases/update-248-iaea-director-general-statement-on-situation-in-ukraine>, accessed 31 May 2025.

532 - Dmitry Gorchakov and Alexander Nikitin, "The Potential Restart of the Zaporizhzhia Nuclear Power Plant: Analysis of Technical and Political Aspects", Bellona, 2024, see <https://etc.bellona.org/publication/znp-restart/>, accessed 29 May 2025.

533 - Greenpeace Ukraine, "Location of Illegal Russian Construction of New Electricity Line for Zaporizhzhia Nuclear Plant – As Rosatom Chief Tells Russian Politicians He Is 'Living The Dream of Restart'", 27 May 2025, see <https://www.greenpeace.org/ukraine/en/news/3658/location-of-illegal-russian-construction-of-new-electricity-line-for-zaporizhzhia-nuclear-plant-as-rosatom-chief-tells-russian-politicians-he-is-living-the-dream-of-restart/>, accessed 29 May 2025.

534 - Neftegaz, "Росатом Начал Строительство Плавучей Насосной Станции Для Запорожской АЭС", 7 June 2025, see <https://neftegaz.ru/news/nuclear/890797-rosatom-nachal-stroitelstvo-plavuchey-nasosnoy-stantsii-dlya-zaporozhskoy-aes->, accessed 15 July 2025.

535 - IAEA, "Nuclear Safety, Security and Safeguards in Ukraine—Report by the Director General", GOV/2025/11, February 2025, op. cit.

536 - *The Associated Press*, "Staff at Ukraine's Experimental Nuclear Site Pick Up Pieces from Russian Strikes", 30 May 2023, see <https://apnews.com/article/ukraine-kharkiv-nuclear-research-lab-damaged-e41e7e8d84a7062d1184d92df1680cdo>, accessed 29 May 2025.

- In February 2025, a Russian Shahed drone struck the New Safe Confinement structure over Chernobyl's Unit 4, creating a 15-square-meter hole in the roof and sparking fires that burned for over two weeks. Although radiation levels remained stable, the incident caused serious structural damage, prompting the IAEA to call for major repairs and raising international concern over nuclear facility security.⁵³⁷

Thus, while Russia is a long-standing and prominent member of the IAEA and a leading player in the international nuclear market through its state corporation Rosatom, it is at the same time—often with Rosatom's direct involvement—engaged in unprecedented hostile actions in Ukraine that pose serious threats to the civilian nuclear sector. These include the seizure of nuclear power plants, attacks on critical energy infrastructure, and challenges to the non-proliferation regime through the capture of large quantities of foreign nuclear material.

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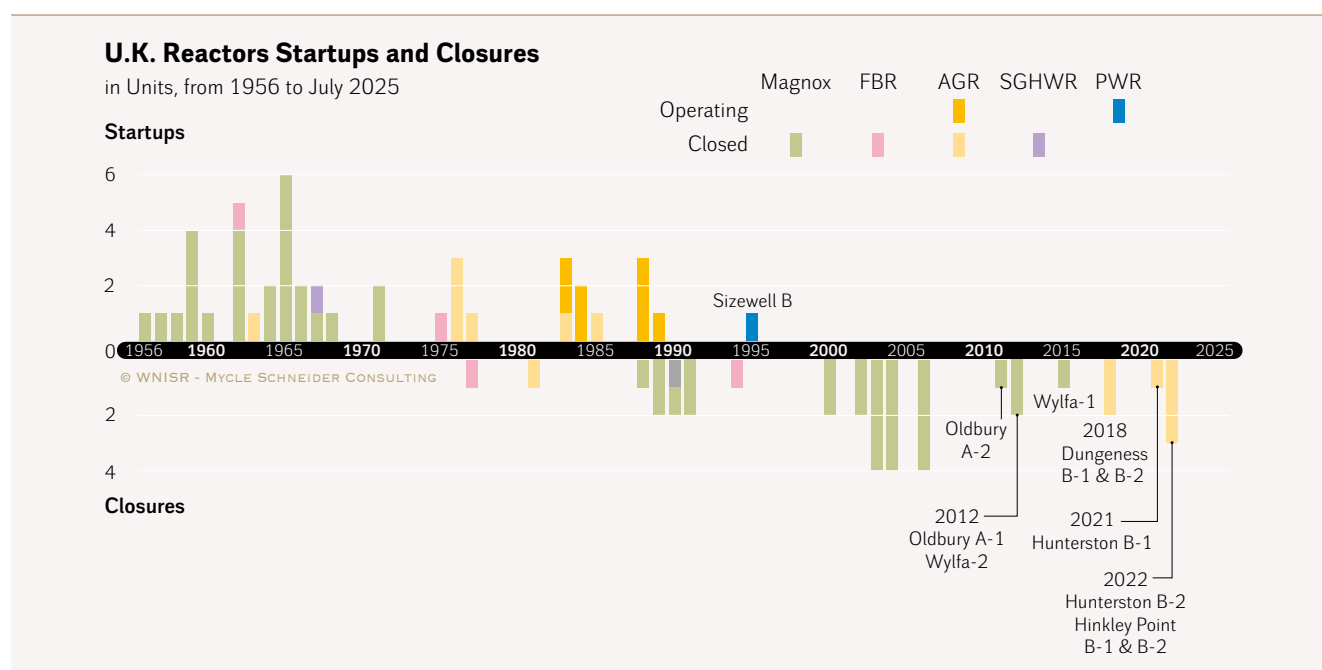
The incoming government, since its election in the summer of 2024, has established new mechanisms and policy changes to deliver climate change and energy security objectives. This has included making available more government funds for constructing two reactors at Sizewell C and SMRs, as well as additional finance for nuclear fusion. This is despite the sector continuing to be plagued by the same old problems of cost overruns, delays in its new projects, and rising costs associated with the existing fleet.

As of mid-2025, the United Kingdom (U.K.) operates just nine reactors, the same as in the previous edition of the WNISR. The average fleet age is 38.1 years (see Figure 44). The last reactors to close were the two units at Hinkley Point B on 6 July 2022 (B-2) and 1 August 2022 (B-1), respectively. This followed the closure of the two reactors at Hunterston in 2021 and 2022, and two units at Dungeness officially closed in 2021 (last power generation in 2018, see Figure 43).

In total, 36 nuclear reactors have been closed, including all 26 Magnox, the first-generation gas-cooled reactors, two fast breeders, one small Steam-Generating Heavy Water Reactor (SGHWR), and seven Advanced Gas Reactors (AGRs). There is now 5.8 GW of nuclear capacity in operation, with 7.8 GW awaiting or undergoing decommissioning.

⁵³⁷ - Dan Sabbagh and Julia Kochetova, "Russian Drone Strike Caused Tens of Millions Worth of Damage to Chernobyl", *The Guardian*, 7 May 2025, see <https://www.theguardian.com/world/2025/may/07/russian-drone-strike-caused-tens-of-millions-worth-of-damage-to-chnobyl>, accessed 29 May 2025.

Figure 43 · U.K. Reactor Startups and Closures



Sources: WNISR with IAEA-PRIS and EDF Energy, 2022–2025

Type of Reactors: **AGR**: Advanced Gas Reactors; **FBR**: Fast Breeder Reactor; **PWR**: Pressurized Water Reactor; **SGHWR**: Steam-Generating Heavy Water Reactor.

In 2024, nuclear power provided stable 38.6 TWh (40 TWh gross), contributing 14.2 percent of the total supply (up 0.3 percentage points), half the contribution of wind, and down from a maximum share of 28 percent in 1997.

Eight of the nine operating reactors are AGRs in pairs at Torness, Heysham (four reactors), Hartlepool, and one PWR at Sizewell. All operating AGRs were completed in the 1980s, while Sizewell B started operating in 1995 (see Figure 43).

Managing reactors as they age is a constant challenge of any technology design, and the AGRs are no exception. As has been commented on in previous editions of the WNISR, issues with the core's graphite moderator bricks have raised continuous concerns.⁵³⁸

In January 2024, Electricité de France (EDF) announced that it was planning to extend the operating lifetimes of eight reactors and that a decision would be taken by the end of 2024.⁵³⁹ In December, EDF announced that they planned to operate Heysham-1 and Hartlepool until March 2027, while Heysham-2 and Torness AGR reactors could operate until March 2030 (see Table 11).⁵⁴⁰ EDF acknowledged that given the technical uncertainties of graphite aging the future generation from the AGRs “remains highly uncertain”.⁵⁴¹ The other reactor, at Sizewell B,

538 - ONR, “Graphite Core Ageing”, Office for Nuclear Regulation, Updated 28 March 2024, see <https://www.onr.org.uk/our-work/what-we-regulate/operational-power-stations/current-issues/graphite-core-ageing>; and ONR, “Graphite Core of AGRs”, Updated 13 March 2024, see <https://www.onr.org.uk/our-work/what-we-regulate/operational-power-stations/current-issues/graphite-core-of-agrs/>; both accessed 28 June 2025.

539 - EDF, “UK Nuclear Investment: Ensuring Output Stability Until 2026”, Electricité de France, 9 January 2024, see <https://www.edfenergy.com/media-centre/investment-boost-maintain-uk-nuclear-output-current-levels-until-least-2026>, accessed 16 June 2025.

540 - EDF, “Universal Registration Document 2024 Including the Annual Financial Report”, March 2025, see <https://www.edf.fr/sites/groupe/files/2025-04/2025-04-10-edf-urd-2024-en.pdf>, accessed 11 April 2025.

541 - Ibidem.

is scheduled to operate until 2035, but an investment decision is expected in 2025 to enable a 20-year lifetime extension.⁵⁴² Although, EDF notes that they need greater cost certainty and confidence in the commercial case before making the decision.⁵⁴³ As of early 2025, to keep the reactors operating, EDF said it had invested £8 billion (US\$10.8 billion) since 2009 and plans to make available £1.3 billion (US\$1.8 billion) more between 2025 and 2027.⁵⁴⁴

Table 11 · Status of EDF's U.K. AGR Nuclear Reactor Fleet (as of 1 July 2025)

Reactor	Net Capacity (MW)	Grid Connection	Closure/ Expected Closure
Dungeness B-1	545	03/04/1983	Closed June 2021
Dungeness B-2	545	29/12/1985	(Last power in 2018)
Hartlepool A-1	590	01/08/1983	March 2027
Hartlepool A-2	595	31/10/1984	
Heysham A-1	485	09/07/1983	March 2027
Heysham A-2	575	11/10/1984	
Heysham B-1	620	12/07/1988	March 2030
Heysham B-2	620	11/11/1988	
Hinkley Point B-1	485	30/10/1976	Closed
Hinkley Point B-2	480	05/02/1976	July/August 2022
Hunterston B-1	490	06/02/1976	Closed November 2021
Hunterston B-2	495	31/03/1977	Closed January 2022
Torness-1	595	25/05/1988	March 2030
Torness-2	605	03/02/1989	

Sources: WNISR and EDF, 2025⁵⁴⁵

In April 2025 the Office for Nuclear Regulation (ONR) had moved Hartlepool into ‘enhanced regulatory attention’ to achieve improved performance in specific areas, such as “conventional health and safety, the number of site incidents and the production of nuclear safety cases.”⁵⁴⁶

⁵⁴² - EDF Energy, “UK Nuclear Investment: Ensuring Output Stability Until 2026”, Press Release, 9 January 2024, see <https://www.edfenergy.com/media-centre/investment-boost-maintain-uk-nuclear-output-current-levels-until-least-2026>, accessed 11 January 2024.

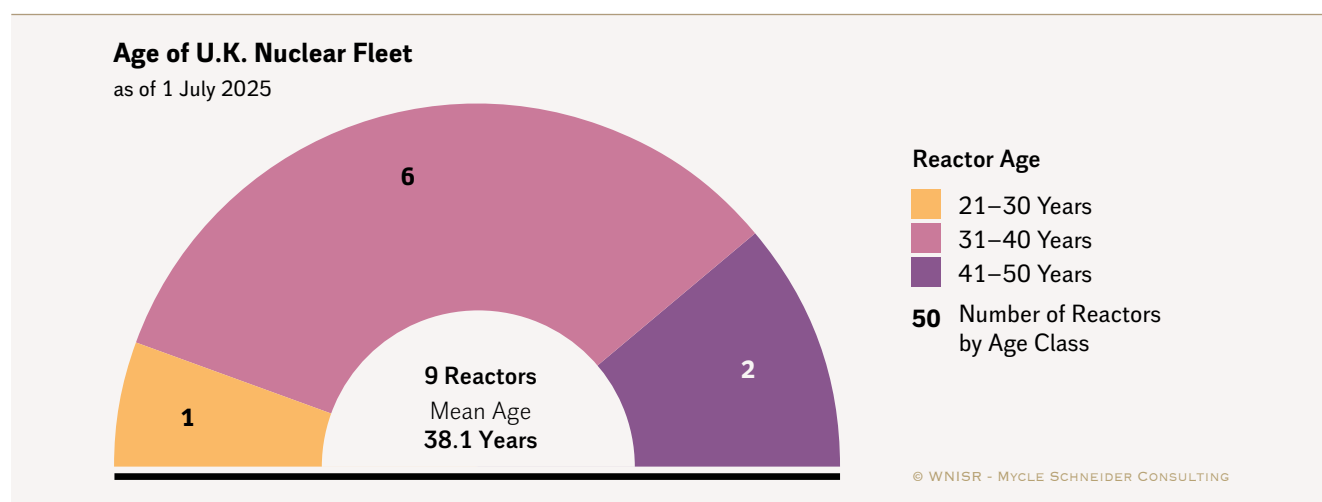
⁵⁴³ - EDF, “Sizewell B turns thirty!”, 14 February 2025, see <https://www.edfenergy.com/media-centre/sizewell-b-turns-thirty>, accessed 13 July 2025.

⁵⁴⁴ - EDF Energy, “EDF Confirms Nuclear Power Station Life Extensions”, 4 December 2024, see <https://www.edfenergy.com/media-centre/edf-confirms-boost-uks-clean-power-targets-nuclear-life-extensions>, accessed 8 December 2024; and EDF, “UK Nuclear Fleet Stakeholder Update”, January 2025, see <https://www.edfenergy.com/sites/default/files/2025-01/FM11351-UK-Nuclear-Fleet-Strategy-Update-2025-FINAL.pdf>, accessed 28 June 2025.

⁵⁴⁵ - EDF Energy, “EDF Confirms Nuclear Power Station Life Extensions”, 4 December 2024, see <https://www.edfenergy.com/media-centre/edf-confirms-boost-uks-clean-power-targets-nuclear-life-extensions>, accessed 8 December 2024.

⁵⁴⁶ - ONR, “Nuclear Site Moved into Enhanced Regulatory Attention”, Office for Nuclear Regulation, 7 April 2025, see <https://www.onr.org.uk/news/all-news/2025/04/nuclear-site-moved-into-enhanced-regulatory-attention/>, accessed 7 April 2025; and Oliver Adelman, “Regulator puts 1.3-GW Hartlepool reactors in UK into ‘enhanced attention’”, *Power in Europe*, S&P Global, 11 April 2025.

Figure 44 · Age Distribution of U.K. Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2025

U.K. Power Mix

The year 2024 broke several records in the electricity sector:

- Wind power reached the largest-ever share on the grid at any one time, providing over 68 percent of the country's electricity on 18 December 2024.⁵⁴⁷
- Wind provided a total of 84 TWh of electricity and is now very close to natural gas – providing 86 TWh, as the leading provider of power. The contribution of coal in 2024 was just 1.9 TWh, with the final station closing mid-year—this is down from 100 TWh a decade ago. Nuclear provided 40 TWh.⁵⁴⁸
- CO₂ emissions from the sector were also at a historic low, with the carbon intensity averaging just 125g CO₂/kWh.⁵⁴⁹

While wind production growth has slowed down in recent years, additional large offshore wind capacity is expected to come online in 2025 and 2026.⁵⁵⁰

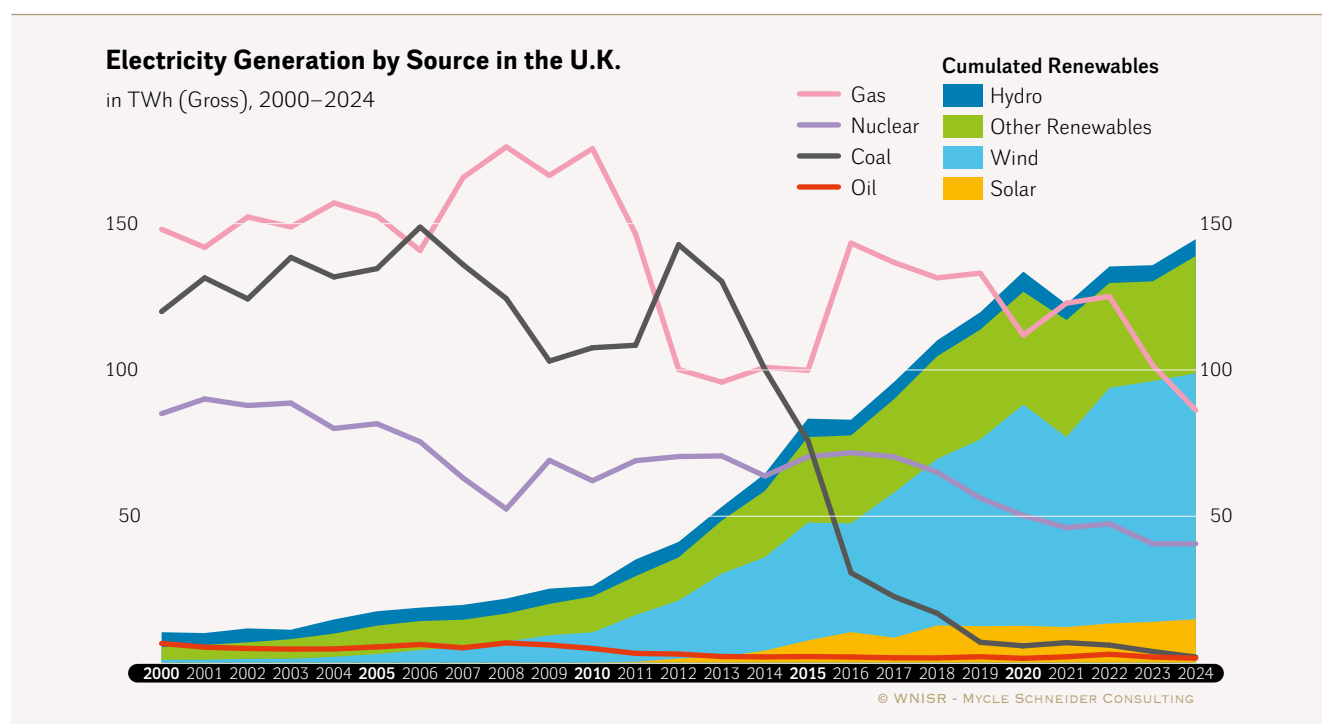
⁵⁴⁷ - NESO, "Britain's Electricity Explained: 2024 Review", National Energy System Operator, 7 January 2025, see <https://www.neso.energy/news/britains-electricity-explained-2024-review>, accessed 15 June 2025.

⁵⁴⁸ - Department of Energy Security and Net Zero, "Energy Trends: UK Electricity", U.K. Government, 26 June 2025, see <https://www.gov.uk/government/statistics/electricity-section-5-energy-trends>, accessed 13 July 2025.

⁵⁴⁹ - NESO, "Britain's Electricity Explained: 2024 Review", National Energy System Operator, 7 January 2025, see <https://www.neso.energy/news/britains-electricity-explained-2024-review>, accessed 15 June 2025.

⁵⁵⁰ - Simon Evans and Verner Viisainen, "Analysis: UK's electricity was cleanest ever in 2024", *Carbon Brief*, 2 January 2025, see <https://www.carbonbrief.org/analysis-uks-electricity-was-cleanest-ever-in-2024/>, accessed 15 June 2025.

Figure 45 · Electricity Generation by Source in the U.K. – The Coal Plunge

Source: U.K. Government, 2025⁵⁵¹

The U.K. has set some of the world's most ambitious greenhouse gas emission targets, committing to a 68 percent reduction from 1990 levels by 2030 and an 81 percent reduction by 2035.⁵⁵²

The Labour Government

On 4 July 2024, a Labour Government was elected for the first time in over 15 years. Under Prime Minister Sir Keir Starmer, the government made six key commitments, including one related to energy: the establishment of a new financial vehicle, 'Great British Energy', to help finance the energy transition.

Ed Miliband was re-appointed as the Secretary of State for Energy Security and Net Zero—a post held both in opposition and in the previous Labour Government, so he has considerable experience with the brief. He rapidly set out to reform the power sector and reconfirmed the election pledge to make the U.K. a “clean energy superpower”. This included a commitment to have a zero-carbon electricity system by 2030, which included plans to “double onshore wind, triple solar power and quadruple offshore wind.” To support these and other developments, the government is establishing a publicly-owned energy company—Great British Energy—

⁵⁵¹ - Department for Energy Security and Net Zero, “Electricity Statistics—Fuel Used in Electricity Generation And Electricity Supplied”, U.K. Government, Updated 26 June 2025, see <https://www.gov.uk/government/statistics/electricity-section-5-energy-trends>, accessed 27 June 2025.

⁵⁵² - Department for Energy Security and Net Zero, “UK's 2035 Nationally Determined Contribution (NDC) Emissions Reduction Target Under the Paris Agreement”, U.K. Government, 30 January 2025, see <https://www.gov.uk/government/publications/uk-2035-nationally-determined-contribution-ndc-emissions-reduction-target-under-the-paris-agreement>, accessed 15 June 2025; and U.K. Parliament, “The UK's Plans and Progress to Reach Net Zero by 2050”, 26 September 2024, see <https://commonslibrary.parliament.uk/research-briefings/cbp-9888/>, accessed 29 June 2025.

which was capitalized by the government with £8.3 billion (US\$11.2 billion).⁵⁵³ Although it later transpired that this would also fund nuclear projects.

In addition, the government lifted the de facto ban on onshore wind and changed grid connection rules so that projects ready to go were prioritized over those higher up the queue.⁵⁵⁴ In December 2024, the government published a Clean Power 2030 Action Plan, which, if fully implemented, would see the power sector generate 95 percent from “clean sources” in a “typical weather year”, with some 35 GW of unabated gas in reserve capacity.⁵⁵⁵

On nuclear, the plan stated

We are also committed to nuclear, including the lifetimes of existing nuclear projects where possible and the development of emerging low-carbon and renewable technologies that will play an important role beyond 2030.

The government further stated that

decisions on Sizewell C and the Great British Nuclear-led Small Modular Reactor programme will be taken at the Spending Review.

which took place in June 2025 (see following sections).⁵⁵⁶

Nuclear Newbuild

The U.K. has one power station with two reactors under construction at Hinkley Point C, and one project also with two units awaiting a Final Investment Decision (FID) at Sizewell C as of mid-2025.⁵⁵⁷ Both projects are based on the Franco-German European Pressurized Water Reactor (EPR) design.

Hinkley Point C

As has been documented in earlier editions of the WNISR, the construction of Hinkley Point C (HPC), instead of being the beginning of a bright new future for the nuclear industry, is the flagship project that exemplifies the scale of problems plaguing the

⁵⁵³ - Alan Walker, Suzanna Hinson and Nikki Sutherland, “Making Britain a Clean Energy Superpower”, Debate Pack 2024/0110, House of Commons, 25 July 2024, see <https://researchbriefings.files.parliament.uk/documents/CDP-2024-0110/CDP-2024-0110.pdf>, accessed 23 June 2025.

⁵⁵⁴ - U.K. Government, “Clean Power 2030: Action Plan: A New Era of Clean Electricity”, December 2024, see <https://assets.publishing.service.gov.uk/media/677bc80399c93b7286a396d6/clean-power-2030-action-plan-main-report.pdf>, accessed 23 June 2025.

⁵⁵⁵ - U.K. Government, “Clean Power 2030: Action Plan: A New Era of Clean Electricity”, December 2024, see <https://assets.publishing.service.gov.uk/media/677bc80399c93b7286a396d6/clean-power-2030-action-plan-main-report.pdf>, accessed 23 June 2025.

⁵⁵⁶ - HM Treasury, Department for Energy Security and Net Zero, “Thousands of Jobs to Be Created as Government Announces Multi-Billion-Pound Investment to Build Sizewell C”, Press Release, U.K. Government, 10 June 2025, see <https://www.gov.uk/government/news/thousands-of-jobs-to-be-created-as-government-announces-multi-billion-pound-investment-to-build-sizewell-c>, accessed 11 June 2025; and HM Treasury, “Spending Review 2025”, U.K. Government, June 2025, see <https://www.gov.uk/government/publications/spending-review-2025-document/spending-review-2025-html>, accessed 23 June 2025.

⁵⁵⁷ - The U.K. Government agreed FID on 22 July 2025; see Department for Energy Security and Net Zero, “Sizewell C Gets Green Light with Final Investment Decision”, Press Release, U.K. Government, 22 July 2025, see <https://www.gov.uk/government/news/sizewell-c-gets-green-light-with-final-investment-decision>, accessed 23 July 2025.

U.K. nuclear program. It was initially estimated at £₂₀₁₆ 18 billion (US\$₂₀₁₆ 24.3 billion) in 2016.⁵⁵⁸ At the time, Vincent de Rivaz, then chief executive of EDF, said, “We have the expertise, the supply chains and the teams ready to build Hinkley Point C safely, on time and on budget.”⁵⁵⁹ Since then the project’s costs have escalated dramatically to between £31 billion and £34 billion (US\$47–52 billion), in 2015 values,⁵⁶⁰ in 2025 money this is £43–47 billion (~US\$58–64 billion). This represents an increase of over 150 percent from the original budget, fundamentally undermining the economic case for new nuclear power. The rising construction cost is of concern to EDF, and it is seeking to find additional investors.⁵⁶¹ In June 2025, EDF announced that it had signed an agreement with Apollo to provide an additional £4.5 billion (US\$6 billion) in financing to assist with, among other things, the completion of HPC. The bonds would be issued in three tranches, starting with £1.5 billion (US\$2 billion) in June 2025 and then an equal amount in the following two years.⁵⁶²

The project timeline has suffered equally significant setbacks. Scheduled at construction start for completion in 2025, the first unit is not expected to begin operations before 2029 at the earliest, with more realistic scenarios from EDF pushing this to 2031. The delays stem from multiple factors, including the complexity of civil engineering work, construction conditions during the COVID-19 restrictions, and the challenge of restarting nuclear construction in Britain after a 20-year hiatus.

In 2013, to prepare the project for the Final Investment Decision, the government introduced a price guarantee for 35 years, a Contract for Difference (CfD), depending on the number of units ultimately built. If only HPC were built, the strike price would be £92.5/MWh (US\$₂₀₁₂ 146/MWh), but if Sizewell C was also built, the price for both would be £89.5/MWh (US\$₂₀₁₂ 141/MWh). However, the figure was not fixed; the £92.5/MWh is to rise in line with the Consumer Price Index from 2013.⁵⁶³ Therefore, if the plant had operated in 2025, the price EDF would have received would have already increased to £132/MWh (US\$₂₀₂₅ 178/MWh), and by 2030, will reach around £150/MWh (US\$₂₀₂₅ 202/MWh). Given that the CfD is expected to operate for 35 years, EDF can expect prices of around £350/MWh (US\$₂₀₂₅ 472/MWh) by 2065. In comparison, the latest round of offshore wind (AR6) in September 2024 awarded contracts with strike prices ranging from £₂₀₁₂ 54–59/MWh (US\$₂₀₁₂ 85–93/MWh) with an outlier floating wind turbine

558 - Department for Business, Energy & Industrial Strategy, “Hinkley Point C Contract Signed”, U.K. Government, 29 September 2016, see <https://www.gov.uk/government/news/hinkley-point-c-contract-signed>; and National Audit Office, “Report by the Comptroller and Auditor General—Hinkley Point C”, HC 40, Department for Business, Energy and Industrial Strategy, June 2017, see <https://www.nao.org.uk/wp-content/uploads/2017/06/Hinkley-Point-summary.pdf>; both accessed 29 June 2025.

559 - Rachel Millard, “Hinkley Point C Delay Deals Blow to UK Energy Strategy”, *The Financial Times*, 27 January 2024, see <https://www.ft.com/content/55ef86b4-f55c-47a9-8121-c6c8cf6b5b18>, accessed 13 July 2025.

560 - EDF, “Hinkley Point C Update”, Press Release, 23 January 2024, see <https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/hinkley-point-c-update-1>, accessed 23 January 2024.

561 - Ibidem.

562 - EDF, “EDF Announces the Signature of an Agreement with Apollo for the Issue of Up To £4.5 Billion of Unlisted Bonds”, Press Release, 20 June 2025, see <https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-announces-the-signature-of-an-agreement-with-apollo-for-the-issue-of-up-to-ps45-billion-of-unlisted-bonds>, accessed 23 June 2025.

563 - EDF, “Agreement Reached on Commercial Terms for the Planned Hinkley Point C Nuclear Power Station”, Press Release, 21 October 2013; and Department for Energy Security and Net Zero, and Department for Business, Energy and Industry Strategy, “Hinkley Point C”, Updated 17 July 2018, see <https://www.gov.uk/government/collections/hinkley-point-c>, accessed 28 June 2025.

project at £₂₀₁₂ 140/MWh (US\$₂₀₁₂ 221/MWh).⁵⁶⁴ Furthermore, wholesale prices, which are currently predominantly set by the price of natural gas, are expected to fall as more renewable sources of electricity are brought online.⁵⁶⁵ According to the *Financial Times*, consultancy Aurora Energy Research estimates wholesale electricity prices would be in the region of ~£78/MWh (US\$₂₀₂₅ 106/MWh) in the 2030s.⁵⁶⁶

Within the original agreement, if commercial operation starts after November 2029, the CfD is reduced by one year for every year of delay until 2033. This is the “longstop date”, after which the contract could be cancelled if the project is not completed. On 29 November 2022, the longstop date was extended from 1 November 2033 to 1 November 2036.⁵⁶⁷

The delay in completion has had an impact not only on EDF but also on the broader power market, which was expected to have 3.2 GW of capacity available. An assessment from early 2024 by Aurora Energy Research looked at the market implications of a three-year delay at Hinkley. It concluded that the wholesale price of electricity would rise by £₂₀₂₄ 5/MWh (US\$₂₀₂₄ 6.7/MWh) in 2029, assuming it was replaced by gas and an increase of 6.2 Mt of CO₂. However, they also concluded that the

cost of not paying for Hinkley C’s CfD is substantial, adding up to £1.6₂₀₂₂ billion [US\$₂₀₂₂ 2 billion] over the three years we are considering here [2028–2030]. That offsets a bit less than half the cost of rising wholesale prices from the delay to Hinkley C.

The assessment concluded that

in short, the delay of Hinkley C is bad news for everyone, unless they happen to own an unabated gas plant or an interconnector, of course.⁵⁶⁸

Sizewell C

Initially, it was proposed that EDF and China General Nuclear Power Co. (CGN) would develop a follow-on to HPC, the Sizewell C or SZC project, a copy of HPC, with two 1.6-GW EPR units. Chinese investment was limited to 20 percent, leaving EDF with 80 percent of the company that would take the project to FID; neither party was obliged to take any share in the company that built, owned, and operated it. In 2022, EDF stated that it had planned to pre-finance the development of its share of the initial budget of up to £458 million (US\$₂₀₂₂ 565 million), with no agreement to invest beyond that stage.⁵⁶⁹ On 24 June 2020, the U.K. Planning Inspectorate

⁵⁶⁴ - Department for Energy Security and Net Zero, “Contracts for Difference Allocation Round 6 Results”, 3 September 2024, see https://assets.publishing.service.gov.uk/media/66d6ad7c6eb664e57141db4b/Contracts_for_Difference_Allocation_Round_6_results.pdf, accessed 29 June 2025; and Maria Isabel Santaella, “UK Awards 5.3 GW of New Offshore Wind and 990 MW of New Onshore Wind”, Press Release, WindEurope, 3 September 2024, see <https://windeurope.org/newsroom/press-releases/uk-awards-5-3-gw-of-new-offshore-wind-and-990-mw-of-new-onshore-wind/>, accessed 23 June 2025.

⁵⁶⁵ - Rachel Millard, “Why Are the UK’s Industrial Electricity Prices so High?”, *The Financial Times*, 9 June 2025, see <https://www.ft.com/content/f3bcd4a4-0a5f-4fc1-ad8a-cf2530e6001a>, accessed 23 June 2025.

⁵⁶⁶ - Ibidem.

⁵⁶⁷ - Department for Energy Security & Net Zero, “Hinkley Point C: Contractual Documents”, U.K. Government, Updated 29 November 2022, see <https://www.gov.uk/government/publications/hinkley-point-c-documents>, accessed 4 July 2024.

⁵⁶⁸ - Tom Smout, “Comment: Missing the Point: What a Delay to Hinkley Point C Means for the GB Power Market”, Aurora Energy Research, 13 February 2024, see <https://auroraer.com/resources/aurora-insights/articles/comment-missing-the-point-what-a-delay-to-hinkley-point-c-means-for-the-gb-power-market>, accessed 23 June 2025.

⁵⁶⁹ - EDF, “Universal Registration Document 2021—Including the Annual Financial Report”, filed 17 March 2022, see <https://www.edf.fr/sites/groupe/files/2022-03/edf-2021-universal-registration-document.pdf>, accessed 4 July 2024.

accepted the application for development consent received the previous month.⁵⁷⁰ In July 2022, the government gave its development consent to build Sizewell C.⁵⁷¹

EDF was optimistic that it could reduce construction costs, and in 2020—less than two years into the official construction of HPC—it estimated that they would be £18 billion (US\$₂₀₂₀ 23 billion).⁵⁷² However, it was also hoping to reduce the financing costs of Sizewell C by shifting from the CfD mechanism to the Regulated Asset Base (RAB) model. EDF has suggested that with a better financing model and no “first-of-a-kind costs” (FOAK)⁵⁷³, the strike price could “peel away” by £36/MWh (US\$₂₀₁₂ 56.9/MWh).⁵⁷⁴ In its 2020, planning documents, EDF confirmed construction cost estimates of “circa £20 billion” (US\$₂₀₂₀ 25.6 billion).⁵⁷⁵

Then in early 2025, the *Financial Times* reported that the cost of the project was expected to be around £40 billion (US\$54 billion), “double the £20bn [US\$25.6 billion] estimate given by developer EDF and the UK government for the project in 2020.”⁵⁷⁶ Meanwhile, the French state auditor had recommended that it not take a final investment decision in Sizewell until it has reduced its financial exposure to HPC.⁵⁷⁷

In March 2021, EDF’s financial report for 2020 said an FID was likely to be made in mid-2022 but used cautious language on the whole about the project, stating “to date, it is not clear whether the group will reach this target,”⁵⁷⁸ which it did not.

There are two companies involved in the development of the project. A development company that took the project to the FID—Sizewell C Limited—and the company that then owns the project. The ownership structure of these two companies does not need to be the same. The government has bit by bit bought into the project and invested in the development company

570 - The Planning Inspectorate, “Application by NNB Nuclear Generation (SZC) Limited for an Order Granting Development Consent for The Sizewell C Project—Notification of decision to accept an application for Examination for an Order Granting Development Consent”, Email to Richard Bull, EDF Energy, National Infrastructure Planning, Ministry of Housing, Communities and Local Government, U.K. Government, 24 June 2020, see https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010012/EN010012-002268-A05%20Notification%20of%20decision%20to%20accept%20application_.pdf, accessed 19 July 2023.

571 - Planning Inspectorate, “The Sizewell C Project Development Consent Decision Announced”, Press Release, U.K. Government, 20 July 2022, see <https://www.gov.uk/government/news/the-sizewell-c-project-development-consent-decision-announced>, accessed 4 July 2024.

572 - *NEI Magazine*, “Plans For Sizewell C Submitted To UK Planning Inspectorate”, *Nuclear Engineering International*, 28 May 2020, see <https://www.neimagazine.com/news/newsplans-for-sizewell-c-submitted-to-uk-planning-inspectorate-7943163>, accessed 4 July 2024.

573 - Technically SZC is sharing HPC’s FOAK costs with £1.4 billion (US\$1.9 billion) to be handed over at FID; see Cour des comptes, “La Filière EPR : Une Dynamique Nouvelle, Des Risques Persistants”, French Court of Accounts, January 2025, p. 40, see <https://www.ccomptes.fr/sites/default/files/2025-01/20250114-La-filiere-EPR%20-une-dynamique-nouvelle-des-risques-persistants.pdf>, accessed 21 January 2025.

574 - Phil Chaffee, “United Kingdom: Industry Pushes for Government Action”, *Nuclear Intelligence Weekly*, 6 March 2020.

575 - SZC, “The Sizewell C Project—4.2 Funding Statement”, Revision 1.0, EDF Energy and CGN, submitted to Infrastructure Planning Inspectorate, May 2020, see https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010012/EN010012-001678-SZC_Bk4_4.2_Funding_Statement.pdf, accessed 4 July 2024.

576 - Gill Plimmer, Jim Pickard and Rachel Millard, “Cost of Sizewell C Nuclear Project Expected to Reach Close to £40bn”, *The Financial Times*, 14 January 2025, see <https://www.ft.com/content/0b483728-de5b-4f2e-8d00-c49885c572c9>, accessed 23 June 2025.

577 - Philip Whiterow, “EDF Told to Back Off Sizewell C Investment as Cost Reportedly Doubles”, Proactiveinvestors UK, 14 January 2025, see <https://www.proactiveinvestors.co.uk/companies/news/1064247/edf-told-to-back-off-sizewell-c-investment-as-cost-reportedly-doubles-1064247.html>, accessed 23 June 2025; and Cour des comptes, “La filière EPR : une dynamique nouvelle, des risques persistants”, January 2025, op. cit.

578 - EDF, “2020 Annual Results – Appendices”, February 2021, see <https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/financial-information/publications/financial-results/2020-annual-results/pdf/annual-results-2020-appendices-20210304.pdf>, accessed 4 July 2024.

and has said it will also take a significant share of ownership of Sizewell. The government's past, current and expected financial support includes:

- ➔ In June 2022, the government announced that it had taken out the £100 million (US\$₂₀₂₂ 123 million) option which would be converted into equity to take a 20 percent share in Sizewell C, should the project reach an FID.⁵⁷⁹
- ➔ In November 2022, the government made its Investment Decision and confirmed it was investing a further £679 million (US\$₂₀₂₂ 837 million).⁵⁸⁰ In the summer of 2023, the government announced it invested a further £511 million (US\$₂₀₂₃ 635 million) taking the total, at this stage, to **£1.2 billion** (US\$₂₀₂₃ 1.5 billion).⁵⁸¹
- ➔ On 15 January 2024, the Sizewell C Development Consent Order was triggered, opening the path for construction start, despite no FID. Later in January, the government made available £1.3 billion (US\$₂₀₂₄ 1.7 billion)—bringing the total government investment to **£2.5 billion** (US\$3.4 billion)—to enable infrastructure development work, such as roads and railways, to be undertaken prior to any FID.⁵⁸²
- ➔ In August 2024, the government announced the subsidy would be up to £5.5 billion (US\$₂₀₂₄ 7 billion)⁵⁸³ and allocated a further **£1.2 billion** (US\$₂₀₂₄ 1.5 billion) in September/December 2024⁵⁸⁴ then bringing the **total to £3.7 billion** (US\$₂₀₂₄ 4.7 billion).
- ➔ In April 2025, a further **£2.7 billion** (US\$3.7 billion) was announced, to be taken from the £5.5 billion (US\$7.4 billion). In total by April 2025, **£6.4 billion (US\$8.7 billion) had been spent and or handed to the Sizewell C development company**, leaving some £1.6 billion (US\$2.2 billion) from the £5.5 billion potentially still to be allocated.

In the spending review the government announced a further £14.2 billion (US\$19.2 billion) for Sizewell C between now and the financial year 2029–30.⁵⁸⁵ By the end of the decade, the government therefore intends to have allocated £17.9 billion (US\$24.2 billion) for the construction of Sizewell C. Even if there is no delay, construction will still be ongoing at that time and additional government funding can be expected to be needed.

⁵⁷⁹ - Alex Lawson, "UK Buys Option to Take 20% Stake in Sizewell C Nuclear Power Plant", *The Guardian*, 14 June 2022, see <https://www.theguardian.com/environment/2022/jun/14/uk-buys-option-to-take-20-stake-in-sizewell-c-nuclear-power-plant>, accessed 4 July 2024.

⁵⁸⁰ - BEIS and Great British Nuclear, "UK Government Takes Major Steps Forward to Secure Britain's Energy Independence", Press Release, U.K. Government, 29 November 2022, see <https://www.gov.uk/government/news/uk-government-takes-major-steps-forward-to-secure-britains-energy-independence>, accessed 14 January 2023.

⁵⁸¹ - Department for Energy Security and Net Zero, "Sizewell C Starts Private Investment Process", Press Release, U.K. Government, 18 September 2023, see <https://www.gov.uk/government/news/sizewell-c-starts-private-investment-process>, 16 July 2024.

⁵⁸² - Sizewell C, "Green Light for Construction Phase as Sizewell C Triggers Development Consent Order", 15 January 2024, see <https://www.sizewellc.com/news-views/green-light-for-construction-phase-as-sizewell-c-triggers-development-consent-order/>; and Department for Energy Security and Net Zero, "Further Steps to Prepare Sizewell C for Construction", Press Release, U.K. Government, 22 January 2024, see <https://www.gov.uk/government/news/further-steps-to-prepare-sizewell-c-for-construction>; both accessed 16 July 2024; also Rachel Morison, "UK Puts Up an Extra £1.3 Billion to Build Sizewell C Reactor", *Bloomberg*, as published by *Yahoo Finance*.

⁵⁸³ - U.K. Government, "Subsidy Scheme Details—SC11179—Sizewell C Development Expenditure Subsidy Scheme (DEVEX Scheme)", 24 August 2024, see <https://searchforuksubsidies.beis.gov.uk/scheme/?scheme=SC11179>, accessed 14 July 2025.

⁵⁸⁴ - U.K. Government, "Subsidy Scheme Details—SC11179—Sizewell Development Expenditure Subsidy Scheme (DEVEX Scheme)—Subsidy Award Number 25387", awarded 20 September 2024, published 20 December 2024, see <https://searchforuksubsidies.beis.gov.uk/searchresultsawardroute/?page=25387>, accessed 14 July 2025.

⁵⁸⁵ - Susanna Twidale, "Britain to Invest Further 14.2 Billion Pounds in Sizewell C Nuclear Project", *Reuters*, 10 June 2025, see <https://www.reuters.com/sustainability/boards-policy-regulation/britain-invest-142-billion-pounds-sizewell-c-nuclear-project-2025-06-09/>, accessed 23 June 2025.

Funding was not the only issue to be resolved, and in March 2024, a government standalone company, Sizewell C Ltd, signed a deal with EDF to purchase the freehold of the land for the new power plant, followed in April 2024 by Framatome signing contracts “worth multi-billion euros” with Sizewell C Ltd for the delivery of the nuclear steam supply systems, the safety instrumentation and control systems, long-term supply of nuclear fuel, and maintenance services.⁵⁸⁶ The land ownership question was one of the unresolved issues that had held up ONR’s issuing of a site license, which was finally granted in May 2024.⁵⁸⁷

The 2025 Spending Review, also stated that the government announced that it was “ending decades of delay on critical energy projects by giving the green light to Sizewell C, a Small Modular Reactor, and Carbon Capture, Usage and Storage programmes.”⁵⁸⁸ The additional nuclear spending were:⁵⁸⁹

- ➔ £2.5 billion (US\$3.4 billion) for the development of SMRs, with Rolls-Royce selected as the preferred bidder (see *Small Modular Reactors* below).
- ➔ £2.5 billion for nuclear fusion, to be split between research centers in Oxfordshire, West Burton and Cumbria.⁵⁹⁰
- ➔ Less commented in the media was the £13.9 billion (US\$18.8 billion) for the Nuclear Decommissioning Authority (NDA) to continue decommissioning and waste management activities at the existing sites.

Therefore, civil nuclear has received £33.1 billion (US\$44.9 billion), over a quarter of the total economy-wide capital expenditure of £120 billion (US\$162.6 billion) within the entire spending review.

It was expected that a French-U.K. nuclear summit would be held in July 2025, at which the Financial Investment Decision and funding from third parties would be announced. Rather the *Financial Times*, ran a story that suggested that the U.K. Government would increase its stake in the plant to 47.5 percent, with Brookfield Asset Management taking 25 percent, Centrica 15 percent and EDF further reducing its share to 12.5 percent.⁵⁹¹ As of 1 July 2025, details were yet to be confirmed by the U.K. Government.⁵⁹²

⁵⁸⁶ - Framatome, “Framatome Has Signed Contracts Worth Multi-Billion Euros for Sizewell C in the UK”, Press Release, 15 April 2024, see <https://www.framatome.com/medias/framatome-has-signed-contracts-worth-multi-billion-euros-for-sizewell-c-in-the-uk/>, accessed 16 April 2024.

⁵⁸⁷ - ONR, “Progress Update: Sizewell C Site Licence”, Press Release, Office for Nuclear Regulation, 11 July 2024, see <https://www.onr.org.uk/news/all-news/2022/07/progress-update-sizewell-c-site-licence/>; and ONR, “ONR Grants Nuclear Site Licence for Sizewell C”, Press Release, 7 May 2024, see <https://www.onr.org.uk/news/all-news/2024/05/onr-grants-nuclear-site-licence-for-sizewell-c/>; both accessed 16 July 2024.

⁵⁸⁸ - HM Treasury, “Spending Review 2025”, U.K. Government, June 2025, see <https://www.gov.uk/government/publications/spending-review-2025-document/spending-review-2025-html>, accessed 23 June 2025.

⁵⁸⁹ - Susanna Twidale, “Britain to Invest Further 14.2 Billion Pounds in Sizewell C Nuclear Project”, *Reuters*, 10 June 2025, see <https://www.reuters.com/sustainability/boards-policy-regulation/britain-invest-142-billion-pounds-sizewell-c-nuclear-project-2025-06-09/>, accessed 23 June 2025.

⁵⁹⁰ - Ethan Gudge, “Spending Review: Fusion Energy Industry Gets £2.5bn Funding Boost”, *BBC News*, 14 June 2025, see <https://www.bbc.com/news/articles/cvg59p9qeyxvo>, accessed 23 June 2025.

⁵⁹¹ - Ian Johnston, Ashley Armstrong and Jim Pickard, “UK Set to Hold Minority Stake in Sizewell C Nuclear Project”, *The Financial Times*, 9 July 2025, see <https://www.ft.com/content/b4cf9012-bb22-4fe6-b380-4e5d8e452647>, accessed 13 July 2025.

⁵⁹² - On 22 July 2025, Energy Secretary Ed Miliband signed the FID. The U.K. Government will take an “initial 44.9% stake”—the single largest equity share—in the project, La Caisse (Canada) 20%, Centrica and Amber Infrastructure (both U.K.) a 15% and 7.6% stake, respectively. French EDF is taking a 12.5% share in the project. See Department for Energy Security and Net Zero, “Sizewell C Gets Green Light with Final Investment Decision”, 22 July 2025, op. cit.

Other Sites

Other sites have been proposed and developed to various degrees over the years. This includes Moorside in Cumbria being investigated at some point by Toshiba-Westinghouse as well as Hitachi-GE owned Wylfa Newydd on Anglesey and Oldbury on Severn in South Gloucestershire.

In March 2024, the previous government announced that it had, through Great British Nuclear, purchased the nuclear sites in Wylfa and Oldbury and that the Wylfa site was the preferred option for a third large-scale nuclear project after Hinkley and Sizewell.⁵⁹³

In February 2025, in a gung-ho press release titled, “Government Rips up Rules to Fire-up Nuclear Power”, the government announced it was going to change the planning rules for nuclear. In particular, to lift the restrictions on the construction of reactors in England and Wales that are currently limited to the siting of new reactors at the eight existing sites, to include SMRs in planning rules and to remove the expiry date of nuclear planning rules. The government hopes that this will change the rules to “back the builders”.⁵⁹⁴

Small Modular Reactors (SMRs)

The government has continued to promote SMRs as a means of meeting future energy security and decarbonization objectives. This has gone beyond talk, and the government has made significant funding pledges.

In November 2020, to support the development of a potential next generation of reactors, the government proposed to feed up to £385 million (~US\$500 million) in an Advanced Nuclear Fund, with up to £215 million (US\$₂₀₂₀ 276 million) going to Rolls-Royce’s SMR program.⁵⁹⁵ This, in November 2021, led to Rolls-Royce announcing that it had received £210 million (US\$₂₀₂₁ 289 million) in government funding, £195 million (US\$₂₀₂₁ 268 million) in private funds,⁵⁹⁶ and an additional £85 million (US\$₂₀₂₁ 117 million) from the Qatar Investment Authority the following month.⁵⁹⁷

Rolls-Royce is developing a now 470-MW reactor—thus technically, it does not fall under the SMR definition with nominal capacities in the 30–300 MW range. In 2021, Rolls-Royce hoped its technology would complete the Generic Design Assessment (GDA) process with

⁵⁹³ - Department for Energy Security and Net Zero and Office of the Secretary of State for Wales, “New Nuclear Power Plant Earmarked for North Wales”, Press Release, 22 May 2024, see <https://www.gov.uk/government/news/new-nuclear-power-plant-earmarked-for-north-wales>, accessed 23 May 2024.

⁵⁹⁴ - Prime Minister’s Office and Department for Energy Security and Net Zero, “Government Rips up Rules to Fire-up Nuclear Power”, Press Release, U.K. Government, 6 February 2025, see <https://www.gov.uk/government/news/government-rips-up-rules-to-fire-up-nuclear-power>, accessed 19 February 2025.

⁵⁹⁵ - U.K. Government, “The Ten Point Plan for a Green Industrial Revolution”, November 2020, see https://assets.publishing.service.gov.uk/media/5fb5513de90e0720978b1a6f/10_POINT_PLAN_BOOKLET.pdf; and Department for Business, Energy and Industrial Strategy, “Advanced Nuclear Technologies”, Policy Paper, Updated 15 August 2023, see <https://www.gov.uk/government/publications/advanced-nuclear-technologies/advanced-nuclear-technologies>; both accessed July 2024.

⁵⁹⁶ - Rolls-Royce SMR, “Funding Secured to Enable Small Modular Reactor Delivery to Meet Net Zero”, Press Release, 8 November 2023, see <https://www.rolls-royce-smr.com/press/funding-secured-to-enable-small-modular-reactor-delivery-to-meet-net-zero>, accessed 5 July 2024.

⁵⁹⁷ - Rolls-Royce SMR, “Rolls-Royce and QIA Announce Nuclear Investment”, Press Release, 20 December 2021, see <https://www.rolls-royce-smr.com/press/rolls-royce-and-qia-announce-nuclear-investment>, accessed 5 July 2024.

U.K. regulators around September 2024 and deliver first power in the early 2030s,⁵⁹⁸ but the company concluded Step 2 in July 2024,⁵⁹⁹—out of three steps expected to take four years in total—and had already revised its expectations as of 2023, aiming for the conclusion of the final phase in August 2026.⁶⁰⁰ Per latest announcements, the process is now to end in December 2026.⁶⁰¹

Rolls-Royce has suggested that the nth-of-a-kind reactor (after ten have been built) would cost in the order of £1.8 billion (US\$2.4 billion) per 470-MW unit⁶⁰² and would generate power at £₂₀₁₉40–75/MWh (US\$₂₀₁₉51–96/MWh)⁶⁰³. In evidence submitted in 2017, Rolls-Royce told the House of Lords, that 7 GW would “be of sufficient scale to provide a commercial return on investment from a U.K.-developed SMR, but it would not be sufficient to create a long-term, sustainable business for U.K. plc.” The House of Lords concluded: “Therefore, any SMR manufacturer would have to look to export markets to make a return on their investment.”⁶⁰⁴ In May 2024, the Polish government announced that it had decided in principle on ordering the Rolls-Royce SMRs, although no timetable was made clear at this time.⁶⁰⁵ In June, Vattenfall announced that it was on a shortlist of two for an SMR order in Sweden.⁶⁰⁶ In September 2024, the Czech Republic selected Rolls-Royce from a choice of 7 designs to be taken forward for further review with the objective of building reactors near Temelín in the 2030s.⁶⁰⁷ And in March 2025, CEZ Group became a shareholder in Rolls-Royce SMR, subject to terms and conditions to progressively acquire 20 percent of the company.⁶⁰⁸ The agreement is to supply up to 3 GW of electricity.⁶⁰⁹

598 - WNN, “Rolls-Royce on Track for 2030 Delivery of UK SMR”, 11 February 2021, see <https://world-nuclear-news.org/Articles/Rolls-Royce-on-track-for-2030-delivery-of-UK-SMR>, accessed 5 July 2024.

599 - Environment Agency, “Rolls-Royce Small Modular Reactor Design Completes Second Step of Regulatory Assessment”, Press Release, U.K. Government, 30 July 2024, see <https://www.gov.uk/government/news/rolls-royce-small-modular-reactor-design-completes-second-step-of-regulatory-assessment>, accessed 31 July 2024.

600 - Environment Agency and Natural Resources Wales, “GDA Step 1 Statement: Summary on the Rolls-Royce SMR”, 3 April 2023, see <https://www.gov.uk/government/publications/gda-step-1-of-the-rolls-royce-smr-statement-of-findings/gda-step-1-statement-summary-on-the-rolls-royce-smr>, accessed 5 July 2024; and Science, Innovation and Technology Committee, “Delivering Nuclear Power”, HC 626, House of Commons, U.K. Parliament, July 2023, see <https://committees.parliament.uk/publications/41092/documents/200324/default/>, accessed 13 September 2023.

601 - Environment Agency, “New Nuclear Power Stations: Assessing Reactor Designs”, Updated 12 December 2024, see <https://www.gov.uk/guidance/new-nuclear-power-stations-assessing-reactor-designs>, accessed 14 July 2025.

602 - Science and Technology Committee, “Oral Evidence: Delivering Nuclear Power”, HC 626, House of Commons, 23 November 2022, see <https://committees.parliament.uk/oralevidence/11928/html/>, accessed 17 July 2024.

603 - Energy Security and Net Zero Committee, “Oral Evidence: Securing the Domestic Supply Chain”, HC 298, House of Commons, 13 March 2024, see <https://committees.parliament.uk/oralevidence/14492/pdf/>, accessed 17 July 2024.

604 - Science and Technology Committee, “Nuclear Research and Technology: Breaking the Cycle of Indecision”, HL Paper 160, House of Lords, published 2 May 2017, see <https://publications.parliament.uk/pa/ld201617/ldselect/ldsctech/160/160.pdf>, accessed 5 July 2024.

605 - Rolls Royce, “Polish Government Issues Decision in Principle on Rolls-Royce SMRs”, Press Release, 14 May 2024, see <https://www.rolls-royce-smr.com/press/polish-government-issues-decision-in-principle-on-rolls-royce-smrs>, accessed 27 July 2024.

606 - Vattenfall, “Vattenfall Takes the Next Step for New Nuclear Power at Ringhals in Sweden”, Press Release, 12 June 2024, see <https://group.vattenfall.com/press-and-media/pressreleases/2024/vattenfall-takes-the-next-step-for-new-nuclear-power-at-ringhals-in-sweden>, accessed 12 June 2024.

607 - Ministry of Industry and Trade, “ČEZ to Form Strategic Cooperation with Rolls-Royce SMR”, Press Release, Government of the Czech Republic, 19 September 2024, see <https://mpo.gov.cz/en/guidepost/for-the-media/press-releases/cez-to-form-strategic-cooperation-with-rolls-royce-smr--283166/>, accessed 29 June 2025.

608 - CEZ Group, “The CEZ Group Has Become a Shareholder in Rolls-Royce SMR”, 4 March 2025, see <http://www.cez.cz/en/investors/inside-information/the-cez-group-has-become-a-shareholder-in-rolls-royce-smr.-the-companies-will-work-together-on-the-construction-of-small-modular-reactors-in-the-united-kingdom-209277>, accessed 29 June 2025.

609 - Rolls-Royce, “Rolls-Royce SMR and ČEZ Group Partner to Deploy SMRs in UK and Czechia”, Press Release, 29 October 2024, see <https://www.rolls-royce.com/media/press-releases/2024/29-10-2024-rolls-royce-smr-and-cez-group-partner-to-deploy-smrs-in-uk-and-czechia.aspx>, accessed 6 November 2024.

Progress is also being made on the licensing of other reactor designs. In December 2023, the Office for Nuclear Regulation (ONR) began its GDA for a different reactor design from Holtec International,⁶¹⁰ and then in January 2024 for GE's BWRX-300 design.⁶¹¹ In December 2024, the ONR, the Environment Agency, and Natural Resources Wales announced that the BWRX-300 reactor, being designed by GE-Hitachi, had progressed to Step 2 of the GDA.⁶¹²

As mentioned above, in June 2025, the Spending Review, allocated £2.5 billion (US\$3.4 billion) for SMRs and to Rolls-Royce in particular, to identify a site later this year and connect projects to the grid in the mid-2030s. The funding will be for three SMR units. Simon Bowen, the interim chair of Great British Energy-Nuclear told the *Financial Times* that he would have liked to back more than one developer, but there was not any money.⁶¹³ Even this money was taken from Great British Energy, which was, when established in 2023 by the previous administration, not expected to fund nuclear projects.⁶¹⁴

Over the past 12 months, the government and private investors have considerably increased funding available for nuclear power in the U.K., and there has been agreement for the extension of the operating lives of existing reactors, so by some measures, it has been a successful year for the industry. However, despite this, by the end of the decade, nuclear contribution to the power sector is expected to decrease as the power sector is expected to be close to fully decarbonized, mainly due to the contribution of renewable energies.

UNITED STATES FOCUS



Overview

With 94 commercial reactors operational, the United States still has the largest nuclear fleet in the world. Nuclear energy generation in 2024 increased slightly—+0.9 percent—to 782 TWh. The nuclear sector's share of utility-scale electricity generation decreased to 18.2 percent, matching the historic low (since the 1980s) of 2022. When generation supplied by small-scale solar PV is included, nuclear provided only 17.8 percent of total generation, 0.2 percentage points less than in 2022.⁶¹⁵

Despite two new reactor startups between April 2023 and March 2024, the U.S. fleet continues to age, with a mid-2025 average of 43.7 years, making it amongst the oldest in the world:

⁶¹⁰ - ONR, "ONR Begins New SMR Reactor Assessment", Office for Nuclear Regulation, 7 December 2023, see <https://news.onr.org.uk/2023/12/onr-begins-new-smr-reactor-assessment/>, accessed 13 January 2024.

⁶¹¹ - ONR, "Generic Design Assessment (GDA) of New Nuclear Power Stations", 21 June 2024, see <https://www.onr.org.uk/news/all-news/2024/01/onr-begins-new-small-modular-reactor-assessment/>, accessed 16 July 2024.

⁶¹² - ONR, "GE-Hitachi's BWRX-300 Completes the First Step of Generic Design Assessment", 12 December 2024, see <https://www.onr.org.uk/news/all-news/2024/12/ge-hitachi-s-bwr-x-300-completes-the-first-step-of-generic-design-assessment/>, accessed 29 June 2025.

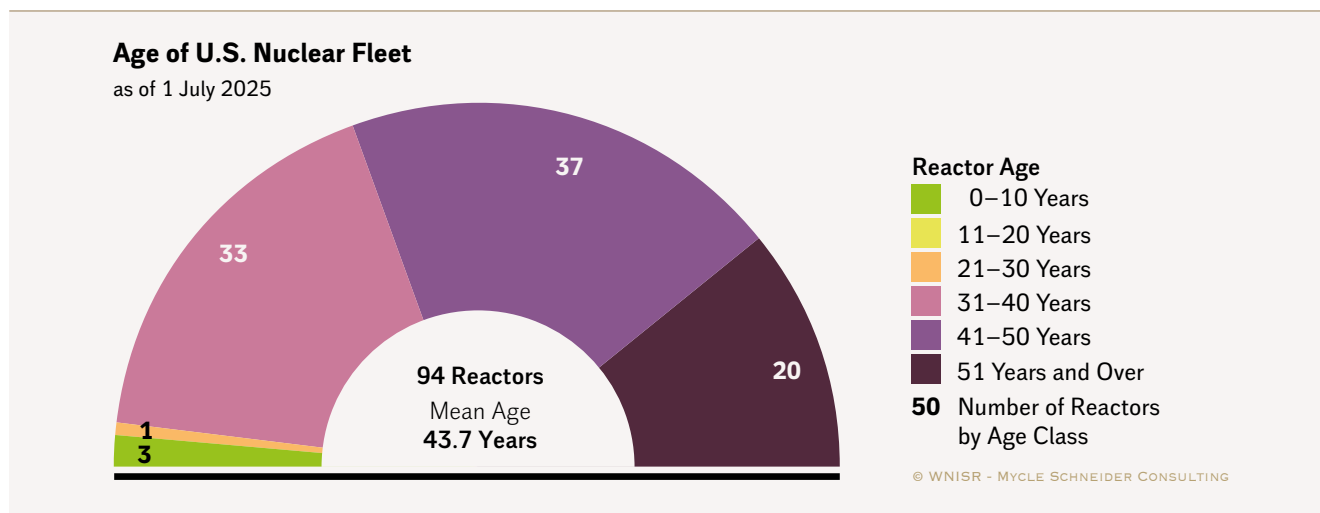
⁶¹³ - Jim Pickard and Rachel Millard, "GB Energy Handed £2.5bn Bill for Funding Small Modular Reactors", *The Financial Times*, 11 June 2025, see <https://www.ft.com/content/a8e3a775-33c9-4ad6-b01a-bfb212dfdcbe>, accessed 13 July 2025.

⁶¹⁴ - Nils Pratley, "Great British Energy's Budget Has Been Nuked", *The Guardian*, 11 June 2025, see <https://www.theguardian.com/business/nils-pratley-on-finance/2025/jun/11/great-british-energys-budget-has-been-nuked>, accessed 23 June 2025.

⁶¹⁵ - U.S. EIA, "Electric Power Monthly— Table 1.1. Net Generation by Energy Source: Total (All Sectors), 2015-January 2025", U.S. Energy Information Administration, 25 March 2025, see https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_1_01, accessed 11 April 2025.

57 units have operated for 41 years or more (of which 20 for more than 51 years) and all but four for 31 years or more (see Figure 46).

Figure 46 · Age Distribution of U.S. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2025

Since the March 2024 grid connection of the second Westinghouse AP-1000 reactor at Plant Vogtle—Unit 4—there are no new reactors under construction in the U.S. Construction permits for two new commercial nuclear power plants have been submitted to the Nuclear Regulatory Commission (NRC) since March 2024:

- ➔ The 340-MW TerraPower Natrium reactor project proposed to be built in the State of Wyoming; TerraPower submitted the Natrium application in March 2024, and the NRC reports that the review is expected to be completed in 2026.
- ➔ The 320-MW Long Mott project to be built in Texas. The Long Mott permit application is for four 80-MW small modular reactors and was submitted in March 2025. The reactors would provide power and process heat to an existing Dow chemical facility.

The U.S. Department of Energy (DOE) is sponsoring both projects through over US\$1 billion awards under the department's Advanced Reactor Demonstration Program.

Several factors have led to a perception that new market opportunities are opening up for nuclear generation in the U.S.: the availability of federal financing and subsidies; expressions of political and economic support from state government officials; and projections of sharply increasing electricity demand. This has resulted in a few proposals to restart reactors after permanent retirement. Licensing reviews have progressed in the first of these cases, to restart the Palisades reactor from its retirement in May 2022. The restart plan and its total cost were somewhat clouded by the findings of a mid-2024 inspection of the reactor's steam generators, which identified around 1,000 cracked tubes that must be plugged or repaired before restart.⁶¹⁶

⁶¹⁶ - Mitchell Boatman, "Holtec Pitches Repair Plan For Palisades Steam Generators", *The Holland Sentinel*, 22 January 2025, see <https://www.hollandsentinel.com/story/news/environment/2025/01/22/holtec-repair-plan-for-palisades-steam-generators-covert-township/77845104007/>, accessed 6 May 2025; and Office of Nuclear Reactor Regulation, "Palisades Nuclear Plant - Summary of Conference Call Regarding Steam Generator Tube Inspections (EPID L-2024-NFO-0008)", U.S. NRC, 1 October 2024, see <https://www.nrc.gov/docs/ML2426/ML24267A296.pdf>, accessed 7 July 2025.

In February 2025, Holtec applied for a license amendment to authorize an alternative to plugging the damaged tubes by installing stainless steel sleeves.⁶¹⁷ The NRC reports that it could issue the license amendment as soon as September 2025,⁶¹⁸ which could enable restart by the end of the year, according to Holtec.⁶¹⁹ In addition, the owners of the retired Duane Arnold-1 (2020) and Three Mile Island-1 (2019) reactors intend to submit restart applications to the NRC.

The submission rate of applications for license extensions declined between mid-2024 and mid-2025. The proposal to extend operation of the Diablo Canyon-1 and -2 reactors for five years continues to progress, with the ongoing review of Pacific Gas and Electric Company's (PG&E) license renewal application. No applications for Initial License Renewal (ILR) were submitted in the period, and only two applications (for a total of three units) for Subsequent License Renewal (SLR)⁶²⁰ from 60 to 80 years were submitted.⁶²¹

However, owners of 30 more reactors have notified the NRC they intend to file applications for license renewals in the coming years: one reactor for initial license renewal and 29 for subsequent license renewal. Between applications that are approved, currently under review, or pending submission, owners have decided to pursue SLRs for 51 of the 91 currently operating reactors built before the year 2000. In addition, owners are also planning to seek SLRs for three reactors that are currently proposed to restart from permanent shutdown: Duane Arnold-1, Palisades-1, and Three Mile Island-1.⁶²²

Subsidies and Financing for Nuclear Power

Following the January 2025 inauguration of President Donald Trump, there was renewed uncertainty about the availability of federal subsidies for the nuclear industry, clouding the potential for both new reactor construction and retirements of existing reactors. The principal subsidies of interest to the nuclear energy industry are:

- ➔ the Nuclear Power Production Tax Credit (Nuclear PTC), which provides tax credit subsidies to nuclear reactors built before 16 August 2022;
- ➔ the Clean Electricity Production Tax Credit (CE PTC) and the Clean Electricity Investment Credit (CE ITC), which provide tax credits to new “clean” generation sources, including new reactors;

⁶¹⁷ - U.S. NRC, “Holtec Palisades, LLC; Palisades Nuclear Plant; License Amendment Request”, United States Nuclear Regulatory Commission, *Federal Register*, Vol. 90, No. 71, 15 April 2025, see <https://www.federalregister.gov/documents/2025/04/15/2025-06396/holtec-palisades-llc-palisades-nuclear-plant-license-amendment-request>, accessed 7 July 2025.

⁶¹⁸ - U.S. NRC, “Palisades Nuclear Plant”, Updated 11 February 2025, see <https://www.nrc.gov/info-finder/reactors/pali.html>, accessed 28 August 2025.

⁶¹⁹ - Holtec International, “Palisades Restart Forges Ahead with Several Key Milestones Achieved”, 7 April 2025, see <https://holtecinternational.com/2025/04/07/hh-40-08/>, accessed 1 June 2025.

⁶²⁰ - Initial License Renewal (ILR) refers to extensions of operating licenses beyond the original 40-year license period, to as much as 60 years. Subsequent License Renewal (SLR) is the designation the U.S. Nuclear Regulatory Commission (NRC) uses for second license extensions, authorizing operation of a reactor beyond 60 years to 80 years.

⁶²¹ - U.S. NRC, “Status Of Subsequent License Renewal Applications”, Updated 17 July 2025, see <https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html>, accessed 28 August 2025.

⁶²² - Ibidem.

- ➔ the Clean Hydrogen Production Tax Credit (H₂ PTC), tax credits for producing hydrogen through processes with low/zero greenhouse gas (GHG) emissions.

2024 was the first tax year for which the Nuclear PTC subsidy can be claimed, and it has perhaps the greatest implications for the industry. Under the language of the IRA (Inflation Reduction Act), the value of the subsidy is reduced for reactors that earn revenues over US\$25/MWh during the tax year, zeroing out at US\$43.75/MWh.⁶²³ According to Constellation, the largest U.S. nuclear power plant owner/operator, the subsidy essentially underwrites the continued operation of existing reactors by creating a type of revenue floor through 2032. It said that

The nuclear production tax credit (PTC) in the IRA provides a stable foundation for consistent and growing earnings that will allow Constellation to continue investing in growth opportunities, including by adding clean energy generation to its fleet through uprates, repowering wind assets, license extensions and asset acquisitions while also returning capital to shareholders. The PTC provides revenue visibility and also preserves Constellation's ability to capture upside from tightening power market conditions.⁶²⁴

While it is unclear what the new government may do to roll back incentives for renewable energy, there are indications that the administration may not move to curtail programs that support nuclear power.⁶²⁵ One of the earliest signals was the Trump administration's affirmation of financing and subsidies to support a proposed restart of the retired Palisades-1 reactor. In March 2025, DOE disbursed the second installment of a US\$1.5 billion loan guarantee,⁶²⁶ and the U.S. Department of Agriculture (USDA) affirmed the award of US\$1.3 billion to rural energy cooperatives in the states of Michigan and Indiana for the purchase of electricity from Palisades.⁶²⁷ Together with US\$300 million in grants from the State of Michigan,⁶²⁸ Palisades' restart is to receive more than US\$3 billion in public sector support.

The USDA grant is effectively a subsidy to Holtec, helping the cooperatives cover the excessive cost of power from Palisades. The reactor closed in 2022, when a 15-year Power Purchase Agreement (PPA) between Entergy and the utility Consumers Energy (CE) expired.⁶²⁹ CE was unwilling to continue the PPA at what had proven to be significantly greater than wholesale

623 - U.S. Congress, "Public Law 117-169—An Act to Provide for Reconciliation Pursuant to Title II of S. Con. Res. 14", approved 16 August 2022, see <https://www.congress.gov/bills/117th-congress/house-bill/5376/text>, accessed 16 July 2024.

624 - Constellation, "Constellation Forecasts Strong Earnings Growth in 2024 and Beyond As Demand and Support for Clean Energy Builds", Press Release, 27 February 2024, see <https://www.constellationenergy.com/newsroom/2024/Constellation-Forecasts-Strong-Earnings-Growth-in-2024-and-Beyond-As-Demand-and-Support-for-Clean-Energy-Builds.html>, accessed 1 June 2025.

625 - On 4 July 2025, President Donald Trump signed legislation that includes amendments to the IRA which rapidly phase out tax credits for wind and solar energy sources, while preserving the Nuclear PTC for existing reactors and production and investment tax credits for new reactors until 2033; see Tara Patterson, "One Big Beautiful Bill Act Cuts the Power: Phase-Outs, Foreign-Entity Restrictions, and Domestic Content in Clean-Energy Credits", Frost Brown Todd Attorneys, 4 July 2025, see <https://frostbrowntodd.com/one-big-beautiful-bill-act-cuts-the-power-phase-outs-foreign-entity-restrictions-and-domestic-content-in-clean-energy-credits>, accessed 7 July 2025.

626 - U.S. Department of Energy, "DOE Approves Loan Disbursement for Palisades Nuclear Plant", United States Government, 17 March 2025, see <https://www.energy.gov/articles/doe-approves-loan-disbursement-palisades-nuclear-plant>, accessed 4 April 2025.

627 - Lucas Smolic Larson, "Trump Officials Unfreeze \$1.3B For Rural Co-Ops to Buy Michigan Nuclear Plant Power", *mLive*, 2 April 2025, see <https://www.mlive.com/environment/2025/04/trump-officials-unfreeze-13b-for-rural-co-ops-to-buy-michigan-nuclear-plant-power.html>, accessed 30 April 2025.

628 - Spencer Kimball, "Michigan Nuclear Plant Shows the Challenges the U.S. Will Face in Safely Restarting Old Reactors", *CNBC*, 22 March 2025, see <https://www.cnbc.com/2025/03/22/michigan-nuclear-plant-shows-challenges-us-safely-restart-old-reactors-.html>, accessed 30 April 2025.

629 - Entergy Corporation, "Entergy to Continue Operating Palisades Power Plant Until Spring 2022", Press Release, as published on *PR Newswire*, 28 September 2017, see <https://www.prnewswire.com/news-releases/entergy-to-continue-operating-palisades-power-plant-until-spring-2022-300527496.html>, accessed 30 April 2025.

market prices,⁶³⁰ averaging US\$68/MWh in the final year,⁶³¹ while annual average market electricity prices in the Midcontinent ISO had not exceeded US\$40/MWh over the previous decade.⁶³² Entergy was uninterested in continuing to operate Palisades in a competitive market environment, and in 2017 announced its intent to retire the reactor in Spring 2022.⁶³³ In Summer 2024, inspections necessary for the restart effort revealed extensive corrosion of steam generator tubes, requiring nearly 1,000 tubes to be plugged.⁶³⁴ Reportedly, according to a NRC representative speaking at a public meeting reviewing Holtec's plans, the repairs could delay the restart schedule.

States and the federal government continue to provide large volumes of financial support for both new and existing reactors. However, states that adopted nuclear subsidy programs prior to the IRA have taken steps to mitigate the costs of those programs. Via a complex formula in the statute, the Nuclear PTC is limited by the amount of other revenue the reactor receives, zeroing out at earnings of US\$43.75/MWh; however, the IRA permits reactor owners that receive state government subsidies to claim up to the full value of the PTC, if the company uses the funds to defray the cost of the state's subsidy. The subsidies in both Illinois⁶³⁵ and New Jersey⁶³⁶ are capped at values of about US\$10/MWh, less than the maximum amount of the Nuclear PTC. The recently adjusted amount of New York's nuclear subsidy is US\$14.70/MWh, less than the maximum value of the Nuclear PTC.⁶³⁷ As a result, the net cost of each of these state's subsidy programs is expected to reach US\$0 in 2025.

In addition, Massachusetts enacted legislation in 2024 that authorizes the state's utilities to enter into long-term contracts to purchase electricity from nuclear power plants in the neighboring states of Connecticut and New Hampshire.⁶³⁸ The legislation stems from a

630 - Entergy Corporation, "Palisades Power Purchase Agreement to End Early; Nuclear Plant to Close in 2018", Press Release, as published on *PR Newswire*, 8 December 2016, see <https://www.prnewswire.com/news-releases/palisades-power-purchase-agreement-to-end-early-nuclear-plant-to-close-in-2018-300375288.html>, accessed 30 April 2025.

631 - Entergy Nuclear Palisade and Consumers Energy Company, "Exhibit (10)(b): Palisades Nuclear Power Plant Power Purchase Agreement Between Entergy Nuclear Palisades, Llc and Consumers Energy Company", 11 July 2006, see <https://www.sec.gov/Archives/edgar/data/201533/000095012406004182/ko6781exv10wxy.txt>, accessed 30 April 2025.

632 - Potomac Economics, "2021 State of the Market Report: Analytical", Midcontinent Independent System Operator, June 2022, p. 3, see <https://cdn.misoenergy.org/2021%20State%20of%20the%20Market%20Analytical%20Appendix625294.pdf>, accessed 6 June 2025.

633 - Entergy Corporation, "Entergy to Continue Operating Palisades Power Plant Until Spring 2022", Press Release, as published on *PR Newswire*, 28 September 2017, see <https://www.prnewswire.com/news-releases/entergy-to-continue-operating-palisades-power-plant-until-spring-2022-300527496.html>, accessed 30 April 2025.

634 - Mitchell Boatman, "Holtec Pitches Repair Plan for Palisades Steam Generators", *The Holland Sentinel*, 22 January 2025, op. cit.; and Office of Nuclear Reactor Regulation, "Palisades Nuclear Plant - Summary of Conference Call Regarding Steam Generator Tube Inspections (EPID L-2024-NFO-0008)", United States Nuclear Regulatory Commission, addressed to Holtec International, 1 October 2024, see <https://www.nrc.gov/docs/ML2426/ML24267A296.pdf>, accessed 2 October 2024.

635 - Steve Daniels, "How Exelon Will Keep Getting Bailout Money in Illinois—Whether It Needs It or Not", *Crain's Chicago Business*, 2 August 2017, see <https://www.chicagobusiness.com/article/20170802/NEWS11/170809972/how-exelon-will-keep-getting-bailout-money-in-illinois-whether-it-needs-it-or-not>, accessed 6 June 2025; and Illinois General Assembly, "Bill Status of SB2814", enacted 7 December 2016, see <https://www.ilga.gov/Documents/Legislation/PublicActs/99/PDF/099-0906.pdf>, accessed 2 May 2025.

636 - Tom Johnson, "PSEG Says Without \$300M Ratepayer Nuclear Subsidy, It Will Close South Jersey Plants", *NJ Spotlight News*, 9 March 2021, see <https://www.njspotlightnews.org/2021/03/pseg-says-without-300m-ratepayer-nuclear-subsidy-it-will-close-south-jersey-plants/>, accessed 6 June 2025; and New Jersey Office of Legislative Services, "P.L. 2018, CHAPTER 16, approved May 23, 2018—An Act concerning nuclear energy, and supplementing Title 48 of the Revised Statutes.", approved 23 May 2018, see https://pub.njleg.gov/bills/2018/AL18/16_.HTM, accessed 2 May 2025.

637 - David G. Drexler, "Re: PSC Case 15-E-0302 - Proceeding on Motion of the Commission to Implement a Large-Scale Renewable Program and a Clean Energy Standard", Deputy General Counsel, New York State Department of Public Service, 24 January 2025, see <https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B00B99994-0000-C815-BF4C-3DF97450AAB7%7D>, accessed 6 May 2025.

638 - Jon Chesto, "With New Climate Bill, Mass. Politicians Are Ready to Go Nuclear", *The Boston Globe*, 22 November 2024, see <https://www.bostonglobe.com/2024/11/22/business/climate-bill-massachusetts-nuclear-power-energy/>, accessed 2 May 2025.

negotiation initiated by the governor of Connecticut to get Massachusetts to share the cost of his state's power purchase contracts with the Millstone Nuclear Power Plant, the costs of which have become unpopular with Connecticut consumers.⁶³⁹

The U.S. Congress has enacted other measures to promote the expansion of nuclear energy, the development and licensing of new reactor designs, and exports of nuclear reactors. President Biden signed the Prohibition on Russian Uranium Act in May 2024, which contains provisions that unlock US\$2.7 billion for domestic production and/or procurement of enriched uranium from non-Russian sources, including High-Assay Low-Enriched Uranium (HALEU).⁶⁴⁰ The HALEU issue raised eyebrows within the U.S. non-proliferation community.⁶⁴¹ The legislation offers the industry waivers through 2028, if reactor owners continue to rely on Russia for fuel. In another budgetary measure enacted in March 2024, Congress renewed and extended the Price-Anderson Act nuclear liability statute for another forty years.⁶⁴² Under a previous extension of Price-Anderson enacted in 2005, all existing reactors enjoy its protections in perpetuity with no further legislation required, but industry desired the new extension to ensure all reactors built after 2025 will be covered, as well.

Other Support Measures for the Nuclear Industry

In July 2024, President Biden enacted a bill, S. 870,⁶⁴³ which includes the Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy (ADVANCE) Act of 2024, an omnibus nuclear energy bill.⁶⁴⁴ The ADVANCE Act does not contain any direct subsidies for nuclear energy, but it includes several measures intended to promote nuclear energy and relax regulations on nuclear safety and licensing. It supports a U.S. Government agenda to compete with Russia and China for reactor exports, through tasking the NRC with creating the “International Nuclear Export and Innovation Branch” (within the Office of International Programs) to collaborate with domestic agencies involved in nuclear export deals, interact with international governance bodies, and assist other countries in establishing their own regulatory systems. It also relaxes the Section 810 procedures for authorizing nuclear technology exports that were established to ensure compliance with the Nuclear Nonproliferation Treaty; relaxation of Section 810 could expedite export deals but raises concerns about the potential

⁶³⁹ - Bruce Mohl, “Healey, Lamont Eyeing Possible Nuclear/Wind Deal”, *CommonWealth Beacon*, 13 September 2024, see <http://commonwealthbeacon.org/energy/healey-lamont-eyeing-possible-nuclear-wind-deal/>, accessed 6 May 2025.

⁶⁴⁰ - Paul Day, “Ban On Russian Uranium Aims to Revive American Supply”, *Reuters*, 4 June 2024, see <https://www.reuters.com/business/energy/ban-russian-uranium-aims-revive-american-supply-2024-06-04/>, accessed 16 July 2024; and U.S. Congress, “Public Law 118–62–May 13, 2024—Prohibiting Russian Uranium Import Act”, approved 13 May 2024, see <https://www.congress.gov/118/plaws/publ62/PLAW-118publ62.pdf>, accessed 5 August 2024.

⁶⁴¹ - John Carlson, “HALEU: Potential Safeguards and Non-Proliferation Implications”, Vienna Center for Disarmament and Non-Proliferation, 12 September 2024, see <https://vcdnp.org/haleu-potential-safeguards-and-non-proliferation-implications/>, accessed 20 May 2025.

⁶⁴² - Alex Polonsky and Molly Mattison, “Congress Gives 40-Year Extension for Price-Anderson Nuclear Liability Framework”, *Morgan Lewis*, 3 April 2024, see <https://www.morganlewis.com/blogs/upandatom/2024/04/congress-gives-40-year-extension-for-price-anderson-nuclear-liability-framework>, accessed 16 July 2024.

⁶⁴³ - U.S. Congress, “S. 870—An Act to Authorize Appropriations for the United States Fire Administration and Firefighter Assistance Grant Programs, to Advance the Benefits of Nuclear Energy, and for Other Purposes.”, approved 9 July 2024, see <https://www.congress.gov/bill/118th-congress/senate-bill/870/text>, accessed 5 August 2024.

⁶⁴⁴ - Ibidem; and Andres Picon, “E&E News: How a Nuclear Bill Became This Congress’ First Big Energy Win”, *E&E News/Politico*, 20 June 2024, see <https://subscriber.politicopro.com/article/eenews/2024/06/20/how-a-nuclear-bill-became-this-congress-first-big-energy-win-00164046>, accessed 16 July 2024.

for exporting technologies like uranium enrichment that could enable the proliferation of nuclear weapons.

The ADVANCE Act does away with the prohibition on foreign ownership of nuclear power plants in the U.S. for OECD (Organization for Economic Cooperation and Development) members and India, while prohibiting NRC from approving imports of enriched uranium from Russia and China without prior authorization by the Secretary of Energy and Secretary of State. The new statute also requires the NRC to modify its mission statement to include language stating that:

licensing and regulation of the civilian use of radioactive materials and nuclear energy be conducted in a manner that is efficient and does not unnecessarily limit—

- (1) the civilian use of radioactive materials and deployment of nuclear energy; or
- (2) the benefits of civilian use of radioactive materials and nuclear energy technology to society.

The act requires NRC to hire more employees to review license applications, expedite and relax its licensing procedures, and to exclude more topics from consideration in environmental reviews by expanding NRC’s practice of issuing “categorical exclusions.”

Extended Reactor Licenses

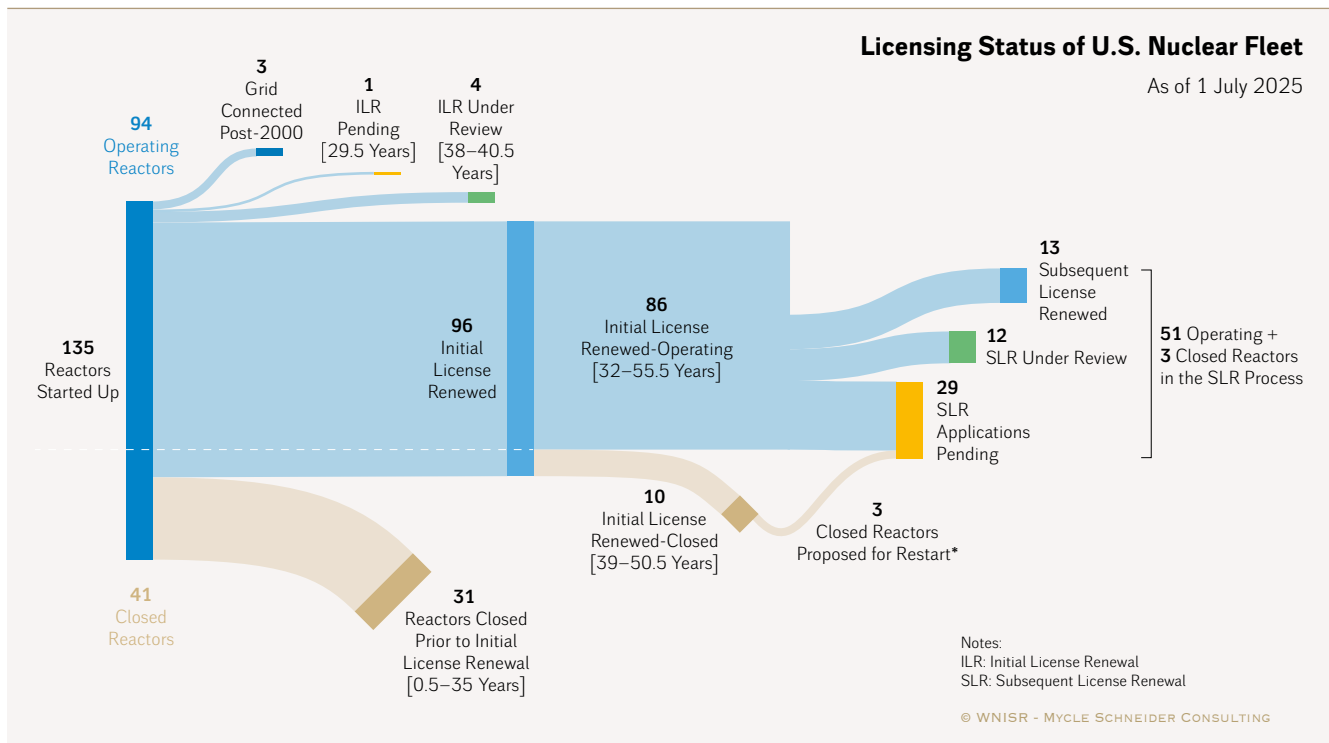
Under the Atomic Energy Act (AEA) and NRC regulations, the NRC issues initial operating licenses for commercial power reactors for 40 years. Regulations provide for license extensions in increments of up to 20 additional years. Due to the advanced age of the U.S. reactor fleet, reactor owners have begun applying for second license extensions, to permit operation out to as much as 80 years.

As shown on [Figure 47](#), as of mid-2025, 86 of the 94 operating U.S. units (91.5 percent) had already received 20-year Initial License Renewals (ILRs), which permit reactor operation beyond 40 and up to 60 years. The NRC previously approved ILRs of three currently retired reactors that are the subject of proposed restarts (Duane Arnold-1, Palisades-1, and Three Mile Island-1). Owners have filed ILR applications for four of the eight operating reactors which are not (yet) recipients of license renewals.⁶⁴⁵ The other four reactors have not been operating long enough to qualify for ILRs: Watts Bar-1 and -2, which began operation in 1996 and 2016, respectively; and Vogtle-3 and -4, which entered commercial operation within the last 24 months. TVA has notified NRC of its intention to apply for an ILR for Watts Bar-1 by the end of 2026.⁶⁴⁶

⁶⁴⁵ - U.S. NRC, “Status of Initial License Renewal Applications and Industry Initiatives”, Updated 25 March 2025, see <https://www.nrc.gov/reactors/operating/licensing/renewal/applications.html>, last accessed 28 August 2025.

⁶⁴⁶ - TVA, “Notice of Intent to Pursue License Renewal for Watts Bar Nuclear Plant, Unit 1 - Submittal Schedule”, Tennessee Valley Authority, filed with U.S. NRC, 25 March 2024, see <https://www.nrc.gov/docs/ML2408/ML24085A212.pdf>, 7 July 2025.

Figure 47 · Status of License Renewal Applications in the U.S.



Sources: compiled by WNISR with NRC, 2025

Notes: **ILR**: Initial License Renewal; **SLR**: Subsequent License Renewal.

* Subsequent License Renewal applications expected for three closed reactors: 2025 (Duane Arnolds), 2026 (Palisades), 2029 (TMI-1).

As of mid-2025, the NRC had approved Subsequent License Renewals (SLR) for thirteen reactors, which would permit their operation from 60 to 80 years. Applications for a further twelve reactors are under review,⁶⁴⁷ and owners have notified of their intentions to submit applications for a further 29 reactors between 2025 and 2034; of those pending applications, three are for currently retired reactors subject to proposed restarts. (See Figure 47) Thus, owners are planning towards or have received second license extensions for 54 percent of currently operating reactors.⁶⁴⁸ It is unclear how owners' plans to submit SLR applications may change if the Nuclear PTC subsidy program created by the Inflation Reduction Act is not extended past its current expiration date of 2032.

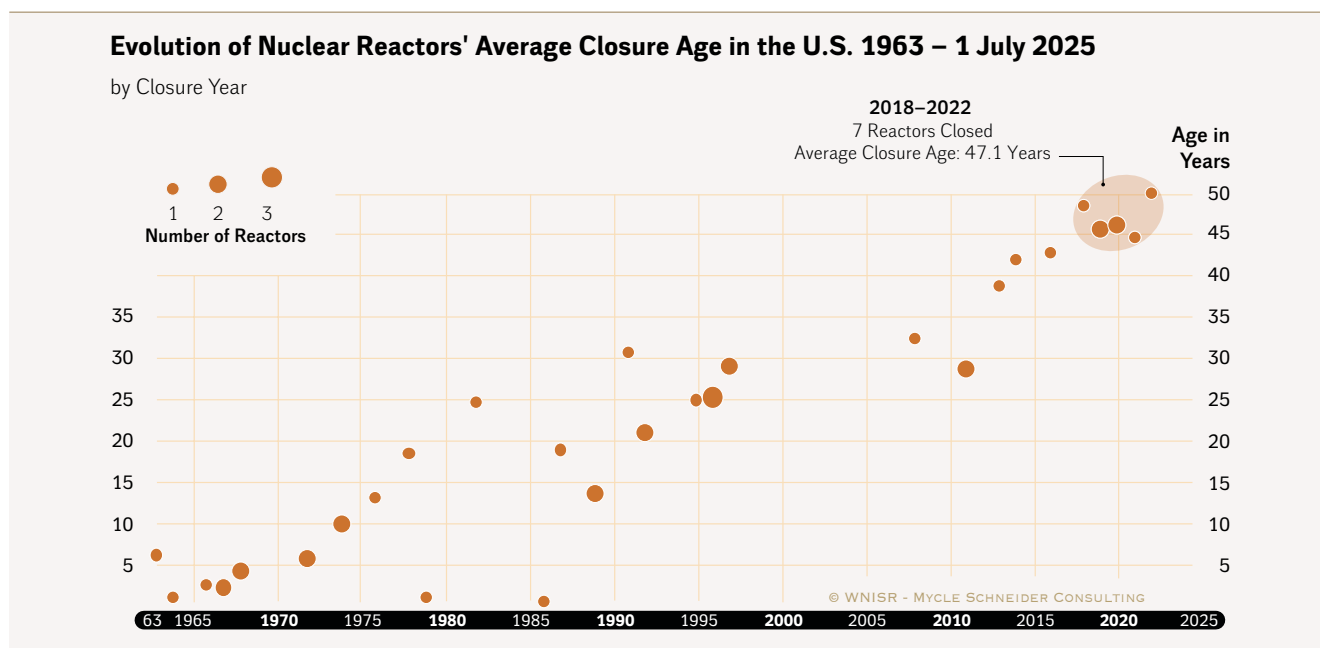
⁶⁴⁷ - U.S. NRC, "Status of Subsequent License Renewal Applications", Updated 17 July 2025, op. cit.

⁶⁴⁸ - Ibidem. Eight of the notices provided to the NRC do not specify for which reactors the owners intend to submit applications. Based on the reactors owned by those companies (Constellation and Vistra) which have already received ILRs; the current license expiration dates of those reactors; and the estimated dates by which the owners expect to submit applications, it is likely that the applications will involve 12 reactors: Quad Cities-1 and -2 (Constellation, 2027); Beaver Valley-1 and -2 (Vistra, 2028); Davis-Besse-1 (Vistra, 2029); FitzPatrick-1 (Constellation, 2030); Calvert Cliffs-1 and -2 (Constellation, 2030); LaSalle-1 and -2 (Constellation, 2034); and either Limerick-1 and -2 or Byron-1 and -2 (Constellation, 2034).

Reactor Closures and Proposed Restarts

The average age of the seven reactors closed in the U.S. over the five-year period 2018–2022—no unit was closed since—was 47.1 years (see Figure 48), significantly below their licensed lifetimes of 60 years.

Figure 48 · Evolution of Average Reactor Closure Age in the U.S.



Sources: WNISR with IAEA-PRIS, 2025

The retirement of Palisades in May 2022 marked the thirteenth closure in ten years, starting with the retirements of four reactors in the first half of 2013. With the effort to extend the operation of Diablo Canyon-1 and -2, there are no further anticipated closures before 2029, when the operating licenses of the oldest reactors in operation expire (Nine Mile Point-1 and Ginna-1). Constellation has notified the NRC of its intent to seek SLRs for Nine Mile Point-1 and Ginna-1,⁶⁴⁹ but the company has already delayed submittal of those applications,⁶⁵⁰ likely due to uncertainty regarding the ongoing availability of subsidies: New York State's ZEC program expires in March 2029, and the federal Nuclear PTC expires in 2032, just three years into the reactors' SLR periods.

Restarts of Retired Reactors

The effort by Holtec and Michigan officials to bring Palisades-1 out of retirement would make it the first reactor in the U.S.—and only the second in the world after the restart of Armenian-2 (also Metsamor-2) in Armenia, several years after its closure in 1989—to return to operation after entering decommissioning. In recent months, the owners of two other reactor owners have notified the NRC that they plan to seek restarts: NextEra to pursue bringing

649 - U.S. NRC, "Status of Subsequent License Renewal Applications", Updated 17 July 2025, op. cit.

650 - Christopher D. Wilson, "Updated Notice of Intent to Pursue Subsequent License Renewal Applications", Constellation, 9 May 2024, see <https://www.nrc.gov/docs/ML2413/ML24130A126.pdf>, accessed 7 July 2025.

Duane Arnold-1 back into service, after its retirement in 2020⁶⁵¹; and Constellation plans to restart Three Mile Island-1.⁶⁵² The latter is in consequence of an agreement with Microsoft to sell power from the reactor under a forthcoming 20-year Power Purchase Agreement (PPA). As part of the restart project, Constellation proposes to rebrand Three Mile Island-1 as the Crane Clean Energy Center, named after the deceased CEO of Exelon under whose tenure the reactor was retired in 2019. In both cases, the restart plans surfaced in connection with anticipated growth in electricity demand and the development of energy-intensive hyperscale data centers and artificial intelligence technology.⁶⁵³

The proposed restart of Palisades-1 could establish regulatory pathways and test the practical feasibility of the practice for the rest of the industry. Holtec faces significant obstacles to doing so.⁶⁵⁴ it has no experience building or operating nuclear reactors, its core businesses are in developing and manufacturing irradiated fuel storage systems and, since 2018, in managing the decommissioning of reactors. Palisades is known to have a long list of maintenance needs, such as the control rod drive seals, which would require significant expense for a new owner to take on.⁶⁵⁵ As reported above, inspections in Summer 2024 discovered extensive corrosion of steam generator tubes, requiring maintenance that could delay Holtec's proposed restart schedule.

Because the restart of a reactor that has entered decommissioning is unprecedented in the U.S., the NRC licensing process may take longer than expected and be subject to interventions and legal challenges. Holtec has submitted nine applications for license amendments, technical specification changes, and other approvals necessary to resume operations.⁶⁵⁶ NRC projects that these reviews could be completed before September 2025, subject to completion of repairs and other contingencies.⁶⁵⁷

⁶⁵¹ - NextEra Energy Duane Arnold LLC, "Request for Exemption from Certain Termination of License Requirements of 10 CFR § 50.82", filed with U.S. Nuclear Regulatory Commission, 23 January 2025, see <https://www.nrc.gov/docs/ML2502/ML25023A270.pdf>, accessed 1 June 2025; and Donnelle Eller, "Iowa's Sole Nuclear Plant May Restart by Late 2028 to Meet Growing Demand, Owner Says", *The Des Moines Register*, 24 January 2025, see <https://www.desmoinesregister.com/story/money/business/2025/01/24/duane-arnold-nuclear-plant-iowa-might-reopen-by-2028-nextera/77926765007/>, accessed 8 May 2025.

⁶⁵² - Constellation, "Regulatory Path to Reauthorize Power Operations", submitted to U.S. Nuclear Regulatory Commission, November 2024, see <https://www.nrc.gov/docs/ML2431/ML24310A104.pdf>, accessed 1 June 2025; and Sonal Patel, "Constellation Races to Revive Crane Nuclear Plant Amid Tight Timelines, Market Shifts", *POWER Magazine*, 26 February 2025, see <https://www.powermag.com/constellation-races-to-revive-crane-nuclear-plant-amid-tight-timelines-market-shifts/>, accessed 8 May 2025.

⁶⁵³ - Ibidem; and Sonal Patel, "Constellation Races to Revive Crane Nuclear Plant Amid Tight Timelines, Market Shifts", *POWER Magazine*, 26 February 2025, see <https://www.powermag.com/constellation-races-to-revive-crane-nuclear-plant-amid-tight-timelines-market-shifts/>, accessed 8 May 2025; and Constellation, "Constellation to Launch Crane Clean Energy Center, Restoring Jobs and Carbon-Free Power to The Grid", Press Release, 20 September 2024, see <https://www.constellationenergy.com/newsroom/2024/Constellation-to-Launch-Crane-Clean-Energy-Center-Restoring-Jobs-and-Carbon-Free-Power-to-The-Grid.html>, accessed 1 June 2025.

⁶⁵⁴ - David Eggert, "Michigan Dangles US\$150M Toward Restarting Nuclear Plant, but What Else Would It Take?", *Crain's Detroit*, 7 August 2023, see <https://www.craigslist.com/energy/will-michigan-nuclear-plant-restart-state-money>, accessed 10 August 2023.

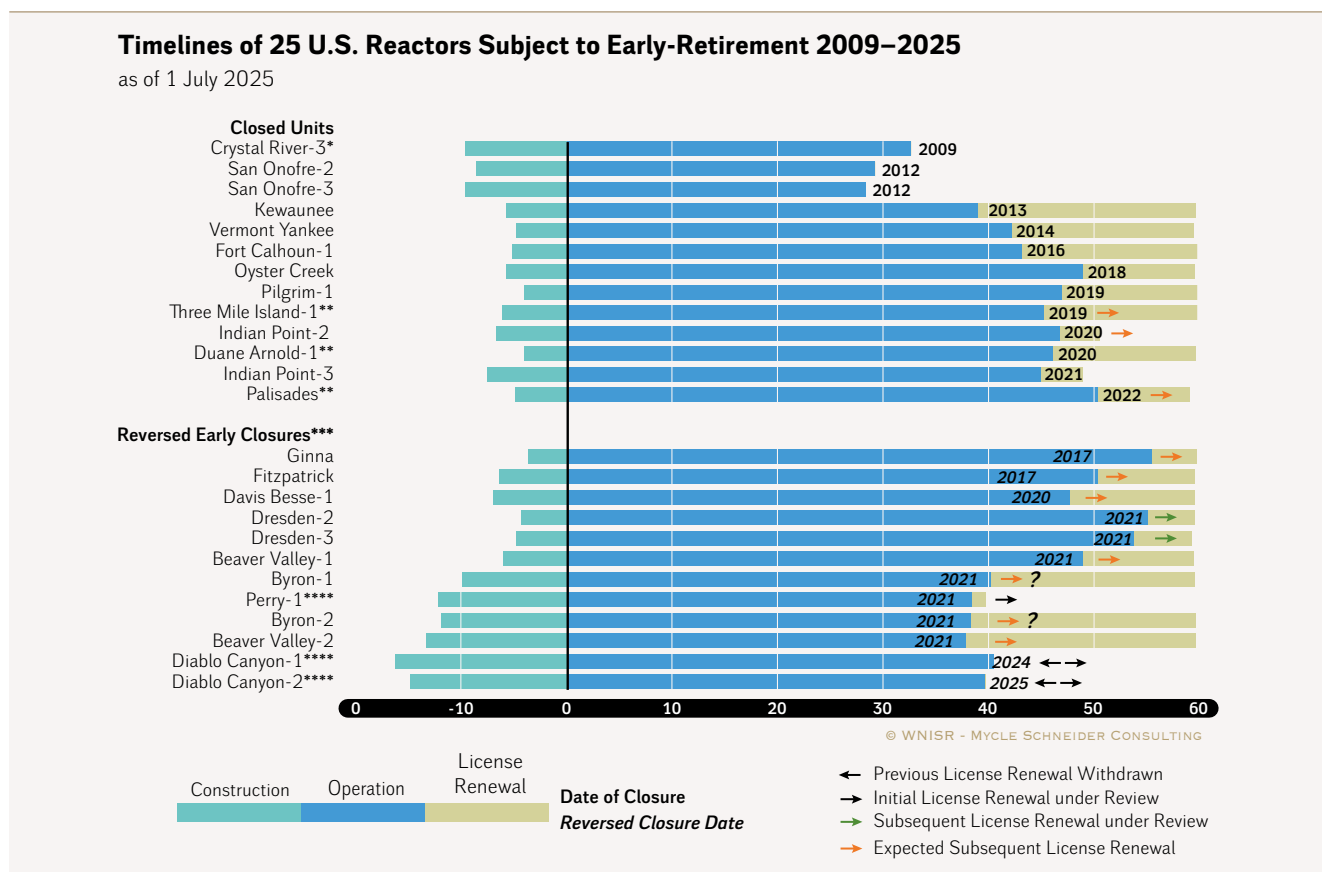
⁶⁵⁵ - Audrey Whitaker, "Neighbors Show Concern About Possible Restart of Palisades Nuclear Plant", *mlive*, 18 April 2024, see <https://www.mlive.com/public-interest/2024/04/neighbors-show-concern-about-possible-restart-of-palisades-nuclear-plant.html>, accessed 28 July 2024.

⁶⁵⁶ - U.S. NRC, "Power Reactor Sites—Palisades Nuclear Plant", Updated 11 February 2025, see <https://www.nrc.gov/info-finder/reactors/pali.html>, accessed 8 May 2025.

⁶⁵⁷ - On 24 July 2025, the NRC released a statement saying: "The Nuclear Regulatory Commission has approved a series of licensing and regulatory actions that will pave the way for restart of the Palisades Nuclear Plant."; see U.S. NRC, "NRC Approves Major Licensing Actions Required for Restart of Palisades NPP", Press Release 25-046, 24 July 2025, see <https://www.nrc.gov/cdn/doc-collection-news/2025/25-046.pdf>, accessed 26 July 2025.

Figure 49 provides an overview of reactors retired between 2009 and 2022 (some of which are now subject to reversals) or previously considered for “early closure”.

Figure 49 · U.S. Early Reactor Retirements and Some Reversals



Sources: Various, compiled by WNISR, 2025

Notes: Eight of the notices (Letters of Intent) provided to the NRC do not specify for which reactors the owners intend to submit applications and likely involves Fitzpatrick, Davis Besse-1 & -2, and possibly Byron-1 & -2; see above.

* Crystal River: No production after 2009 (WNISR considers it closed as of this date). Official closure announced in 2013. Renewal application submitted in 2008, withdrawn in 2013; see U.S. NRC, “Crystal River – License Renewal Application”, Updated 9 December 2016, see <https://www.nrc.gov/reactors/operating/licensing/renewal/applications/crystal-river.html>, accessed 8 September 2020.

** Potential restart from early closure. Future Subsequent License Renewal applications expected in 2025 (Duane Arnolds), 2026 (Palisades), 2029 (TMI-1).

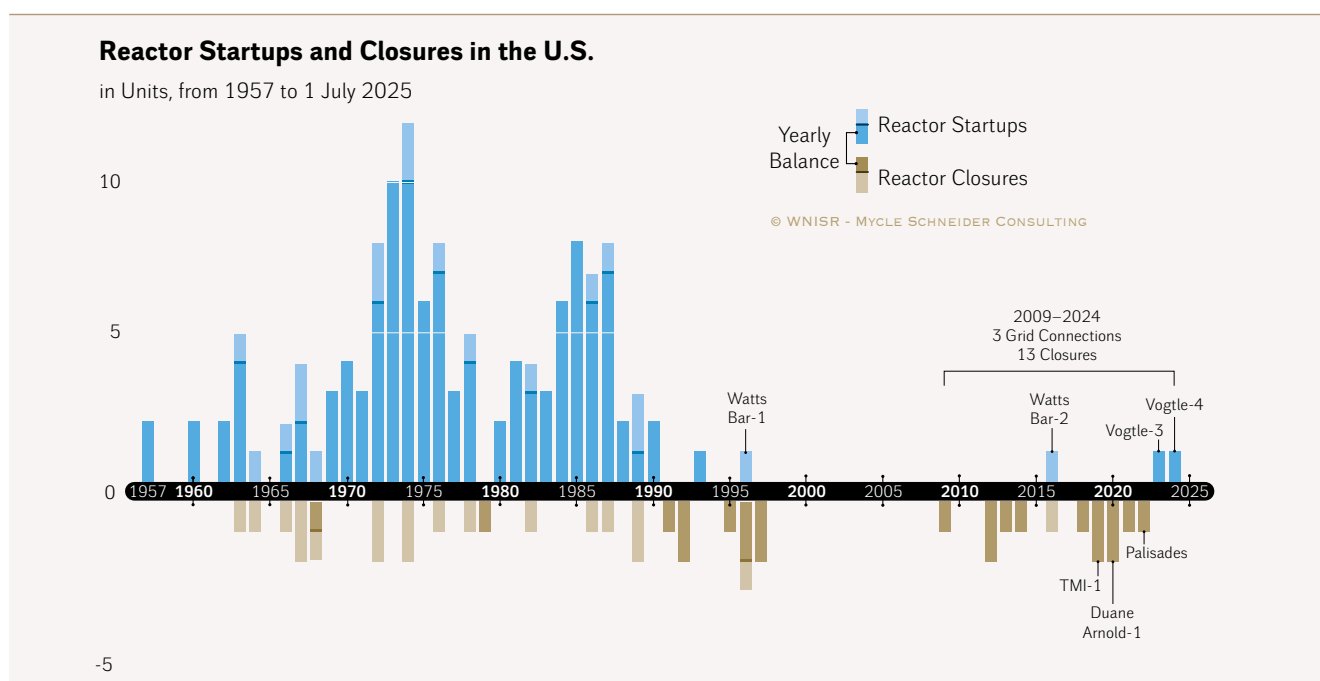
*** Early closure reversed following access to new subsidies.

**** Initial License Renewal application canceled or withdrawn in 2018. New applications submitted in 2023, currently under review.

New Reactors: Proposals, Planning, and Policy Developments

After a 20-year pause, three reactors were connected to the grid between 2016 and 2024 (see Figure 50). Since the completion of Vogtle Unit 3 and 4, there are no new commercial reactors under construction in the U.S. for the first time since construction of Watts Bar-2 was reactivated in 2007 (see Figure 51).

Figure 50 · Reactor Startups and Closures in the U.S.



Sources: WNISR with IAEA-PRIS, 2025

NRC is currently reviewing three construction permit applications. One reactor design received Standard Design Approval (SDA) in May 2025.⁶⁵⁸

- ➔ **TerraPower’s Natrium project** in Kemmerer, Wyoming, to build a 345-MW sodium-cooled fast neutron reactor based on General Electric’s PRISM design. The facility design includes a molten salt thermal storage loop capable of generating an additional 150-MW for up to six hours. TerraPower submitted the Construction Permit Application (CPA) in March 2024, and NRC expects the review to be completed in 2026.⁶⁵⁹ The company broke ground on a “test and fill facility” for the reactor’s sodium coolant/moderator in June 2024.⁶⁶⁰
- ➔ **Dow Chemical’s Long Mott Generating Station (LMGS)**, a 320-MW plant comprising four X-energy Xe-100 high-temperature gas-cooled, graphite-moderated reactors. LMGS would be located at Dow’s UCC Seadrift petrochemical plant in Texas. The reactors would have a nominal electricity generating capacity of 320 MW and could produce up to

⁶⁵⁸ - U.S. NRC, “NRC Approves Standard Design for NuScale US460 Small Modular Reactor”, 28 May 2025, see <https://www.nrc.gov/cdn/doc-collection-news/2025/25-033.pdf>, accessed 6 June 2025.

⁶⁵⁹ - U.S. NRC, “Advanced Reactor Application Projects—TerraPower, LLC -- Kemmerer Power Station Unit 1 Application”, Updated 28 April 2025, see <https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/applicant-projects/terrapower.html>, accessed 13 May 2025.

⁶⁶⁰ - Brian Martucci, “Terrapower Begins Construction at 345-MW Advanced Reactor Site in Wyoming”, *Utility Dive*, 12 June 2024, see <https://www.utilitydive.com/news/terrapower-smr-advanced-nuclear-reactor-bill-gates/718722/>, accessed 13 May 2025.

800 MWt of steam process heat. Dow submitted the CPA in March 2025.⁶⁶¹ It projects a five-year construction schedule, with completion in 2033.⁶⁶²

- ➔ **TVA's Clinch River SMR project**, to construct a 300-MW GE-Hitachi BWRX-300 reactor. In 2019, TVA received an Early Site Permit (ESP) to construct a then-unspecified SMR at the Clinch River Site, where U.S. DOE canceled construction of a demonstration breeder reactor in 1983. TVA completed submission of the CPA in May 2025.⁶⁶³
- ➔ **Nuscale's US-460**, a standardized 462-MW facility comprised of six 77-MW light-water SMRs, received a Standard Design Approval (SDA) from the NRC in May 2025.⁶⁶⁴ In November 2023, due to cost escalation, NuScale canceled its Carbon-Free Power Project that would have demonstrated the US-460 design. The company continued to pursue SDA for the US-460, but it has no proposed projects or procurement deals to build it. SDA does not confer the same degree of technical review and approval as Standard Design Certification (SDC), as it “does not prevent issues resolved by the design review process from being reconsidered during a rulemaking for a design certification or during hearings associated with a construction permit or combined license application”; rather, NRC characterizes the SDA as providing “incremental progress towards the licensing or certification” of a reactor design.⁶⁶⁵

The only nuclear reactor construction projects currently underway are three prototypes of commercial reactors and the U.S. Department of Defense's Project Pele, a 5-MW mobile microreactor demonstration project from BWXT Advanced Technologies.⁶⁶⁶ The prototype reactors are:

- ➔ In May 2025, Kairos began nuclear construction of its Hermes non-power test reactor (35 MWt), at Oak Ridge National Laboratory in Tennessee, a molten-fluoride-salt design;⁶⁶⁷

⁶⁶¹ - U.S. NRC, “Advanced Reactor Application Projects—Long Mott Energy, LLC – Long Mott Generating Station Xe-100 Power Reactor Application”, Updated 4 April 2025, see <https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/applicant-projects/long-mott.html>, accessed 13 May 2025.

⁶⁶² - Long Mott Energy, “Long Mott Generating Station—Construction Permit Application—Part I General and Financial Information”, Revision 0, filed with U.S. NRC, March 2025, see <https://www.nrc.gov/docs/ML2509/ML25090A059.pdf>, accessed 1 June 2025.

⁶⁶³ - U.S. NRC, “Tennessee Valley Authority; Clinch River Nuclear Site; Construction Permit Application”, *Federal Register*, 10 June 2025, see <https://www.federalregister.gov/documents/2025/06/10/2025-10465/tennessee-valley-authority-clinch-river-nuclear-site-construction-permit-application>, accessed 7 July 2025.

⁶⁶⁴ - U.S. NRC, “Standard Design Approval for the Nuscale Power Company, LLC US460 Power Plant Design”, addressed to NuScale Power, 29 May 2025, see <https://www.nrc.gov/docs/ML2512/ML25129A004.pdf>; and U.S. NRC, “NRC Approves Standard Design for NuScale US460 Small Modular Reactor”, Press Release, 29 May 2025, see <https://www.nrc.gov/cdn/doc-collection-news/2025/25-033.pdf>; both accessed 1 June 2025.

⁶⁶⁵ - U.S. NRC, “A Regulatory Review Roadmap for Non-Light Water Reactors” October 2016, see <https://www.nrc.gov/docs/ML1629/ML16291A248.pdf>, accessed 6 June 2025.

⁶⁶⁶ - U.S. Department of Defense, “DoD Breaks Ground on Project Pele: A Mobile Nuclear Reactor for Energy Resiliency”, Press Release, Government of the United States, 24 September 2024, see <https://www.defense.gov/News/Releases/Release/Article/3915633/dod-breaks-ground-on-project-pele-a-mobile-nuclear-reactor-for-energy-resiliency/https%3A%2F%2Fwww.defense.gov%2FNews%2FReleases%2FRelease%2FArticle%2F3915633%2Fdod-breaks-ground-on-project-pele-a-mobile-nuclear-reactor-for-energy-resiliency%2F>, accessed 2 June 2025.

⁶⁶⁷ - Kairos Power, “Kairos Power Begins Nuclear Safety-Related Construction of Hermes Low-Power Demonstration Reactor”, Press Release, 8 May 2025, see https://kairopower.com/external_updates/kairos-power-begins-nuclear-construction-of-hermes-demonstration-reactor/; and U.S. NRC, “New Facility Licensing—Hermes–Kairos Application”, 5 March 2025, see <https://www.nrc.gov/reactors/non-power/new-facility-licensing/hermes-kairos.html>; both accessed 8 May 2025.

- ➔ In November 2024, Kairos received a construction permit for the two-unit Hermes 2 non-power test reactors (2 x 35 MWt), at Oak Ridge National Laboratory,⁶⁶⁸ but, as of mid-2025, has not announced the start of nuclear construction;
- ➔ In September 2024, NRC issued the construction permit for the Natura molten salt research reactor at Abilene Christian University (1 MWt).⁶⁶⁹ The university announced the opening of the research laboratory where the reactor will be housed in 2023, but, as of mid-2025, has not announced the start of nuclear construction. The research reactor is intended to demonstrate the feasibility of the molten salt technology, based on which Natura has reportedly struck agreements to develop commercial power reactors at Texas Tech University and Texas A&M University's proposed RELIS facility⁶⁷⁰—the latter, a planned test-bed for various new reactor designs for which the college is seeking an Early Site Permit at its Bryan, TX satellite campus.⁶⁷¹

Six of the seven projects above have benefited from significant, direct federal government sponsorship. DOE's Advanced Reactor Demonstration Program has awarded X-energy, TerraPower, and Kairos a combined US\$2.8 billion in matching grants to construct their reactors; DOE is providing land to Kairos at Oak Ridge National Lab⁶⁷² and to TVA at the Clinch River Site, and offered land for NuScale's Carbon-Free Power Project until it was canceled in 2023;⁶⁷³ TVA itself is a federal government corporation with independent ratemaking authority, under which it sells power to municipal utilities and rural electric cooperatives across seven states; and Project Pele is funded by the Department of Defense, with the intent to develop mobile microreactor technologies that could also be deployed commercially.⁶⁷⁴ Furthermore, the Department of Defense has conducted a procurement for a microreactor to power the

668 - Kairos Power, "Nuclear Regulatory Commission Approves Construction Permits for Hermes 2 Demonstration Plant", Press Release, 20 November 2024, see https://kairopower.com/external_updates/nuclear-regulatory-commission-approves-construction-permits-for-hermes-2-demonstration-plant/, accessed 8 May 2025; and U.S. NRC, "New Facility Licensing—Hermes 2 – Kairos Application", 3 March 2025, see <https://www.nrc.gov/reactors/non-power/new-facility-licensing/hermes2-kairos.html>, accessed 12 May 2025.

669 - Natura Resources, "Natura Resources' Molten Salt Reactor at ACU Receives Historic NRC Construction Permit", 16 September 2024, see <https://www.naturaresources.com/natura-resources-molten-salt-reactor-at-acu-receives-historic-nrc-construction-permit>; and U.S. NRC, "New Facility Licensing—MSRR – Abilene Christian University Application", 13 February 2025, see <https://www.nrc.gov/reactors/non-power/new-facility-licensing/msrr-acu.html>; both accessed 12 May 2025.

670 - The campus name RELIS stands for respect, excellence, leadership, loyalty, integrity, and selfless service.

671 - Natura Resources, "Natura Resources Announces Two Advanced Nuclear Deployments in Texas", 18 February 2025, see <https://www.naturaresources.com/natura-resources-announces-two-advanced-nuclear-deployments-in-texas>, accessed 2 June 2025; and Texas A&M University System, "Texas A&M System Goes Nuclear", 4 February 2025, see <https://stories.tamu.edu/news/2025/02/04/texas-am-system-goes-nuclear/>; both accessed 2 June 2025; also Karley Cross, "Texas A&M System Announces Partnership with 4 Nuclear Reactor Companies to Build at RELIS", KBTX, 4 February 2025, see <https://www.kbtx.com/2025/02/04/texas-am-system-announces-partnership-with-4-nuclear-reactor-companies-build-rellis/>, accessed 13 May 2025.

672 - Carolyn Krause, "Kairos Power's Reactor Plans for Oak Ridge and Beyond", *Oak Ridger*, 28 February 2025, see <https://www.oakridger.com/story/news/local/2025/02/28/kairos-powers-reactor-plans-for-oak-ridge-and-beyond/79325875007/>, accessed 7 July 2025.

673 - Office of Nuclear Energy, "SMR LTS Site Permitting and Licensing Projects", Department of Energy, United States Government, Undated, see <https://www.energy.gov/ne/smr-lts-site-permitting-and-licensing-projects>, accessed 14 May 2025.

674 - U.S. Department of Defense, "DoD to Build Project Pele Mobile Microreactor and Perform Demonstration at Idaho National", Press Release, United States Government, 13 April 2022, see <https://www.defense.gov/News/Releases/Release/Article/2998460/dod-to-build-project-pele-mobile-microreactor-and-perform-demonstration-at-idah>, accessed 14 May 2025.

Eielson Air Force Base in Alaska,⁶⁷⁵ and the U.S. Army's Corps of Engineers has recommended procurement of an SMR to power the Fort Drum Army Base in New York.⁶⁷⁶

The official schedules for two commercial reactor demonstration projects have slipped beyond 2030, TerraPower's Natrium and X-energy's Xe-100 reactor designs, funded by the Infrastructure Investment and Jobs Act (IIJA). The projects had been selected in 2020 as the flagship projects of DOE's Advanced Reactor Demonstration Program (ARDP), with a goal of bringing reactors online in five to seven years.⁶⁷⁷ The ARDP is also supporting development of eight other power reactor designs, with goals for deployment of demonstration reactors in the early- to mid-2030s, at the soonest. The Department of Defense is sponsoring development of three microreactors, with projected operation dates in or around 2027.⁶⁷⁸

TerraPower submitted its application for a construction permit at its Kemmerer site, in Wyoming, to the NRC in March 2024. According to the agency, as of December 2024, its review of the application was less than half complete, with a projected completion date of December 2026.⁶⁷⁹ While the ARDP originally expected both the Natrium and Xe-100 reactors to be in operation in 2027, TerraPower now projects Natrium will begin commercial operation in 2031.⁶⁸⁰ TerraPower frequently states that the projected cost of the Natrium project is US\$4 billion;⁶⁸¹ however, in a July 2024 interview, the company's co-founder, former Microsoft CEO Bill Gates, stated that its full development cost could be "close to US\$10 billion".⁶⁸² With 345 MW of nuclear generation capacity, the cost would be US\$12,000–29,000/kW. At the low end, the pre-construction estimate is nearly double that of the Vogtle 3&4 reactors at a similar stage, prior to construction (US\$6,000/kW); at the high end, it is substantially greater than the final, all-in cost of the Vogtle reactors (US\$16,000/kW).

675 - Matthew Cox, "Air Force Still Planning Nuclear Microreactor in Alaska—and More", *Air & Space Forces Magazine*, 23 April 2025, see <https://www.airandspaceforces.com/air-force-nuclear-microreactor-eielson-and-more/>, accessed 14 May 2025.

676 - Brian Dwyer, "Fort Drum Selected as 'Optimal' Option for Nuclear Power", *Spectrum News*, 4 April 2025, see <https://spectrumlocalnews.com/nys/central-ny/news/2025/03/26/fort-drum-nuclear-power>, accessed 14 May 2025.

677 - Office of Nuclear Energy, "Advanced Reactor Demonstration Program", U.S. Department of Energy, Undated, see <https://www.energy.gov/ne/advanced-reactor-demonstration-program>, accessed 5 August 2023, Office of Nuclear Energy, "INFOGRAPHIC: Advanced Reactor Development", U.S. Department of Energy, 15 December 2020, see <https://www.energy.gov/ne/articles/infographic-advanced-reactor-development>, accessed 5 August 2024.

678 - U.S. Department of Defense, "DOD Exercises Option on Second Micro Nuclear Reactor Design", Press Release, United States Government, 13 September 2023, see <https://www.defense.gov/News/Releases/Release/Article/3524458/dod-exercises-option-on-second-micro-nuclear-reactor-design/> <https://www.defense.gov/News/Releases/Release/Article/3524458/dod-exercises-option-on-second-micro-nuclear-reactor-design/>; and Eielson Air Force Base, "Eielson Micro-reactor Quarterly Newsletter—05.03.2024", U.S. Air Force, 3 May 2024, see https://www.eielson.af.mil/Portals/40/ENVIRONMENT/Micro-Reactor/07_MR%20Quarterly%20Newsletter_May%202024.pdf?ver=xE8xcn-4bufNg6uEJ-tfbA%3D%3D; both accessed 9 August 2024.

679 - U.S. NRC, "Advanced Reactor Application Projects—TerraPower, LLC -- Kemmerer Power Station Unit 1 Application Dashboard", 6 December 2024, see <https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/applicant-projects/terrapower/dashboard.html>, accessed 7 July 2025; and American Nuclear Society, "Kairos Power, DOE Agree on Milestone Approach to Hermes Support", *Nuclear Newswire*, 22 February 2024, see <https://www.ans.org/news/article-5809/kairos-power-doe-agree-on-milestone-approach-to-hermes-support/>, access 9 June 2025.

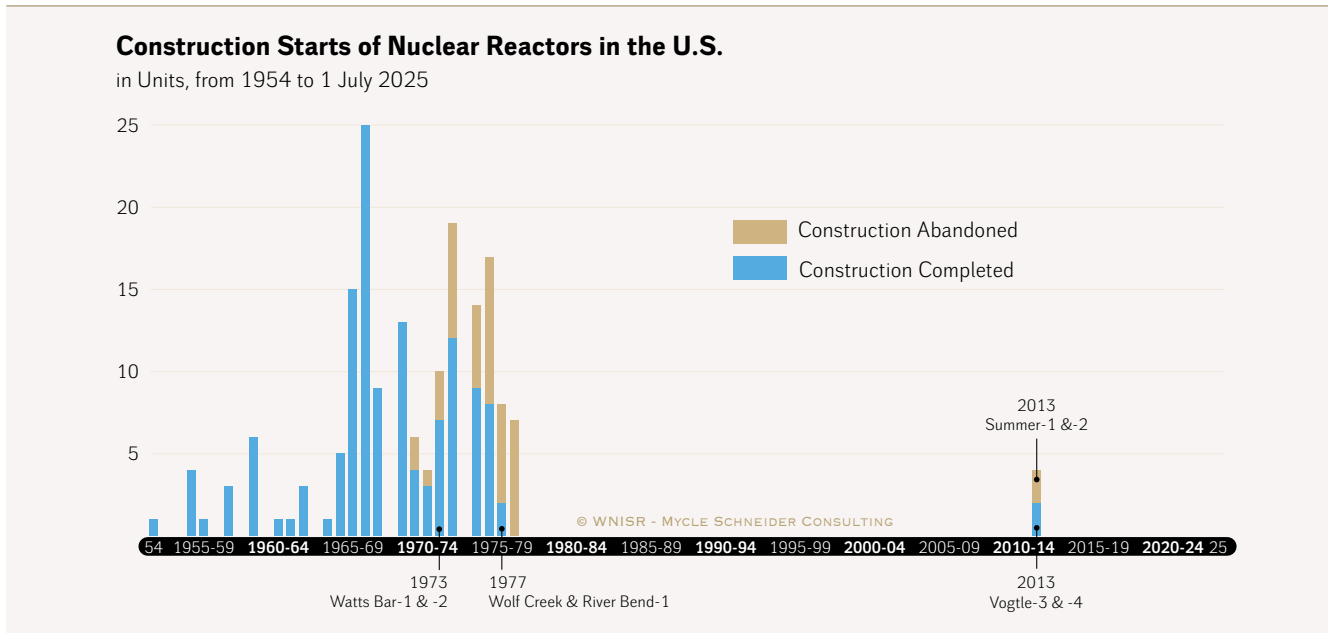
680 - Sonal Patel, "Kemmerer 1—TerraPower's Pioneering Fourth-Generation Nuclear Project—Hits Key NRC Milestone Ahead of Schedule", *POWER Magazine*, 27 February 2025, see <https://www.powermag.com/kemmerer-1-terrapowers-pioneering-fourth-generation-nuclear-project-hits-key-nrc-milestone-ahead-of-schedule/>, accessed 8 May 2025.

681 - E.g., in the FAQs on their website; see TerraPower, "Frequently Asked Questions", Undated, see <https://www.terrapower.com/faq/>, accessed 26 July 2025.

682 - CBS News, "Transcript: Bill Gates on 'Face the Nation,' June 16, 2024", 16 June 2024, see <https://www.cbsnews.com/news/bill-gates-transcript-face-the-nation-06-16-2024/>, accessed 2 June 2025.

In the past 45 years, there were only two construction starts of commercial reactors in the U.S. that were completed, at the Vogtle site, while construction of two more started but was later abandoned, at the V.C. Summer site (see Figure 51).

Figure 51 · Seventy Years of Nuclear Reactor Constructions in the U.S.



Sources: WNISR with IAEA-PRIS, various dates

Note: Construction-start years refer to dates initially indicated in IAEA-PRIS database, subject to later modifications.

The X-energy demonstration project is being undertaken by a subsidiary of Dow Chemical, to be constructed at Dow's UCC Seadrift chemical production facility in Texas. The four-reactor, high-temperature gas-cooled SMR plant would have a gross generating capacity of 320 MW, though it would also provide process heat (in the form of steam) to support UCC Seadrift's production processes. Dow submitted a construction permit application for the reactors, to be titled Long Mott Generating Station, in March 2025. The application expresses hope that the NRC will issue the permit in 2027, that nuclear construction will begin in early 2028, and that the plant will begin operation in 2033.⁶⁸³

Many Projects in Early Stages—Modest Private Sector Investment

Private sector investment in new reactors remains limited primarily to research and development and venture capital, rather than commercial deployment. As a result, reactor design startup companies that have little if any business income continue to proliferate in the U.S., with ten reactor concepts added to the NRC's pre-application engagement docket between

⁶⁸³ - Long Mott Energy, LLC, "Construction Permit Application: Part I - General and Financial Information", Revision 0, submitted to the U.S. Nuclear Regulatory Commission, March 2025, see <https://www.nrc.gov/docs/ML2509/ML25090A059.pdf>, accessed 8 May 2025.

8 February⁶⁸⁴ and 9 June 2025.⁶⁸⁵ However, only one established commercial nuclear generation company (Tennessee Valley Authority, or TVA) has taken concrete steps toward building a new reactor: TVA's selection of the GE-Hitachi BWRX-300 for its Clinch River site,⁶⁸⁶ for which TVA received an Early Site Permit (ESP) to build a then-unspecified SMR in 2019.⁶⁸⁷ Even that decision is tentative. In April and May 2025, TVA submitted a construction permit application for the reactor in two parts: the environmental report in April⁶⁸⁸; and the preliminary safety analysis report in May. The filing from 28 April 2025 states:

As communicated previously, the TVA Board has not yet authorized the deployment of a SMR at the CRN [Clinch River Nuclear] Site. TVA's submittal of the CPA is an important step to de-risk the licensing aspect of a potential, future SMR deployment. Any decisions about deployment will be subject to support, risk sharing, required internal and external approvals, and completion of necessary environmental and permitting reviews.⁶⁸⁹

Several nuclear utilities have expressed interest in pursuing possible new reactor projects, for instance, through applying for ESPs or including new reactors in public utility commission planning dockets:

- ➔ Appalachian Power, a subsidiary of American Electric Power (AEP), initiated pre-application activities with the NRC in March 2025 for an ESP for an SMR⁶⁹⁰ at its Joshua Falls substation site;⁶⁹¹
- ➔ AEP's Indiana & Michigan Power subsidiary has included SMRs in its 2024 Integrated Resource Plan (IRP) filed with the Indiana Utility Regulatory Commission (IURC), and indicated that to “partially offset the cost of the early site permit process” it is seeking a grant from the DOE;⁶⁹²

684 - U.S. NRC, “Pre-Application Activities for Advanced Reactors”, Updated 18 December 2024, via *Wayback Machine*, as of 8 February 2025, see <https://web.archive.org/web/20250208142539/https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/pre-application-activities.html>, accessed 13 May 2025.

685 - U.S. NRC, “Pre-Application Activities for Advanced Reactors”, 9 June 2025, see <https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/pre-application-activities.html>, accessed 9 June 2025.

686 - TVA, “Tennessee Valley Authority, Ontario Power Generation, and Synthos Green Energy Invest in Development of GE Hitachi Small Modular Reactor Technology”, Press Release, 23 March 2023, see <https://www.tva.com/newsroom/press-releases/tennessee-valley-authority-ontario-power-generation-and-synthos-green-energy-invest-in-development-of-ge-hitachi-small-modular-reactor-technology>, accessed 5 August 2024.

687 - U.S. NRC, “Issued Early Site Permit - Clinch River Nuclear Site”, Updated 21 September 2022, see <https://www.nrc.gov/reactors/new-reactors/large-lwr/esp/clinch-river.html>, accessed 5 August 2024.

688 - TVA, “Submittal of the Environmental Report in Support of the Clinch River Nuclear Site Construction Permit Application”, filed with U.S. NRC, 28 April 2025, see <https://www.nrc.gov/docs/ML2511/ML25118A209.pdf>, accessed 2 June 2025; and Sonal Patel, “TVA Submits First Portion of Construction Permit Application to NRC for Clinch River BWRX-300 SMR”, *POWER Magazine*, 8 May 2025, see <https://www.powermag.com/tva-submits-first-portion-of-construction-permit-application-to-nrc-for-clinch-river-bwr-x-300-smr/>, accessed 12 May 2025.

689 - Ibidem.

690 - U.S. NRC, “Pre-Application Activities—Appalachian Power Company”, 4 April 2025, see <https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/pre-application-activities/apco-joshua-falls.html>, accessed 14 May 2025.

691 - American Electric Power, “Appalachian Power Explores Small Modular Reactors to Meet Future Energy Demand in Virginia”, Press Release, 14 November 2024, see <https://www.aep.com/news/stories/view/9868/>, accessed 14 May 2025.

692 - Indiana Michigan Power, “I&M is Future Ready with Plans to Enhance Diverse Energy Mix”, Press Release, 1 April 2025, see <https://indianamichiganpower.com/company/news/view?releaseID=10119>, accessed 14 May 2025.

- ➔ Constellation is seeking DOE funding to apply for an ESP at its Nine Mile Point Nuclear Power Plant, supported by the New York State Energy Research and Development Authority which pledged a matching share of the application cost;⁶⁹³
- ➔ Duke Energy has initiated pre-application activities with the NRC for an ESP at its Belews Creek coal power plant site,⁶⁹⁴ and the company included SMRs in the most recent IRP it submitted to the IURC;⁶⁹⁵
- ➔ Energy Northwest has initiated pre-application engagement with the NRC for a CPA to build up to 12 X-energy Xe-100 SMRs on the DOE's Hanford Reservation, adjacent to Columbia Generating Station site, Washington,⁶⁹⁶ for which Amazon has reportedly committed US\$334 million to fund a “multiyear feasibility study”;⁶⁹⁷
- ➔ PacifiCorp has included development of new reactors in IRPs its utilities have submitted to public utility commissions in Utah⁶⁹⁸ and in Wyoming (TerraPower's Natrium project).⁶⁹⁹

None of these activities represent a formal investment decision. Even less, some seem contingent on further public financing. For instance, Constellation intends to fund its ESP application for Nine Mile Point entirely with government funding: 50 percent from the New York State Energy Research and Development Authority and 50 percent from a DOE grant program announced in late 2024.⁷⁰⁰

The majority of federal and state government investments are going toward prolonging the operation of existing reactors rather than into new construction. For instance, while existing nuclear generation companies have not ordered any new reactors and, with the exception of TVA's Clinch River CPA, have not named specific plans to do so, since April 2024, six companies have announced plans to implement power uprates of 16–19 reactors, which would total more than 1200 MW in increased generating capacity:

⁶⁹³ - Constellation, “New York Joins Constellation in Pursuit of Energy Department Funding for Advanced Nuclear Reactor”, Press Release, 15 January 2025, see <https://www.constellationenergy.com/newsroom/2025/new-york-joins-constellation-in-pursuit-of-energy-department-funding-for-advanced-nuclear-reactor.html>, accessed 2 June 2025; and Darrell Proctor, “Constellation Seeking Permit for Small Modular Reactor at Nine Mile Point”, *POWER Magazine*, 16 January 2025, see <https://www.powermag.com/constellation-seeking-permit-for-small-modular-reactor-at-nine-mile-point/>, accessed 14 May 2025.

⁶⁹⁴ - U.S. NRC, “Pre-Application Activities—Duke Energy Belews Creek, NC”, 6 May 2025, see <https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/pre-application-activities/duke-energy-belews-creek.html>, accessed 14 May 2025.

⁶⁹⁵ - Chelsea Hotaling, Anna Sommer et al, “Report on Duke Energy Indiana's 2024 Integrated Resource Plan”, Energy Futures Group, on behalf of Citizens Action Coalition, Earthjustice, Solar United Neighbors, and Vote Solar, submitted to the Indiana Utility Regulatory Commission, 13 February 2025, see https://www.in.gov/iurc/files/Duke-2024-IRP-EFG-Modeling-Report-for-CAC-EJ-SUN-VS-2-13-2025-PUBLIC_Redacted.pdf, accessed 13 May 2025.

⁶⁹⁶ - U.S. NRC, “Pre-Application Activities—Energy Northwest”, 18 April 2025, see <https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/pre-application-activities/energy-northwest.html>, accessed 14 May 2025.

⁶⁹⁷ - John Stang, “Amazon Offers \$334M for Nuclear Reactors to Be Built at Hanford”, *Cascade PBS*, 26 November 2024, see <https://www.cascadepbs.org/news/2024/11/amazon-offers-334m-nuclear-reactors-be-built-hanford>, accessed 14 May 2025.

⁶⁹⁸ - PacifiCorp, “Utah 2025 Integrated Resource Plan—Volume I”, submitted to the Utah Public Service Commission, 31 March 2025, see <https://pscdocs.utah.gov/electric/25docs/2503522/339034RMP2025IRPVlmI3-31-2025.pdf>, accessed 13 May 2025.

⁶⁹⁹ - Sean Wolfe and Kevin Clark, “Rocky Mountain Power Intends to Keep Coal Units, Adopt More Carbon Capture”, *Power Engineering*, 3 April 2024, see <https://www.power-eng.com/coal/rocky-mountain-power-intends-to-keep-coal-units-adopt-more-carbon-capture/>, accessed 14 May 2025.

⁷⁰⁰ - Constellation, “New York Joins Constellation in Pursuit of Energy Department Funding for Advanced Nuclear Reactor”, Press Release, 15 January 2025, op. cit.; and Darrell Proctor, “Constellation Seeking Permit for Small Modular Reactor at Nine Mile Point”, *POWER Magazine*, 16 January 2025, op. cit.

- ➔ Constellation has stated it will implement power uprates of Braidwood-1 and -2 (135 MW),⁷⁰¹ Byron-1 and -2 (135 MW),⁷⁰² and Calvert Cliffs-1 and -2 (175 MW);⁷⁰³
- ➔ DTE Energy is considering to uprate Fermi-2 (150 MW);⁷⁰⁴
- ➔ Energy Northwest is planning an uprate of Columbia Generating Station (186 MW);⁷⁰⁵
- ➔ Entergy intends to implement up to 275 MW in uprates across its five-reactor fleet, starting with a 40 MW uprate of Waterford-3;⁷⁰⁶
- ➔ PSEG intends to pursue uprates of Salem-1 and -2 (168 MW),⁷⁰⁷ which it co-owns with Constellation; and
- ➔ Southern Co. announced that it will seek power uprates of Hatch-1 and -2 (58 MW) and Vogtle-1 and -2 (54 MW).⁷⁰⁸

Together with the industry's plans to seek ILR and SLR operating license extensions, these indicators suggest the U.S. industry is focused on treading water with existing reactors rather than on significant amounts of new reactor construction within the next decade.

Nevertheless, the large amount of financial support in the Inflation Reduction Act (IRA) and Infrastructure Investment and Jobs Act (IIJA)—amplified by media coverage of deals between major Information Technology (IT) corporations and mostly startup reactor design companies—has correlated with political interest in pursuing new reactors. Since the IIJA was enacted in 2021, several states have enacted legislation and initiated programs to promote nuclear energy, and several utilities have initiated feasibility studies or included deployment of new reactors in their IRPs. The federal structure of U.S. governance provides states a significant role in energy infrastructure development—and a primary role where many investment decisions are concerned. This dynamic was evident in previous periods of nuclear construction, in which states' enactment of Construction Work In Progress (CWIP) financing

701 - Will Wade, "Top US Nuke Plant Owner Wants to Add Equivalent of One Reactor", *Bloomberg*, 9 May 2024, see <https://www.bloomberg.com/news/articles/2024-05-09/top-us-nuke-plant-owner-wants-to-add-equivalent-of-one-reactor-to-meet-ai-boom>, accessed 15 May 2025.

702 - Constellation, "Constellation Making Major Investment in Two Illinois Nuclear Plants to Increase Clean Energy Output", Press Release, 21 February 2023, see <https://www.constellationenergy.com/newsroom/2023/Constellation-Making-Major-Investment-in-Two-Illinois-Nuclear-Plants-to-Increase-Clean-Energy-Output.html>, accessed 2 June 2025.

703 - Constellation, "Constellation Makes Big Investment in Calvert Cliffs to Power Customer Growth, Ensure Continued Safety and Reliability", Press Release, 11 February 2025, see <https://www.constellationenergy.com/newsroom/2025/constellation-makes-big-investment-in-calvert-cliffs-to-power-customer-growth-ensure-continued-safety-and-reliability.html>, accessed 2 June 2025.

704 - Peter Dietrich, "Supporting Michigan's Nuclear Industry (MI House Bills 4124-4129)", Hearing, DTE Energy, before the Committee on Energy, Michigan House of Representatives, 4 March 2025, see <https://www.house.mi.gov/Document/?DocumentId=48001&DocumentType=CommitteeTestimony>, accessed 2 June 2025; and *Nuclear Newswire*, "DTE Energy Studying Uprate at Fermi-2, Considers Fermi-3's Prospects", American Nuclear Society, 28 April 2025, see <https://www.ans.org/news/2025-04-28/article-6986/dte-energy-studying-uprate-at-fermi2-considers-fermi3s-prospects/>, accessed 15 May 2025.

705 - Steve Ernst, "ENW Studying Increasing Output of Columbia Generation Station", *NewsData*, LLC, 3 March 2023, see https://www.newsdata.com/clearing_up/supply_and_demand/enw-studying-increasing-output-of-columbia-generation-station/article_obf968a8-b9fa-11ed-8764-8fd84892b6d2.html; and Elaine Goodman, "Northwest's Only Nuclear Plant Could Get Uprate", *RTO Insider*, 9 April 2025, see www.rtoinsider.com/102493-northwest-only-nuclear-plant-uprate/, both accessed 15 May 2025.

706 - Kevin Clark, "Entergy Plans for Nuclear Uprates, Potential New Reactor", *Power Engineering*, 30 April 2025, see <https://www.power-eng.com/news/entergy-plans-for-nuclear-uprates-potential-new-reactor/>, accessed 15 May 2025.

707 - PSEG, "Salem Generating Station Power Uprate Project", presented at U.S. NRC Licensing Alignment Meeting, 5 March 2025, see <https://www.nrc.gov/docs/ML2505/ML25056A067.pdf>, accessed 2 June 2025.

708 - Georgia Power, "2025 Integrated Resource Plan", Docket No. 56002, January 2025, see <https://www.georgiapower.com/content/dam/georgia-power/pdfs/company-pdfs/2025-Integrated-Resource-Plan.pdf>, accessed 2 June 2025.

policies played a foundational role enabling utilities to proceed with nuclear projects. In the U.S.'s latest limited newbuild period, state CWIP policies were evidently more significant than the forgivable loans available through the Loan Guarantee program (see *United States Focus* in *WNISR2023*). Construction of the Summer-2 & -3, and Vogtle-3 and -4 projects both proceeded with CWIP financing, whereas utilities in South Carolina opted to move forward without seeking loan guarantees for the Summer reactors.

State policy developments may be bellwethers and enablers of future investment trends, and trends evidence efforts to lay groundwork for reactor construction. In some cases, states have gone so far as to authorize CWIP or similar financing mechanisms; in others, states are making investments that entail less risk exposure but are aimed at building workforce and/or industrial infrastructure that would facilitate reactor construction. Since 2023, six states have established programs or offices to promote development of new reactors and/or related industrial infrastructure:

- ➔ **Kentucky:** The state legislature overturned Governor Andy Beshear's veto in 2024 to create the Kentucky Nuclear Energy Development Authority (KNEDA).⁷⁰⁹ The state also created a US\$8 million Nuclear Energy Development Grant Program for FY2025–26 to be administered by KNEDA.⁷¹⁰
- ➔ **New York:** Governor Kathy Hochul ordered the New York State Energy Research and Development Authority (NYSERDA) to commission a Draft Blueprint on Advanced Nuclear Energy.⁷¹¹ Following the publication of the final Blueprint in January 2025, Hochul announced the state's support for Constellation's ESP application for Nine Mile Point and further directed NYSERDA to create a Master Plan for Responsible Advanced Nuclear Development, which is expected in late 2026.⁷¹²
- ➔ **Ohio:** In 2023, Ohio enacted legislation establishing the Ohio Nuclear Development Authority,⁷¹³ with the stated purpose of making the state “a leader in the development and construction of new-type advanced-nuclear-research reactors; a national and global leader in the commercial production of isotopes and research; a leader in the research and development of high-level-nuclear-waste reduction and storage technology.”⁷¹⁴

709 - Kentucky General Assembly, “Senate Bill 198—Actions”, Updated 26 September 2024, see <https://apps.legislature.ky.gov/record/24rs/sb198.html>, accessed 15 May 2025.

710 - Kentucky General Assembly, “Chapter 51 (SB 179)—An Act Relating To Nuclear Energy Development, Making an Appropriation Therefor, and Declaring an Emergency”, signed 24 March 2025, see <https://apps.legislature.ky.gov/law/acts/25RS/documents/0051.pdf>, accessed 2 June 2025.

711 - Brian Martucci, “Clean, dispatchable generation is key to meeting state emissions goals: New York governor”, *Utility Dive*, 13 September 2024, see <https://www.utilitydive.com/news/clean-dispatchable-generation-nuclear-energy-storage-nyserda-new-york/726976/>, accessed 15 May 2025.

712 - NYSERDA, “Advanced Nuclear Energy”, New York State Energy Research and Development Authority, 2025, see <https://www.nyserda.ny.gov/All-Programs/Advanced-Nuclear-Energy>, accessed 15 May 2025; and Constellation, “New York Joins Constellation in Pursuit of Energy Department Funding for Advanced Nuclear Reactor”, Press Release, 15 January 2025, op. cit.

713 - Kathiann M. Kowalski, “Hydrogen, Nuclear Among Winners in Last-Minute Changes to Ohio budget bill”, *Canary Media*, 6 July 2023, see <https://www.canarymedia.com/articles/enn/hydrogen-nuclear-among-winners-in-last-minute-changes-to-ohio-budget-bill>, accessed 16 May 2025.

714 - General Assembly of Ohio, “Amended Substitute House Bill Number 33”, as released by LegiScan, passed 4 July 2023, see <https://legiscan.com/OH/text/HB33/id/2832385/Ohio-2023-HB33-Enrolled.pdf>, accessed 3 June 2025; and Kathiann M. Kowalski, “Ohio Budget Amendment Seeks to Study and Promote Advanced Nuclear Power”, *Canary Media*, 6 June 2023, see <https://www.canarymedia.com/articles/enn/ohio-budget-amendment-seeks-to-study-and-promote-advanced-nuclear-power>, accessed 15 May 2025.

- ➔ **Tennessee:** Governor Bill Lee empaneled a Tennessee Nuclear Energy Advisory Council in 2023,⁷¹⁵ which returned its Final Report and Recommendations in October 2024.⁷¹⁶
- ➔ **Texas:** Texas Governor Greg Abbott directed the formation of an Advanced Nuclear Reactor Working Group in August 2023,⁷¹⁷ which submitted a report in November 2024 with seven legislative recommendations to “bring ANR [Advanced Nuclear Reactor] projects to Texas.”⁷¹⁸ Through legislation enacted in 2025, the state followed up the working group’s recommendations by establishing the Texas Advanced Nuclear Energy Office.⁷¹⁹ In addition, in February 2025, Texas A&M University announced agreements with four reactor design companies to construct demonstration reactors at the RELIS campus: Aalo Atomics, Kairos Power, Natura Resources, and Terrestrial Energy.⁷²⁰
- ➔ **Virginia:** In 2023, state legislation established a Nuclear Innovation Hub within the Virginia Power Innovation Program and created a Nuclear Education Grant Fund.⁷²¹

In addition, through the National Association of State Energy Officials (NASEO), ten states have formed, in early 2025, a collaboration “to reduce the cost of advanced nuclear projects,” the Advanced Nuclear First Movers Initiative (ANMFI). Co-chaired by Indiana, Kentucky, New York, Tennessee, and Wyoming, the ANMFI also says it will seek to expedite federal licensing of projects and form public-private partnerships.⁷²²

Eight states enacted policy changes or initiated planning processes to promote nuclear energy since July 2024. The measures range from authorizing CWIP financing and providing direct subsidies, to classifying nuclear for clean energy incentives and conducting feasibility and planning studies:

715 - Office of the Governor of Tennessee, “Gov. Lee Issues Executive Order to Advance Nuclear Energy Innovation & Investment”, Press Release, 16 May 2023, see <https://www.tn.gov/governor/news/2023/5/16/gov-lee-issues-executive-order-to-advance-nuclear-energy-innovation---investment.html>, accessed 26 July 2023.

716 - Tennessee Nuclear and Energy Advisory Council, “Final Report and Recommendations for Governor Bill Lee, Lt. Governor Randy McNally and Speaker Cameron Sexton”, Tennessee Department of Environment & Conservation, 31 October 2024, see https://www.tn.gov/content/dam/tn/environment/energy/documents/tneac/tneac_final-report-and-recommendations.pdf, accessed 15 May 2025.

717 - Public Utility Commission of Texas, “Texas Advanced Nuclear Reactor Working Group”, Undated, see <https://www.puc.texas.gov/industry/nuclear/>, accessed 15 May 2025.

718 - Texas Advanced Nuclear Reactor Working Group, “Deploying a World-Renowned Advanced Nuclear Industry in Texas—Considerations and Recommendations for Action”, Public Utility Commission of Texas, November 2024, p. vii, see https://gov.texas.gov/uploads/files/press/TANRWG_Advanced_Nuclear_Report_v11.17.24c_.pdf, accessed 7 December 2024.

719 - Governor Greg Abbott, “Governor Abbott Congratulates Texas Legislature For Passing Nuclear Power Legislation”, Office of the Texas Governor, 2 June 2025, see <https://gov.texas.gov/news/post/governor-abbott-congratulates-texas-legislature-for-passing-nuclear-power-legislation>, accessed 9 June 2025.

720 - Texas A&M University, “Texas A&M System Goes Nuclear”, 4 February 2025, see <https://stories.tamu.edu/news/2025/02/04/texas-am-system-goes-nuclear/>, accessed 2 June 2025; and Tom Perumean, “Texas A&M Partners with Four Companies on Nuclear Reactor Project Near Campus”, *Houston Public Media*, 5 February 2025, see <https://www.houstonpublicmedia.org/articles/news/energy-environment/2025/02/05/513014/texas-am-partners-with-four-companies-on-nuclear-reactor-project-near-campus/>, accessed 15 May 2025.

721 - Virginia General Assembly, “Chapter 505 an Act to Amend the Code of Virginia by Adding in Chapter 17 of Title 45.2 an Article Numbered 9, Consisting of a Section Numbered 45.2-1734, Relating to Virginia Power Innovation Fund and Program; Created [S 1464]”, enacted 24 March 2023, see <https://legacylis.virginia.gov/cgi-bin/legp604.exe?231+ful+CHAPo505>; and Virginia General Assembly, “Chapter 508 an Act to Amend the Code of Virginia by Adding in Article 2 of Chapter 2 of Title 23.1 a Section Numbered 23.1-212.1, Relating to Nuclear Education Grant Fund and Program Established [H1779]”, approved 24 March 2023, see <https://legacylis.virginia.gov/cgi-bin/legp604.exe?231+ful+CHAPo508>; both accessed 3 June 2025.

722 - NASEO, “NASEO Initiative Aims to Propel Advanced Nuclear Energy Projects Across Multiple States”, Press Release, National Association of State Energy Officials, 5 February 2025, see <https://www.naseo.org/news-article?NewsID=4102>, accessed 3 June 2025; and John Siciliano, “US States Start Project to Cut Costs, Speed Permitting for Advanced Nuclear Units”, S&P Global Commodity Insights, 6 February 2025, see <https://www.spglobal.com/commodity-insights/en/news-research/latest-news/electric-power/020625-us-states-start-project-to-cut-costs-speed-permitting-for-advanced-nuclear-units>, accessed 15 May 2025.

- ➔ **Arkansas:** The legislature enacted SB 307, authorizing utilities to use CWIP-ratemaking to fund construction of nuclear reactors (as “strategic investments”).⁷²³ Another new law, HB 1572, directs the Arkansas Department of Energy and Environment to commission a “technical feasibility study on implementing nuclear energy generation.”⁷²⁴
- ➔ **Colorado:** The legislature enacted a bill (HB25-1040)⁷²⁵ classifying nuclear power as a “clean energy resource” toward the state’s energy policies and 2050 resource targets.⁷²⁶
- ➔ **Indiana:** Legislation enacted categorizes nuclear power as a “clean energy” or “green energy” resource (SB 178)⁷²⁷; creates a pilot program for SMRs under the Indiana Utility Regulatory Commission, with ratepayer financing (SB 423)⁷²⁸; amends the CWIP financing statute enacted in 2024 to authorize recovery of other project development costs, such as an Early Site Permit application (SB 424)⁷²⁹; and creates a subsidy for manufacturers of SMRs in Indiana, through a Small Modular Nuclear Reactor Manufacturing Expense Tax Credit (HB 1007).⁷³⁰
- ➔ **Kentucky:** A concurrent resolution introduced in the House (HCR 22) declares nuclear energy “a clean and dispatchable means of providing baseload electricity” and implies that it should be prioritized in state energy plans⁷³¹; and SB 179 creates and funds the Nuclear Energy Development Grant Program, to be administered by the Kentucky Nuclear Energy Development Authority.⁷³²
- ➔ **Maryland:** A key provision of the Next Generation Energy Act (HB 1035 / SB 937) directs Maryland’s Public Service Commission (PSC) to create a procurement process for nuclear

723 - 95th General Assembly of Arkansas, “2025 AR S 307—Act 373 of the Regular Session—Senate Bill 307 For An Act To Be Entitled An Act to Amend the Law Concerning Public Utilities; to Create the Generating Arkansas Jobs Act of 2025; to Declare an Emergency; and for Other Purposes—to Amend the Law Concerning Public Utilities; to Create The Generating Arkansas Jobs Act Of 2025; and to Declare an Emergency.”, as distributed by State Net, enacted 20 March 2025, see https://custom.statenet.com/public/resources.cgi?id=ID:bill:AR2025000S307&ciq=ncl29e&client_md=f4813daa4ceab979a591d523f7cb6210&mode=current_text, accessed 16 May 2025.

724 - 95th General Assembly of Arkansas, “2025 AR H 1572—Act 707 of the Regular Session—House Bill 1572— for an Act to Be Entitled an Act to Create a Technical Feasibility Study on New Nuclear Energy Generation; to Declare an Emergency; and for Other Purposes—to Create a Technical Feasibility Study on New Nuclear Energy Generation; and to Declare an Emergency.”, as distributed by State Net, enacted 16 April 2025, see https://custom.statenet.com/public/resources.cgi?id=ID:bill:AR2025000H1572&ciq=ncl29e&client_md=178d459a531fb76f6f0078c852309f2f8&mode=current_text, accessed 16 May 2025.

725 - 75th General Assembly of Colorado, “HB25-1040—Adding Nuclear Energy as a Clean Energy Resource”, enacted 31 March 2025, see <https://leg.colorado.gov/bills/hb25-1040>, accessed 15 May 2025.

726 - Allie Jennerjahn, “Governor Jared Polis signs bill to consider nuclear energy a clean energy source in Colorado”, *Denver 7 Colorado News, ABC*, 3 April 2025, see <https://www.denver7.com/news/politics/governor-jared-polis-signs-bill-to-consider-nuclear-energy-a-clean-energy-source-in-colorado>, accessed 15 May 2025.

727 - Indiana General Assembly, “Senate Bill 178—Natural Gas and Propane as a Clean Energy Resources”, Public Law 46, enacted 10 April 2025, see <https://iga.in.gov/legislative/2025/bills/senate/178/details>, accessed 3 June 2025.

728 - Indiana General Assembly, “Senate Bill 423—Small Modular Nuclear Reactor Pilot Program”, Public Law 137, enacted 1 May 2025, see <https://iga.in.gov/legislative/2025/bills/senate/423/details>, accessed 3 June 2025.

729 - Indiana General Assembly, “Senate Bill 424—Small Modular Nuclear Reactor Development Costs”, Public Law 48, 10 April 2025, see <https://iga.in.gov/legislative/2025/bills/senate/424/details>, accessed 3 June 2025.

730 - 124th General Assembly of Indiana, “House Enrolled Act No. 1007—an Act to Amend the Indiana Code Concerning Utilities.”, Public Law 217, Enacted 6 May 2025, see <https://iga.in.gov/pdf-documents/124/2025/house/bills/HB1007/HB1007.08.ENRS.pdf>, accessed 3 June 2025.

731 - Kentucky General Assembly, “Chapter 137—A Concurrent Resolution Declaring That Nuclear Power Generation Is a Clean and Dispatchable Means of Providing Baseload Electricity to the Residents and Businesses of the Commonwealth”, introduced as House Concurrent Resolution 22 (HCR 22), 2025, see <https://apps.legislature.ky.gov/law/acts/25RS/documents/0137.pdf>, accessed 3 June 2025.

732 - Kentucky General Assembly, “Chapter 51—An Act Relating to Nuclear Energy Development, Making an Appropriation Therefor, and Declaring an Emergency”, introduced as Senate Bill 179 (SB 179), Enacted 24 March 2025, see <https://apps.legislature.ky.gov/law/acts/25RS/documents/0051.pdf>, accessed 3 June 2025.

generation capacity.⁷³³ Modeled on the state's procedures for procuring offshore wind generation, it is the first state policy created for financing nuclear reactor construction costs in a merchant power market. Upon receipt of a petition for a nuclear energy project, the PSC must undertake an application process, soliciting proposals for nuclear energy projects and selecting one or more that satisfy an undisclosed, yet-to-be-determined electricity price limit. Unlike CWIP, the law does not permit recovery of financing costs before the generation facility produces electricity, but it would provide a guaranteed rate for up to 30 years. The statute requires the PSC to conduct at least two more such application periods for new nuclear generation before 2031.

- ➔ **North Dakota:** HB 1025 authorizes up to US\$300,000 from the state treasury for a study of “the feasibility, siting, and deployment of advanced nuclear power plants”⁷³⁴; and SB 2159 removes a prohibition on the state's Energy Research Center at the University of North Dakota from researching or conducting projects resulting in the “exploration, storage, treatment, or disposal of high-level radioactive waste above ground.”⁷³⁵
- ➔ **Tennessee:** HB 1143 defines “clean or green energy or renewable energy” to require the inclusion of specified energy sources, including nuclear power—thereby barring municipalities from excluding nuclear power from their “clean or green energy” policies.⁷³⁶ SB 758 authorizes municipalities' industrial development boards to acquire brownfield sites for nuclear power plant development.⁷³⁷
- ➔ **Texas:** HB 14 establishes the Texas Advanced Nuclear Energy Office and two grant programs that it would administer to support development of new reactors and nuclear infrastructure. Grants would range from up to US\$12.5 million for project planning and development and up to US\$120 for permitting, licensing, and construction. In total, the legislature authorized up to US\$350 million for the program.⁷³⁸
- ➔ **Utah:** HB 249 establishes the Nuclear Energy Consortium and the Utah Energy Council to research and direct priorities for nuclear energy development, designates Energy Development Zones, and creates an Energy Development Investment Fund to provide tax increment financing incentives for energy projects.⁷³⁹ In addition, a concurrent resolution (HCR 5) calls on the U.S. Congress to enact legislation to reform permitting

733 - Maryland General Assembly, “Electricity and Gas - Emissions Reductions, Rate Regulation, Cost Recovery, Infrastructure, Planning, Renewable Energy Portfolio Standard, and Energy Assistance Programs (Next Generation Energy Act)”, Chapter 625, Enacted 20 May 2025, see <https://mgaleg.maryland.gov/mgawebwebsite/Legislation/Details/SB0937?ys=2025RS>, accessed 17 May 2025.

734 - Legislative Assembly of North Dakota, “House Bill No. 1025—An Act to Provide for a Legislative Management Study Relating to Advanced Nuclear Energy; and to Provide an Appropriation.”, signed 16 April 2025, see <https://ndlegis.gov/assembly/69-2025/regular/documents/25-0429-06000.pdf>, accessed 3 June 2025.

735 - Legislative Assembly of North Dakota, “Senate Bill No. 2159—An Act to Amend and Reenact Section 15-11-40 of the North Dakota Century Code, Relating to Projects the State Energy Research Center Is Permitted to Pursue.”, signed 24 April 2025, see <https://ndlegis.gov/assembly/69-2025/regular/documents/25-0797-04000.pdf>, accessed 3 June 2025.

736 - State of Tennessee, “Public Chapter No. 205—House Bill No. 1143—An Act To Amend Tennessee Code Annotated, Title 4; Title 5; Title 6; Title 7; Title 13; Title 64; Title 65; Title 67 and Title 68, Relative to Energy.”, signed 11 April 2025, see <https://publications.tnsosfiles.com/acts/114/pub/pc0205.pdf>, accessed 3 June 2025.

737 - State of Tennessee, “Public Chapter No. 379—Senate Bill No. 758—An Act to Amend Tennessee Code Annotated, Title 7, Chapter 53, Part 3, Relative to Industrial Development Corporations.”, signed 5 May 2025, see <https://publications.tnsosfiles.com/acts/114/pub/pc0379.pdf>, accessed 3 June 2025.

738 - Texas Legislature, “Texas HB 14—An Act Relating to Support for the Development of the Nuclear Energy Industry”, as published on LegiScan, signed 20 June 2025, see <https://legiscan.com/TX/text/HB14/id/3249239>; and Carlos Nogueros Ramos, “Lawmakers Passed Bills This Session to Boost the State Power Grid but Failed to Limit Renewables”, *The Texas Tribune*, 9 June 2025, see <https://www.texastribune.org/2025/06/09/texas-legislature-energy-bills-renewables-power-grid/>; both accessed 9 June 2025.

739 - Utah State Legislature, “H.B. 249 Nuclear Power Amendments”, signed 26 March 2025, see <https://le.utah.gov/-2025/bills/static/HB0249.html>, accessed 3 June 2025.

and environmental reviews to “expedit[e] energy infrastructure deployment,” including nuclear power.⁷⁴⁰

Industry Restructuring and Emerging Business Models

Since WNISR2023, we have detailed intersecting trends related to ownership changes and business strategies within the U.S. nuclear industry. Following publication of WNISR2024, there were several high-profile announcements of deals between major IT firms and nuclear power companies. However, incoming President Donald Trump immediately began efforts to roll back executive orders and policies enacted under the Biden administration. Despite Trump’s support for nuclear energy in his first administration and his inclusion of uranium-based fuels as a national priority in the energy emergency declaration issued on the day he took office, threats to repeal major energy programs in the Inflation Reduction Act created uncertainty about the fate of key financial incentives the nuclear industry is counting on to support major investment decisions in new reactor construction, license extensions, power uprates, and hydrogen co-generation.⁷⁴¹

The industry became worried. Trade journal *Nuclear Engineering International’s* chief editor David Appleyard stated in May 2025 that for the nuclear sector Trumps budget proposals “represent sobering reading”:

There is no question that, even accounting for greater efficiency and better targeting of federal investment, losing hundreds of millions of dollars in annual funding will have dire consequences. (...) For nuclear the hope must be that the budget proposals form part of the on-going mission to ‘break things and move fast’ before eventual retrenchment and a more considered approach. The alternative is that even as much of the world looks to the US for some leadership and future thinking on nuclear, it is actually just breaking things.⁷⁴²

Furthermore, the administration’s promotion of fossil fuels, rejection of climate change, and repeals of climate policy measures have realigned the interests of nuclear generation companies and key industrial customers. For instance, the Biden administration began pressing the IT industry to reduce the emissions impacts of energy-intensive Artificial Intelligence (AI) data centers in 2024⁷⁴³; just months later, the industry is under no such pressure from the Trump administration, which even frowns upon emissions reductions as a business priority. As a result, utilities planning to serve gigawatt-scale loads from expected rapid growth in hyperscale data center operations are sidelining climate as an energy procurement consideration.⁷⁴⁴

Consequently, the pace of new ventures slowed in the early months after Trump’s inauguration. With respect to subsidy and financing programs, the availability of federal

⁷⁴⁰ - Utah State Legislature, “H.C.R. 5 House Concurrent Resolution on Permitting Reform”, signed 3 March 2025, see <https://le.utah.gov/~2025/bills/static/HCR005.html>, accessed 3 June 2025.

⁷⁴¹ - Martha Muir, “US Nuclear Sector Goes On Spending Spree to Fight Subsidy Cuts”, *The Financial Times*, 18 May 2025, see <https://www.ft.com/content/c243fd15-bef8-4c98-b06b-8b13ddda701>, accessed 19 May 2025.

⁷⁴² - David Appleyard, “Trump’s Nuclear Plans Spell Trouble”, *NEI Magazine*, May 2025.

⁷⁴³ - Ben Geman, “Biden Administration Looks to Ease AI-Climate Collision”, *Axios*, 13 September 2024, see <https://www.axios.com/2024/09/13/biden-team-looks-to-ease-ai-climate-collision>, accessed 17 May 2025.

⁷⁴⁴ - Tope Alake, Josh Saul, and Romaine Bostick, “Clean No Longer Tops Agenda for Utilities, Exelon CEO Says”, *Bloomberg*, 22 April 2025, see <https://www.bloomberg.com/news/articles/2025-04-22/clean-no-longer-tops-agenda-for-utilities-exelon-ceo-says>, accessed 17 May 2025.

production and investment tax credits and loan guarantees vitally affects nuclear industry business plans. Significantly, the one major corporate restructuring deal announced since mid-2024 involves large addition of fossil fuel generation: Constellation's US\$16.4 billion deal to acquire Calpine, the largest gas power generator in the U.S. If regulators approve the deal, Constellation will become the largest power generation company in the country, with 60 GW of generation capacity.⁷⁴⁵ Constellation CEO Joe Dominguez was quoted as saying that the Calpine acquisition is intended to capture market share in the data center power supply market:

The hyperscalers and other data providers that want to store AI data do not have enough carbon-free power options today... They're going to have to use some natural gas, and we want to be able to participate in that.⁷⁴⁶

Those considerations notwithstanding, several developments in recent months could have significant implications for nuclear energy development in the U.S.:

- ➔ On 23 May 2025, President Trump issued four executive orders to promote an expansion of nuclear energy.⁷⁴⁷ They include setting a target to quadruple nuclear generation capacity by 2050; setting a 5-GW target for power uprates of existing reactors;⁷⁴⁸ directing the NRC to expedite licensing proceedings, with a limit of one year for license extensions and 18 months for reactor construction permits and licenses;⁷⁴⁹ expanding domestic uranium mining, enrichment, fuel production, and reprocessing capacity; directing the Department of Defense and Department of Energy to initiate construction of ten reactors on federal lands by 2030, outside of NRC licensing review, in order to power military bases and other national security infrastructure, including artificial intelligence data centers.⁷⁵⁰
- ➔ Congress enacted a bill with sweeping amendments to federal tax policies and budgets, which includes a rapid phaseout of tax credits for wind and solar generation.⁷⁵¹ It leaves tax credits for nuclear energy largely unaffected, only adding restrictions on the eligibility of reactors owned by certain countries (including Russia and China) and the use of nuclear fuel produced by those countries.

⁷⁴⁵ - Robert Walton, "Constellation's US\$16.4B Purchase of Calpine Would Create Largest US Power Generator", *Utility Dive*, 10 January 2025, see <https://www.utilitydive.com/news/constellation-acquires-calpine-in-164b-mega-deal/737012/>, accessed 17 May 2025.

⁷⁴⁶ - Carolyn Davis, "Why Calpine? Constellation's Blockbuster Deal Tied to Soaring Power Generation, Especially Natural Gas", *Natural Gas Intelligence*, 13 January 2025, see <https://naturalgasintel.com/news/why-calpine-constellations-blockbuster-deal-tied-to-soaring-power-generation-especially-natural-gas/>, accessed 18 May 2025.

⁷⁴⁷ - Brian Martucci, "Trump Aims for 400 GW of Nuclear by 2050, 10 Large Reactors Under Construction by 2030", *Utility Dive*, 28 May 2025, see <https://www.utilitydive.com/news/trump-aims-for-400-gw-of-nuclear-by-2050-10-large-reactors-under-construct/749107/>, accessed 8 July 2025.

⁷⁴⁸ - The White House, "Reinvigorating the Nuclear Industrial Base", Executive Order, U.S. Presidency, 23 May 2025, see <https://www.whitehouse.gov/presidential-actions/2025/05/reinvigorating-the-nuclear-industrial-base/>, accessed 25 May 2025.

⁷⁴⁹ - The White House, "Ordering the Reform of the Nuclear Regulatory Commission", Executive Order, 23 May 2025, see <https://www.whitehouse.gov/presidential-actions/2025/05/ordering-the-reform-of-the-nuclear-regulatory-commission/>, accessed 8 July 2025.

⁷⁵⁰ - The White House, "Deploying Advanced Nuclear Reactor Technologies for National Security", Executive Order, 23 May 2025, see <https://www.whitehouse.gov/presidential-actions/2025/05/deploying-advanced-nuclear-reactor-technologies-for-national-security/>, accessed 8 July 2025.

⁷⁵¹ - One Big Beautiful Bill Act Cuts the Power: Phase-Outs, Foreign-Entity Restrictions, and Domestic Content in Clean-Energy Credits", Frost Brown Todd Attorneys, 4 July 2025, op. cit.

- ➔ Following issuance of the executive orders, Westinghouse reportedly is meeting with the White House, proposing to provide the ten reactors that the Defense and Energy departments are directed to build, at a cost of US\$75 billion.⁷⁵²
- ➔ Fermi America, a company recently co-founded by former Energy Secretary Rick Perry (during President Trump's first term), announced a proposal to build four Westinghouse AP-1000 reactors on land at a Department of Energy nuclear weapons plant in Amarillo, Texas.⁷⁵³ On 7 July 2025, NRC issued a letter acknowledging Fermi's "initial submittal of a Combined License Application (COLA)."⁷⁵⁴

The concrete implications of these developments are yet to be determined. Some measures covered in the executive orders will be dependent on fiscal appropriations by Congress, including expansions of nuclear fuel infrastructure and construction of reactors by the Defense and Energy departments.

AI, Data Centers, and Nuclear Power

There has also been a significant development affecting the trend of co-location and power supply deals between nuclear generators and data center developers. As reported in WNISR2024, Amazon Web Services (AWS) agreed to pay Talen Energy US\$650 million for the rights to a large data center development planned at Talen's two-unit 2.5-GW Susquehanna Nuclear Power Plant in Pennsylvania.⁷⁵⁵ The data-center campus includes options to expand in subsequent phases to consume as much as 960 MW, 40 percent of Susquehanna's capacity.

A feature of the development included an agreement with grid operator PJM Interconnection that would have permitted AWS to classify an additional 180 MW of its data-center load (up to 480 MW) as located "behind-the-meter," enabling Amazon to avoid costs associated with grid interconnections, transmission system upgrades, and approvals.⁷⁵⁶ Transmission owners Exelon and American Electric Power (AEP) filed a complaint with the Federal Energy Regulatory Commission (FERC) to void the deal and require AWS to go through the interconnection process, arguing that the data center will continue to draw power from the grid during times when Susquehanna is offline, and that other consumers will bear up to US\$140 million in

752 - Jamie Smyth, "Westinghouse Targets \$75bn US Nuclear Expansion After Donald Trump Order", *The Financial Times*, 6 June 2025, see <https://www.ft.com/content/86cecb58-20a1-4eef-8e06-c7a39d0f3536>, accessed 8 July 2025.

753 - Timothy Gardner, "Texas Firm Aims to Build World's Largest Data Energy Complex with Nuclear, Gas, Solar", *Reuters*, 27 June 2025, see <https://www.reuters.com/business/energy/texas-firm-aims-build-worlds-largest-data-energy-complex-with-nuclear-gas-solar-2025-06-26/>, accessed 8 July 2025.

754 - Office of Nuclear Reactor Regulation, "Fermi America - Acknowledgement of Part One of the Combined License Application for the President Donald J. Trump Advanced Energy And Intelligence Campus, Units 1 Through 4", U.S. Nuclear Regulatory Commission, 7 July 2025, see <https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML25182A087>, accessed 8 July 2025.

755 - Dan Swinhoe, "AWS Acquires Talen's Nuclear Data Center Campus in Pennsylvania", *Data Center Dynamics*, 4 March 2024, see <https://www.datacenterdynamics.com/en/news/aws-acquires-talens-nuclear-data-center-campus-in-pennsylvania/>, accessed 28 July 2024; and Talen Energy Corporation, "Q4 2023 and FY 2023 Earnings Presentation", 15 March 2024, see <https://ir.talenenergy.com/static-files/84443b81-b2ab-4774-9ce2-d87a47e8dbb5>, accessed 5 August 2024.

756 - Ethan Howland, "Talen Urges FERC to Reject AEP-Exelon Protest Over Interconnection Pact for Amazon Data Center", *Utility Dive*, 8 July 2024, see <https://www.utilitydive.com/news/talen-ferc-aep-exelon-interconnection-amazon-data-center-nuclear-power/720672/>, accessed 28 July 2024.

transmission and generation costs affected by AWS's load.⁷⁵⁷ In November 2024, FERC ruled in the utilities' favor, voiding the settlement.⁷⁵⁸

The decision had the effect not only of limiting the exemption for AWS to the first 300 MW of its data center load, as previously approved; but of signaling that FERC would view future data center colocations at existing power plants similarly. Talen appealed the decision, but FERC denied the appeal and affirmed the ruling in April 2025.⁷⁵⁹ In May 2025, Talen filed a further appeal in its suit against FERC in the U.S. Court of Appeals for the 5th Circuit.⁷⁶⁰ However, in June 2025, Amazon and Talen announced that they have amended their agreement and converted it into a conventional Power Purchase Agreement (PPA) for up to 1920 MW of Susquehanna's generation capacity. The PPA is no longer specific to the co-located data center but is for the purchase of power for Amazon's data centers in the PJM service area. The parties state that the agreement no longer rests upon the proposed exemptions from interconnection fees and, therefore, no longer requires FERC approval. Talen has not announced whether it will continue its legal action against FERC.

Following FERC's denial of the appeal, Constellation announced that it had adjusted its data center strategy: it will pursue PPAs rather than colocation deals.⁷⁶¹ Constellation had not reached any colocation agreements to date despite expressing interest in doing so already in 2022⁷⁶²; in fact, it is consistent with two prior announced deals with Microsoft. In 2023, Constellation stated it had reached an agreement with Microsoft for a "Virtual Hourly Matching PPA" (VHM PPA), to sell power to the tech giant's Virginia data centers from its nuclear power plants in the region.⁷⁶³ A platform jointly developed by the corporations would ostensibly match transactions for power generated by Constellation reactors to Microsoft's data center loads.⁷⁶⁴ Without further mentioning that VHM PPA, in September 2024, the corporations announced the deal for a 20-year PPA tied to the proposed restart of Three Mile Island-1 in around 2028,

757 - Ethan Howland, "AEP, Exelon Oppose Talen-Amazon Interconnection Pact to Protect Rate Base Growth Potential: Constellation", *Utility Dive*, 24 July 2024, see <https://www.utilitydive.com/news/aep-exelon-talen-amazon-interconnection-rate-base-ferc-constellation/722246/>, accessed 28 July 2024.

758 - FERC, "Order Rejecting Amendments to Interconnection Service Agreement", 1 November 2024, see <https://www.ferc.gov/media/er24-2172-pjms-susquehanna-co-location-proposal>, accessed 3 June 2025; and Ethan Howland, "FERC Rejects Interconnection Pact for Talen-Amazon Data Center Deal at Nuclear Plant", *Utility Dive*, 4 November 2024, see <https://www.utilitydive.com/news/ferc-interconnection-isa-talen-amazon-data-center-susquehanna-exelon/731841/>, accessed 17 May 2025; and David Appleyard, "Trump's nuclear plans spell trouble", *NEI Magazine*, May 2025.

759 - Zachary Skidmore, "FERC Upholds Rejection of Proposed Interconnection Agreement Between AWS Data Center and Pennsylvania Nuclear Plant", *Data Center Dynamics*, 14 April 2025, see <https://www.datacenterdynamics.com/en/news/ferc-upholds-rejection-of-proposed-interconnection-agreement-between-aws-data-center-and-pennsylvania-nuclear-plant/>, accessed 17 May 2025.

760 - Brandon Vigliarolo "Amazon, Talen Energy Sidestep Regulators with New Power Deal", *The Register*, 12 June 2025, see https://www.theregister.com/2025/06/12/amazon_talen_nuclear_deal/, accessed 9 July 2025.

761 - Laila Kearney, "Constellation Refocusing on Grid-Connected AI Data Center Power Projects", *Reuters*, 6 May 2025, see <https://www.reuters.com/business/energy/constellation-refocusing-grid-connected-ai-data-center-power-projects-2025-05-06/>, accessed 19 May 2025.

762 - Dan Swinhoe, "Constellation Energy Splits From Exelon, Aims to Colocate Data Centers at Power Plants", *Data Centre Dynamics*, 4 February 2022, see <https://www.datacenterdynamics.com/en/news/constellation-energy-splits-from-exelon-aims-to-colocate-data-centers-at-power-plants/>, accessed 1 August 2023.

763 - Constellation, "Constellation Signs Hourly Carbon-Free Energy Matching Agreement With Microsoft to Support a Clean-Powered Data Center", Press Release, 29 June 2023, see <https://www.constellationenergy.com/newsroom/2023/Constellation-signs-hourly-carbon-free-energy-matching-agreement-with-Microsoft-to-support-a-clean-powered-data-center.html>, accessed 19 May 2025.

764 - Ibidem.

through which Microsoft would procure power for a number of its data centers connected to the PJM grid.⁷⁶⁵

Following the Three Mile Island restart-deal, major technology companies announced deals to procure nuclear energy. All of these other deals are with startup firms designing new reactors, for future procurement of power. Only two tech companies have made any direct investments as a result of any of the deals: in October 2024, Amazon led a group of investors investing a total of US\$500 million in X-energy.⁷⁶⁶ At the same time, Amazon agreed to contribute a reported US\$334 million to Energy Northwest (ENW) for a feasibility study of the utility's proposal to develop up to three (320 MW) X-energy Xe-100 SMR plants; under that MoU, Amazon would agree to procure power from the first four-reactor Xe-100 plant.⁷⁶⁷ A third procurement MoU which Amazon announced with Dominion Energy to develop X-energy SMRs in Virginia is not reported to include any direct investment.⁷⁶⁸ In June 2025, AI microchip producer Nvidia invested an unspecified amount in Terrapower's "\$650 million fundraiser."⁷⁶⁹

Of other tech majors, Google announced MoUs with SMR developer Kairos Energy (500 MW) in October 2024⁷⁷⁰ and nuclear project developer Elementl (1.8 GW) in May 2025⁷⁷¹; Meta issued a request for proposals for up to 4 GW of new nuclear capacity in December 2024,⁷⁷² and announced a deal with Constellation to purchase zero-emissions credits from the 1120-MW

765 - Constellation, "Constellation to Launch Crane Clean Energy Center, Restoring Jobs and Carbon-Free Power to The Grid", Press Release, 20 September 2024, see <https://www.constellationenergy.com/newsroom/2024/Constellation-to-Launch-Crane-Clean-Energy-Center-Restoring-Jobs-and-Carbon-Free-Power-to-The-Grid.html>, accessed 1 June 2025; and Brian Martucci, "Constellation Plans 2028 Restart of Three Mile Island Unit 1, Spurred by Microsoft PPA", *Utility Dive*, 20 September 2024, see <https://www.utilitydive.com/news/constellation-three-mile-island-nuclear-power-plant-microsoft-data-center-ppa/727652/>, accessed 19 May 2025.

766 - X-energy, "Amazon Invests in X-energy to Support Advanced Small Modular Nuclear Reactors and Expand Carbon-Free Power", Press Release, 16 October 2024, see <https://x-energy.com/media/news-releases/amazon-invests-in-x-energy-to-support-advanced-small-modular-nuclear-reactors-and-expand-carbon-free-power>, accessed 3 June 2025.

767 - John Stang, "Amazon Offers \$334M for Nuclear Reactors to Be Built at Hanford", *Cascade PBS*, 26 November 2024, op. cit.; and Energy Northwest, "Amazon and Energy Northwest Announce Plans to Develop Advanced Nuclear Technology in Washington", Press Release, 16 October 2024, see <https://www.energy-northwest.com/whoware/news-and-info/Pages/Amazon-and-Energy-Northwest-announce-plans-to-develop--advanced-nuclear-technology-in-Washington.aspx>, accessed 2 June 2025.

768 - Jeff Clabaugh, "Amazon Strikes Deal to Develop Nuclear Power at Va.'S Lake Anna", *WTOP News*, 16 October 2024, see <https://wtop.com/business-finance/2024/10/amazon-strikes-deal-to-develop-nuclear-power-at-virginias-north-anna/>, accessed 19 May 2025; and Amazon, "Amazon Signs Agreements for Innovative Nuclear Energy Projects to Address Growing Energy Demands", 16 October 2024, see <https://www.aboutamazon.com/news/sustainability/amazon-nuclear-small-modular-reactor-net-carbon-zero>, accessed 2 June 2025.

769 - Tobias Mann, "Nvidia Bets on Gates-Backed TerraPower Micronuclear Provider", *The Register*, 18 June 2025, see https://www.theregister.com/2025/06/18/nvidia_ai_smr_investment/, accessed 19 June 2025; and TerraPower, "TerraPower Announces \$650 Million Fundraise", Press Release, 18 June 2025, see <https://www.terrapower.com/terrapower-announces-650-million-fundraise>, accessed 18 June 2025.

770 - Kairos Power, "Google and Kairos Power Partner to Deploy 500 MW of Clean Electricity Generation", Press Release, 14 October 2024, see https://kairospower.com/external_updates/google-and-kairos-power-partner-to-deploy-500-mw-of-clean-electricity-generation/, accessed 2 June 2025; and Brian Martucci, "Google, Kairos Power Ink 500-MW Advanced Nuclear Reactor Deal", *Utility Dive*, 15 October 2024, see <https://www.utilitydive.com/news/google-kairos-power-advanced-nuclear-reactor-data-center-electricity-demand-ai/729876/>, accessed 19 May 2025.

771 - Pippa Stevens, "Google Agrees to Fund the Development of Three New Nuclear Sites", *CNBC*, 7 May 2025, see <https://www.cnbc.com/2025/05/07/google-agrees-to-fund-the-development-of-three-new-nuclear-sites.html>, accessed 16 May 2025; and Google, "Google and Elementl Power Are Collaborating to Advance Nuclear Energy Site Development", 7 May 2025, see <https://blog.google/feed/google-and-elementl-nuclear-energy-site-development/>, accessed 3 June 2025.

772 - Brian Martucci, "Meta Seeks Up to 4 GW of New Nuclear Power to Help Meet AI, Sustainability Objectives", *Utility Dive*, 4 December 2024, see <https://www.utilitydive.com/news/meta-seeks-up-to-4-gw-of-new-nuclear-power-to-help-meet-ai-sustainability/734599/>, accessed 19 May 2025; and Meta, "Accelerating the Next Wave of Nuclear to Power AI Innovation", 3 December 2024, see <https://sustainability.atmeta.com/blog/2024/12/03/accelerating-the-next-wave-of-nuclear-to-power-ai-innovation/>, accessed 3 June 2025.

Clinton-1 reactor in Illinois beginning in June 2027, after the state's ZEC program ends.⁷⁷³ Amid those announcements, Oracle reportedly stated to investors in September 2024 that it has secured “building permits for three small modular nuclear reactors (SMRs),”⁷⁷⁴ though NRC has issued no such permits and the company has not provided any details to clarify or substantiate the claim.

In addition, Oklo announced deals with data center developers Equinix (500 MW) and Switch (12 GW).⁷⁷⁵ The Equinix deal included a “US\$25.0 million prepayment made by Equinix to Oklo for the supply of power by Oklo.”⁷⁷⁶ In March 2025, Oklo issued a letter to its shareholders stating that it has “upgraded” its reactor design to 75 MW and providing additional details on the structures of its power supply deals.⁷⁷⁷

Since it submitted a license application to the NRC in 2020, Oklo has increased the capacity of its Powerhouse reactor from a 1.5-MW microreactor, to a 10-MW to 50-MW option it announced in 2022, to a 75-MW design in 2025. The NRC rejected Oklo's 2020 license application in 2022, after the company failed to submit additional information required by the agency to complete its review.⁷⁷⁸ Oklo has been in pre-application discussions with NRC since 2022 and says that it intends, as of May 2025, to submit a new license application in late 2025.⁷⁷⁹ However, according to the information provided to investors in March, it is evident that Oklo's power deals are not dependent on licensing or building reactors.⁷⁸⁰ The company reports that its deals are in the form of “master power agreements”, which apparently only obligate Oklo to deliver power to its customers, regardless of how or where it is generated. According to the shareholder letter, Oklo has contracted with a third company, RPower, a provider of gas-fueled generation, to generate the power for Oklo's customers:

Oklo and RPower are partnering on a first-of-its-kind phased energy strategy to deliver immediate power and long-term clean energy for customers. RPower's natural gas generators will provide bridge power for select projects, then shift to providing backup power as Aurora powerhouses come online, providing high uptime and reliability.⁷⁸¹

773 - Constellation, “Constellation, Meta Sign 20-Year Deal for Clean, Reliable Nuclear Energy in Illinois”, Press Release, 3 June 2025, see <https://www.constellationenergy.com/newsroom/2025/constellation-meta-sign-20-year-deal-for-clean-reliable-nuclear-energy-in-illinois.html>, accessed 3 June 2025.

774 - Georgia Butler, “Oracle to Build Nuclear SMR-Powered Gigawatt Data Center”, *Data Center Dynamics*, 10 September 2024, see <https://www.datacenterdynamics.com/en/news/oracle-to-build-nuclear-smr-powered-gigawatt-data-center/>, accessed 19 May 2025.

775 - Brian Martucci, “Oklo Inks 12-GW Advanced Reactor Supply Agreement with Data Center Developer Switch”, *Utility Dive*, 18 December 2024, see <https://www.utilitydive.com/news/oklo-aurora-smr-advanced-nuclear-reactor-supply-agreement-data-center-developer-switch/735933/>, accessed 19 May 2025.

776 - U.S. SEC, “Amendment No. 4 to Form S-4—AltC Acquisition Corp.”, United States Securities and Exchange Commission, filed 2 April 2024, see <https://www.sec.gov/ix?doc=/Archives/edgar/data/1849056/000110465924042658/alcc-20231231xs4a.htm>, accessed 22 June 2025; and Dan Swinhoe, “Equinix Signs Deal to Procure Up To 500MW of Nuclear Power From Oklo Reactors – Makes \$25m Pre-Payment”, *Data Center Dynamics*, 5 April 2024, see <https://www.datacenterdynamics.com/en/news/equinix-signs-deal-to-procure-up-to-500mw-of-nuclear-power-from-oklo-smrs-makes-25m-pre-payment/>, accessed 19 May 2025.

777 - Brian Martucci, “Oklo Reveals 75-MW Reactor Design, Eyes Late 2027 Commercial Deployment”, *Utility Dive*, 26 March 2025, see <https://www.utilitydive.com/news/oklo-75-mw-reactor-design-smr-nuclear/743578/>, accessed 16 May 2025.

778 - U.S. NRC, “NRC Denies Oklo Combined License Application for Lack of Information; Company May Reapply in the Future”, 6 January 2022, see <https://www.nrc.gov/reading-rm/doc-collections/news/2022/22-002.pdf>, accessed 3 June 2025.

779 - Oklo, “Oklo and Korea Hydro & Nuclear Power to Cooperate on Advanced Nuclear Project”, Press Release, 27 May 2025, see <https://oklo.com/newsroom/news-details/2025/Oklo-and-Korea-Hydro--Nuclear-Power-to-Cooperate-on-Advanced-Nuclear-Project/default.aspx>, accessed 29 May 2025.

780 - Oklo, Inc., “FY 2024—Shareholder Letter”, March 2025, see https://s2o3.q4cdn.com/103172959/files/doc_financials/2024/q4/FY-2024-Shareholder-Letter.pdf, accessed 19 May 2025.

781 - Ibidem.

Oklo did not report whether its power deals require it to complete the transition to supplying nuclear-generated electricity by any particular date, nor whether there are any penalties or contingencies if it does not ultimately succeed in doing so.

There have been limited developments with respect to hydrogen production and other cogeneration applications since mid-2024. Dow Chemical's construction permit application for the Long Mott Generating Station clarifies that the four-reactor facility would have sufficient capacity to meet all of the steam supply needs of its adjacent UCC Seadrift chemical production plant, in addition to providing about 290 MW of net electricity generation.⁷⁸² In early January 2025, the Internal Revenue Service issued tax rules implementing the Hydrogen Production Credit (Hydrogen PTC), which significantly expanded the capability for existing nuclear generation to qualify.⁷⁸³ The IRS rules still capped the eligible capacity from existing reactors for hydrogen production at 200 MW. Together with the uncertain fate of the Hydrogen PTC under the Trump administration, Constellation and other nuclear generation companies have not confirmed plans to proceed with hydrogen production.

Overview – Nuclear Power Contracts with Data Centers

Since 2021, nuclear power corporations and data center developers have announced plans to supply up to 35 GW of nuclear generation capacity to power artificial intelligence, cryptocurrency mining, and other hyperscale data centers.

MAJOR DATA CENTER DEVELOPERS

Amazon

Four deals include power purchase agreements (PPAs) and Memoranda of Understanding (MoUs) for up to 7.2 GW of nuclear generation capacity:

- **Talen (1920 MW):** In March 2024, Amazon bought the rights to develop up to 960 MW of data center capacity at Talen Energy's Susquehanna Nuclear Power Plant.⁷⁸⁴ In June 2025, the companies amended and expanded the PPA to 1920 MW of power for Amazon's data centers in the PJM service territory.⁷⁸⁵
- **X-energy (~5 GW):** In October 2024, Amazon led US\$500 million of investments in X-energy, which included an MoU to develop "more than 5 gigawatts [GW]" of Xe-100 SMRs by 2039.
- **Energy Northwest (320 MW):** In October 2024, Amazon entered an MoU with Energy Northwest, which includes US\$334 million contribution by Amazon toward a feasibility study. The agreement gives Amazon the rights to power from the first of three X-energy SMR power stations (320 MW each) that Energy Northwest proposes to build.

⁷⁸² - U.S. NRC, "NRC: Package ML25090A057 -Long Mott Energy, LLC, Submittal of Construction Permit Application for Long Mott Generating Station", 16 April 2025, see <https://www.nrc.gov/docs/ML2509/ML25090A057.html>, accessed 10 July 2025.

⁷⁸³ - Timothy Gardner, "Biden Team Offers Nuclear Path to Hydrogen Tax Credit", *Reuters*, 3 January 2025, see <https://www.reuters.com/sustainability/climate-energy/biden-administration-offers-nuclear-industry-path-hydrogen-tax-credit-2025-01-03/>, accessed 19 May 2025.

⁷⁸⁴ - Dan Swinhoe, "AWS Acquires Talen's Nuclear Data Center Campus in Pennsylvania", *Data Center Dynamics*, 4 March 2024, see <https://www.datacenterdynamics.com/en/news/aws-acquires-talens-nuclear-data-center-campus-in-pennsylvania/>, accessed 29 July 2024.

⁷⁸⁵ - Brandon Vigliarolo "Amazon, Talen Energy Sidestep Regulators with New Power Deal", *The Register*, 12 June 2025, op. cit.

■ **Dominion (300 MW):** In October 2024, Amazon entered an MoU with Dominion Energy to procure 300 MW of power from an unspecified SMR to be built at the North Anna Nuclear Power Plant.

Alphabet (Google)

Two deals include MoUs for up to 2.3 GW of nuclear generation.

■ **Kairos (500 MW):** In October 2024, Alphabet announced an MoU with molten salt reactor developer Kairos to build up to 500 MW of 70-MW SMRs by 2035.⁷⁸⁶

■ **Elementl (1800 MW):** In May 2025, Alphabet and project developer Elementl announced an MoU for three nuclear projects, totaling 1800 MW.⁷⁸⁷ The announcement did not specify reactor designs or locations.

Meta (Facebook)

One contract and one solicitation, totaling up to 5.1 GW of nuclear generation.

■ **1-4 GW solicitation:** In December 2024, Meta issued a request for proposals (RFP) for up to 4 GW of nuclear generation capacity.⁷⁸⁸ Meta reports it is evaluating “over 50 qualified submissions.”⁷⁸⁹

■ **Constellation (1120 MW):** In May 2025, Meta and Constellation announced a contract for the sale of zero-emissions credits (ZECs) from the Clinton Nuclear Power Plant in Illinois.⁷⁹⁰ The contract begins in June 2027, after Illinois’ state ZEC program expires.

Microsoft

Two MoUs with Constellation, for at least 835 MW of nuclear generation.

■ **Three Mile Island-1 restart (835 MW):** In September 2024, Microsoft and Constellation announced an MoU for a 20-year PPA for the sale of power from the TMI-1 reactor, which was retired in 2019.⁷⁹¹ The term of the PPA would begin when Constellation brings the reactor out of retirement, projected for 2028.

⁷⁸⁶ - Brian Martucci, “Google, Kairos Power Ink 500-MW Advanced Nuclear Reactor Deal”, *Utility Dive*, 15 October 2024, see <https://www.utilitydive.com/news/google-kairos-power-advanced-nuclear-reactor-data-center-electricity-demand-ai/729876/>, accessed 19 May 2025.

⁷⁸⁷ - Pippa Stevens, “Google Agrees to Fund the Development of Three New Nuclear Sites”, *CNBC*, 7 May 2025, see <https://www.cnbc.com/2025/05/07/google-agrees-to-fund-the-development-of-three-new-nuclear-sites.html>, accessed 16 May 2025.

⁷⁸⁸ - Timothy Gardner, “Meta Seeks Nuclear Power Developers for Reactors to Start in Early 2030s”, *Reuters*, 3 December 2024, see <https://www.reuters.com/business/energy/meta-seeks-nuclear-power-developers-reactors-start-early-2030s-2024-12-03/>, accessed 11 July 2025.

⁷⁸⁹ - Meta, “Meta and Constellation Partner on Clean Energy Project”, Press Release, 3 June 2025, see <https://about.fb.com/news/2025/06/meta-constellation-partner-clean-energy-project/>, accessed 11 July 2025.

⁷⁹⁰ - Catrina Barker, “Meta Involvement in Clinton Nuclear Plant Sparks Debate Over IL Energy Future”, *The Center Square*, 17 June 2025, see https://www.thecentersquare.com/illinois/article_seed4e69-f7co-4f3c-a95b-941073d89bfo.html, accessed 11 July 2025.

⁷⁹¹ - Brian Martucci, “Constellation Plans 2028 Restart of Three Mile Island Unit 1, Spurred by Microsoft PPA”, *Utility Dive*, 20 September 2024, see <https://www.utilitydive.com/news/constellation-three-mile-island-nuclear-power-plant-microsoft-data-center-ppa/727652/>, accessed 19 May 2025.

■ **Virtual Hourly Matching PPA:** In June 2023, the companies announced a PPA to purchase power from Constellation reactors in the PJM service territory for Microsoft data centers in Virginia.⁷⁹² Neither the announcement nor Constellation's filings with the Securities Exchange Commission included relevant details on the PPA, neither the amount of power, nor the duration of the contract or the price.⁷⁹³

Oracle

In September 2024, data center developer Oracle reported to shareholders that it has “building permits” to build three SMRs, totaling 1 GW of capacity.⁷⁹⁴ Founder, chairman, and Chief Technology Officer Larry Ellison provided no further details. The NRC has not issued construction permits for any SMR projects, so the factual basis for the corporation's statements is unclear.

Nvidia

■ In June 2025, Microchip manufacturer Nvidia invested in a US\$650 million funding round in TerraPower, developer of the 345 MW Sodium sodium-cooled fast reactor proposed in Wyoming.⁷⁹⁵

MINOR DATA CENTER DEVELOPERS

Smaller players in the data center industry have also signed PPAs and, in some cases, co-location agreements with nuclear power plant owners.⁷⁹⁶

Mawson Infrastructure Group (153 MW)

■ Mawson currently operates 153 MW of modular data centers on retired steel plant sites near the Beaver Valley and Perry nuclear power plants.⁷⁹⁷

NE Edge, LLC (300 MW)

■ In 2023, developer NE Edge secured the rights to develop a 300-MW⁷⁹⁸ data center at Dominion Energy's Millstone-2 and -3 reactor site in Connecticut.⁷⁹⁹ Construction of the data

⁷⁹² - Constellation, “Constellation Signs Hourly Carbon-Free Energy Matching Agreement With Microsoft to Support a Clean-Powered Data Center”, Press Release, 29 June 2023, op. cit.

⁷⁹³ - Constellation, “Constellation Reports Fourth Quarter and Full Year 2023 Results”, Press Release, February 2024, see <https://investors.constellationenergy.com/static-files/9670ado6-09c5-461d-b6b8-aefd1426b6c4>, accessed 1 June 2025.

⁷⁹⁴ - Georgia Butler, “Oracle to Build Nuclear SMR-Powered Gigawatt Data Center”, *Data Center Dynamics*, 10 September 2024, see <https://www.datacenterdynamics.com/en/news/oracle-to-build-nuclear-smr-powered-gigawatt-data-center/>, accessed 19 May 2025.

⁷⁹⁵ - Tim De Chant, “Nvidia Wants in on the Nuclear Renaissance, Invests in Bill Gates-Backed TerraPower”, *TechCrunch*, 20 June 2025, see <https://techcrunch.com/2025/06/20/nvidia-wants-in-on-the-nuclear-renaissance-invests-in-bill-gates-backed-terrapower/>, accessed 11 July 2025; and TerraPower, “TerraPower Announces \$650 Million Fundraise”, Press Release, 18 June 2025, op. cit.

⁷⁹⁶ - Ryan Ori, Candace Carlisle, and Mark Heschmeyer, “AI's Emergence Opens New Real Estate Frontiers”, *CoStar*, 8 January 2025, see <https://www.costar.com/article/890271824/ais-emergence-opens-new-real-estate-frontiers>, accessed 11 July 2025.

⁷⁹⁷ - Ibidem; and Mawson Infrastructure Group Inc., “Form 10-Q—Quarterly Report Pursuant to Section 13 or 15(d) of the Securities Exchange Act of 1934—for the Quarterly Period Ended September 30, 2024”, November 2024, see https://www.sec.gov/Archives/edgar/data/1218683/000121390024097833/ea0219695-10q_mawson.htm, accessed 11 July 2025.

⁷⁹⁸ - Erica E. Phillips, “Millstone Nuclear Plant Would Power Proposed CT Data Center”, *CT Mirror*, 19 January 2024, see <http://ctmirror.org/2024/01/19/millstone-power-plant-ct-data-center-nuclear/>, accessed 11 July 2025.

⁷⁹⁹ - Dan Swinhoe, “NE Edge Proposes 1.5 Million Sq Ft Data Center at Nuclear Power Station in Connecticut”, *Data Center Dynamics*, 22 February 2023, see <https://www.datacenterdynamics.com/en/news/ne-edge-proposes-15-million-sq-ft-data-center-at-nuclear-power-station-in-connecticut/>, accessed 11 July 2025.

center has not begun, pending Dominion's submission and approval of an application to the Connecticut Siting Commission.

Standard Power (112 MW)

■ In 2021, Standard Power entered into PPAs with Energy Harbor (now owned by Luminant) to power its data centers in Ohio.⁸⁰⁰ As of 2024, the company was operating 112 MW of data centers at sites in Coshocton and Conesville, OH.⁸⁰¹ The company reportedly plans to expand the Conesville site with another 1165 MW of data centers under further PPAs with Luminant's nuclear power plants in Ohio and Pennsylvania.

NUCLEAR REACTOR DEVELOPERS

Three other corporations have announced power contracts or development projects to power data centers with nuclear reactors.

Fermi America (4.4 GW)

In June 2025, the new company Fermi America, led by former Texas Governor and U.S. Energy Secretary Rick Perry announced plans to develop the Donald J. Trump Advanced Energy and Intelligence Campus, with up to 11 GW of generation capacity for power data centers, all to be located at the Pantex nuclear warhead facility in Amarillo, TX. Fermi America filed an "initial combined operating license submission" to build four Westinghouse AP-1000 reactors on 17 June 2025.⁸⁰²

Last Energy (600 MW)

Microreactor design company Last Energy has announced plans to construct thirty 20-MW reactors (totaling 600 MW) at a site in Haskell, Texas, to sell power to data centers in Texas.⁸⁰³ It initiated pre-application engagement for an early site permit (ESP) with the NRC in February 2025.⁸⁰⁴

Oklo (14 GW)

Oklo has announced "master power agreements" with four customers, totaling 14 GW of generation capacity. With the exception of oil and gas producer Diamondback Energy, the deals are with data center developers:

■ Switch (12 GW)⁸⁰⁵

⁸⁰⁰ - Dan Swinhoe, "Energy Harbor Corp. & Standard Power Sign Partnership to Power Ohio Crypto-Mining Facility with Nuclear Energy", *Data Centre Dynamics*, 19 July 2021, see <https://www.datacenterdynamics.com/en/news/energy-harbor-corp-standard-power-sign-partnership-to-power-ohio-crypto-mining-facility-with-nuclear-energy-energy/>, accessed 11 July 2025.

⁸⁰¹ - Standard Power, "Sites", 11 July 2025, see <https://standardpwr.com/sites/>, accessed 11 July 2025.

⁸⁰² - Office of Nuclear Reactor Regulation, "Fermi America – Acknowledgment of Part One of the Combined License Application for the President Donald J. Trump Advanced Energy and Intelligence Campus, Units 1 through 4", U.S. NRC, addressed to Fermi America, 7 July 2025, see <https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML25182Ao87>, accessed 8 July 2025.

⁸⁰³ - Matt Vincent, "Last Energy to Deploy 30 Microreactors in Texas for Data Centers", *Data Center Frontier*, 4 March 2025, see <https://www.datacenterfrontier.com/energy/article/55272115/last-energy-to-deploy-30-microreactors-in-texas-for-data-centers>, accessed 11 July 2025.

⁸⁰⁴ - Michael Crabb, "Last Energy Regulatory Engagement Plan Submission", Senior Vice President, Last Energy, filed with U.S. NRC, 6 February 2025, see <https://www.nrc.gov/docs/ML2503/ML25038Ao49.pdf>, accessed 11 July 2025.

⁸⁰⁵ - Brian Martucci, "Oklo Inks 12-GW Advanced Reactor Supply Agreement with Data Center Developer Switch", *Utility Dive*, 18 December 2024, see <https://www.utilitydive.com/news/oklo-aurora-smr-advanced-nuclear-reactor-supply-agreement-data-center-developer-switch/735933/>, accessed 19 May 2025.

■ **Equinix (500 MW)**⁸⁰⁶

■ **Prometheus Hyperscale**⁸⁰⁷ **(100 MW)**⁸⁰⁸

According to a letter it provided to its shareholders, Oklo will initially serve its master power agreements with gas generators provided by a third party, Rpower.⁸⁰⁹

Criminal Investigations of Nuclear Power Corporations

Since 2017, the U.S. Justice Department has opened three separate investigations against utility corporations over criminal activities related to nuclear power. The cases have resulted in indictments of corporate executives, lobbyists, and state officials. The cases have been accompanied by additional lawsuits and state-level investigatory proceedings, and they have had political ramifications which appear to have had further impacts on the industry, economically, as well as legally and politically. For detailed background on these cases see [WNISR2023](#) and [WNISR2024](#). There have been significant developments in all three, in recent months:

SCANA-Westinghouse fraud case. The last remaining criminal indictment was resolved in December 2023, when Jeffrey Benjamin, former senior vice president for new plants and major projects at the Westinghouse Electric Company—who directly supervised all new nuclear projects worldwide during the V.C. Summer project—pleaded guilty for his role in covering up mounting delays and cost overruns during the construction of the V.C. Summer-2 and -3 reactors, which were canceled in 2017 after over US\$9 billion were spent and nine rate increases for electricity customers.⁸¹⁰ On 20 November 2024, Benjamin was sentenced to one year and one day in prison and a fine of US\$100,000.⁸¹¹

Exelon-Commonwealth Edison corruption case. The final suspect to be indicted in the corruption case involving nuclear bailout and utility legislation in Illinois is former Speaker of the state House of Representatives Michael Madigan. The trial was originally scheduled to begin in April 2024, but was postponed until October 2024 in deference to a pending U.S. Supreme Court decision in a criminal case involving so-called “gratuities” paid to elected officials,

⁸⁰⁶ - Dan Swinhoe, “Equinix Signs Deal to Procure up to 500MW of Nuclear Power from Oklo Reactors – Makes \$25m Pre-Payment”, *Data Center Dynamics*, 5 April 2024, see <https://www.datacenterdynamics.com/en/news/equinix-signs-deal-to-procure-up-to-500mw-of-nuclear-power-from-oklo-smrs-makes-25m-pre-payment/>, accessed 19 May 2025.

⁸⁰⁷ - Formerly named Wyoming Hyperscale; see Matthew Gooding, “Wyoming Hyperscale Becomes Prometheus Hyperscale, Reveals Pipeline of Four Additional Sites”, *Data Centre Dynamics*, 4 September 2024, see <https://www.datacenterdynamics.com/en/news/wyoming-hyperscale-becomes-prometheus-hyperscale-reveals-pipeline-of-four-additional-sites/>, accessed 11 July 2025.

⁸⁰⁸ - Oklo, “Oklo Partners with Wyoming Hyperscale to Deliver 100 Megawatts to its Data Centers”, Press Release, 23 May 2024, see <https://oklo.com/newsroom/news-details/2024/Oklo-Partners-with-Wyoming-Hyperscale-to-Deliver-100-Megawatts-to-its-Data-Centers/default.aspx>, accessed 11 July 2025.

⁸⁰⁹ - Oklo, Inc., “FY 2024—Shareholder Letter”, March 2025, see https://s203.q4cdn.com/103172959/files/doc_financials/2024/q4/FY-2024-Shareholder-Letter.pdf, accessed 19 May 2025.

⁸¹⁰ - Caitlin Ashworth, “Ex-Westinghouse Exec Pleads Guilty to Charge in Failed SCANA Nuclear Plant”, *The Post and Courier*, 14 December 2023, see https://www.postandcourier.com/columbia/news/vc-summer-westinghouse-scana-santee-cooper-charged-nuclear-plant/article_e53b9db8-9a8f-11ee-bee6-b3a9533ec1cc.html, accessed 29 July 2024; and John Monk, “Last Defendant in US\$9 Billion SCANA Nuclear Construction Scandal Pleads Guilty”, *The State*, 14 December 2023, see <https://www.thestate.com/news/local/crime/article283048128.html>, accessed 12 July 2024.

⁸¹¹ - U.S. Attorney’s Office for the District of South Carolina, “Fourth and Final V.C. Summer Executive Sentenced for Misconduct in Connection with Failed Nuclear Construction Project”, United States Department of Justice, 21 November 2024, see <https://www.justice.gov/usao-sc/pr/fourth-and-final-vc-summer-executive-sentenced-misconduct-connection-failed-nuclear>, accessed 7 January 2025.

which may have superseded the prosecution's case against Madigan.⁸¹² On 12 February 2025, a jury convicted Madigan on ten of the 23 charges against him, with acquittals on seven charges and six ending in mistrial.⁸¹³ Under each of the three counts of wire fraud charges of which he was convicted, Madigan faced up to 20 years in prison; prosecutors initially also sought US\$3.1 million in restitution for the bribes he accepted, but later dropped that request.⁸¹⁴ On 13 June 2025, Madigan was sentenced to 7.5 years in prison and US\$2.5 million in fines; the judge apparently enhanced the sentence finding that Madigan had “perjured himself repeatedly in his trial testimony.”⁸¹⁵

FirstEnergy corruption case. Former Speaker of the Ohio House of Representatives, Larry Householder, and three lobbyists are serving prison sentences for their role in a bribery and corruption scandal that unfolded between 2017 and 2019. FirstEnergy gave Householder, his associates, and his political action committee, Generation Now, close to US\$60 million to pass HB 6, a bill that provided a US\$1.05 billion “taxpayer-funded bailout” to two reactors that FirstEnergy owned at the time. Householder and co-conspirator Matt Borges, former Ohio Republican Party Chairman, appealed their conviction, but the court denied the petition in May 2025.⁸¹⁶

The case has continued to unfold, with further federal and state indictments since December 2023. That month, federal prosecutors brought charges against Sam Randazzo, the former Chairman of the Public Utility Commission of Ohio (PUCO), who allegedly accepted US\$4.3 million from FirstEnergy and helped to draft and implement HB 6.⁸¹⁷ In February 2024, Ohio Attorney General Dave Yost filed charges against Randazzo and two former FirstEnergy executives, then-CEO Chuck Jones and then-Vice-President Michael Dowling.⁸¹⁸ In April 2024, Randazzo died by suicide.⁸¹⁹ He is the second suspect indicted in the case who has taken his

812 - Hannah Meisel, “Madigan Trial Delayed Until October for SCOTUS Review of Bribery Statute”, *Capitol News Illinois*, 3 January 2024, see <https://capitolnewsillinois.com/news/madigan-trial-delayed-until-october-for-scotus-review-of-bribery-statute>, accessed 19 July 2024.

813 - U.S. Attorney's Office for the Northern District of Illinois, “Former Illinois Speaker of the House Michael J. Madigan Convicted on Federal Conspiracy and Bribery Charges”, Press Release, United States Department of Justice, 12 February 2025, see <https://www.justice.gov/usao-ndil/pr/former-illinois-speaker-house-michael-j-madigan-convicted-federal-conspiracy-and>, accessed 3 June 2025; and Hannah Meisel, “Madigan Trial in Review”, *Capitol News Illinois*, 14 February 2025, see <https://capitolnewsillinois.com/madigan-week-in-review/>, accessed 18 May 2025.

814 - ABC7 Chicago, “US Government Wants Former Illinois House Speaker Mike Madigan to Pay US\$3.1M in Restitution”, 28 March 2025, see <https://abc7chicago.com/post/us-government-wants-former-illinois-house-speaker-mike-madigan-pay-31m-restitution-guilty-verdict-corruption-case/16098454/>, accessed 18 May 2025; and Jon Seidel, “Feds No Longer Seeking \$3.1 Million from Michael Madigan”, *NPR Illinois*, 28 April 2025, see <https://www.nprillinois.org/government-politics/2025-04-28/feds-no-longer-seeking-3-1-million-from-michael-madigan>, accessed 4 June 2025.

815 - U.S. Attorney's Office for the Northern District of Illinois, “Former Illinois Speaker of the House Michael J. Madigan Sentenced to Seven and a Half Years in Prison After Corruption Conviction”, Press Release, United States Department of Justice, 13 June 2025, see <https://www.justice.gov/usao-ndil/pr/former-illinois-speaker-house-michael-j-madigan-sentenced-seven-and-half-years-prison>, accessed 22 June 2025.

816 - U.S. Court Of Appeals for the Sixth Circuit, “United States of America v. Larry Householder; Matthew Borges—Appeal from the United States District Court for the Southern District of Ohio at Cincinnati—Opinion”, File 25ao114p.06, decided 6 May 2025, see <https://www.opn.ca6.uscourts.gov/opinions.pdf/25ao114p-06.pdf>, accessed 4 June 2025.

817 - Kathiann M. Kowalski, “Randazzo Indictment Sparks Renewed Calls for Full Regulatory Review in Ohio”, *Energy News Network*, 5 December 2023, see <http://energynews.us/2023/12/05/randazzo-indictment-sparks-renewed-calls-for-full-regulatory-review-in-ohio/>, accessed 30 July 2024.

818 - Marty Schladen, “Ohio Indictments Provide a Better Picture of Squalid Relationships That Spurred Massive Scandal”, *Ohio Capital Journal*, 14 February 2024, see <https://ohiocapitaljournal.com/2024/02/14/ohio-indictments-provide-a-better-picture-of-squalid-relationships-that-spurred-massive-scandal/>, accessed 5 August 2024.

819 - Marty Schladen, “Indicted Former Ohio Utility Chair Sam Randazzo Reported Dead by Suicide”, *Ohio Capital Journal*, 9 April 2024, see <https://ohiocapitaljournal.com/2024/04/09/indicted-former-ohio-utility-chair-sam-randazzo-reported-dead-by-suicide/>, accessed 30 July 2024.

own life before going to trial, following the death of lobbyist Neil Clark in 2021 subsequent to his indictment.

Yost's prosecution of Jones and Dowling is scheduled to go to trial on 26 January 2026.⁸²⁰ In addition, on 17 January 2025, a federal grand jury indicted the former executives for "participating in a racketeering conspiracy."⁸²¹ Dowling reportedly plans to call Governor Mike DeWine and Lieutenant Governor Jon Husted as witnesses.⁸²² In June 2024, it was reported that text messages between DeWine and Jones suggest the governor may also have been involved in the bribery scheme. The text messages allegedly show that DeWine asked Jones for a significant campaign donation a month before the 2018-election, and messages between Dowling and Jones in 2019 would state that DeWine actively worked to get the state legislature to pass HB 6.⁸²³

In April, a court ruling compelled testimony from three former FirstEnergy lobbyists and a former executive, enabling an investigation by the Public Utilities Commission of Ohio to move forward.⁸²⁴

Conclusion

The number of reactors and annual nuclear generation again increased slightly in 2024, with Vogtle-4's first grid connection resulting in a minimal increase of less than 1 percent in total annual nuclear generation. Despite the startup of both new Vogtle units in 2023–2024, the average age of the U.S. reactor fleet continues to advance, reaching 43.7 years as of mid-2025. Efforts to restart retired reactors expanded somewhat, with two further proposals joining that of Palisades-1: Duane Arnold-1 and Three Mile Island-1, which were retired in 2020 and 2019, respectively. Palisades-1 remains the most advanced proposal, though its timeline, cost, and ultimate prospects have been clouded by inspection results finding that nearly 1,000 steam-generator tubes are cracked and must be plugged. In addition, the proposal to continue operation of Diablo Canyon-1 and -2 has moved forward, with review of the license renewal application underway at the NRC. Further, the industry has announced plans to seek subsequent license extensions (from 60 years of operation out to 80 years) for more than half of currently operating reactors, and to seek power uprates of at least 16 reactors in the coming years.

⁸²⁰ - *Cleveland.com*, "Former FirstEnergy Top Execs to Go to Trial in January in Summit Bribery Case", 29 April 2025, see <https://www.cleveland.com/ohio-utilities/2025/04/former-firstenergy-top-exec-to-go-to-trial-in-january-in-summit-bribery-case.html>, accessed 18 May 2025.

⁸²¹ - U.S. Attorney's Office for the Southern District of Ohio, "Grand Jury Indicts 2 Former FirstEnergy Executives in Racketeering Conspiracy Involving More than US\$60 Million in Bribery Schemes", U.S. Department of Justice, 17 January 2025, see <https://www.justice.gov/usao-sdoh/pr/grand-jury-indicts-2-former-firstenergy-executives-racketeering-conspiracy-involving>, accessed 18 May 2025.

⁸²² - Morgan Trau, "FirstEnergy VP Dowling Plans To Call Dewine And Husted To The Stand In Corruption Trial", *News 5 Cleveland/ABC*, 20 June 2024, see <https://www.news5cleveland.com/news/politics/ohio-politics/firstenergy-vp-dowling-plans-to-call-dewine-and-husted-to-the-stand-in-corruption-trial>, accessed 30 July 2024.

⁸²³ - Morgan Trau, "New Texts Show Firstenergy Allegedly Working With Gov. Dewine To Pass House Bill 6", *Ohio Capital Journal*, 20 June 2024, see <https://ohiocapitaljournal.com/2024/06/20/new-texts-show-firstenergy-allegedly-working-with-gov-dewine-to-pass-house-bill-6/>, accessed 30 July 2024.

⁸²⁴ - Laura A. Bischoff, "Ohio HB6 Scandal: Judge Orders Former FirstEnergy Officials to Testify", *The Columbus Dispatch*, 25 April 2025, see <https://www.dispatch.com/story/news/politics/courts/2025/04/25/ohio-hb6-scandal-judge-orders-former-firstenergy-officials-to-testify/83269405007/>, accessed 18 May 2025.

Vogtle-4's first grid connection in March 2024 means there are no commercial power reactors under construction in the U.S. for the first time since 2007 (official date of Watts Bar-2 construction restart). No utility companies have made final investment decisions to build new reactors of any type, and the cancellation of NuScale's Carbon Free Power Project in November 2023 has shaken confidence that new designs for SMRs and non-LWRs (Light Water Reactors) will break the pattern of cost escalation and construction delays. Three construction permit applications are currently under review: TerraPower's Natrium project in Wyoming, a sodium-cooled fast neutron design; Dow Chemical's Long Mott Generating Station, comprising four X-energy Xe-100 graphite-moderated, high-temperature, gas-cooled SMRs; and TVA's Clinch River SMR project to build a GE-Hitachi BWRX-300 reactor.

Executive orders issued by President Donald Trump and legislation enacted by Congress in May and July 2025, respectively, could have significant impacts on new reactor construction in the coming years. The legislation largely preserves federal subsidies for nuclear power plants enacted in 2022, while rapidly phasing out subsidies for wind and solar generation. Among other measures, the executive orders call for a quadrupling of nuclear generation capacity by 2050, direct the NRC to rapidly accelerate review of license applications, and direct the departments of Defense and Energy to initiate construction of ten new large reactors by 2030. In response, the NRC has issued statements committing itself to comply with Trump's licensing directives, and companies have announced proposals for new reactor projects: Westinghouse has reportedly met with government officials, offering to construct ten AP-1000 reactors at a projected cost of US\$75 billion; and a new company, Fermi America, has submitted an "initial license application" to build four AP-1000 reactors to power a large data center complex at a Department of Energy plutonium production plant.

Corruption and fraud investigations involving both new reactors and subsidies for operating reactors continued, with the final prosecution in one of them concluding with the sentencing to federal prison of former Westinghouse Vice President Jeffrey Benjamin in the V.C. Summer fraud case. Former Illinois House Speaker Michael Madigan was convicted on ten corruption charges for accepting bribes from Exelon; he was sentenced in June 2025 to 7.5 years in prison and US\$2.5 million in fines. In the US\$61 million FirstEnergy bribery case, federal and state indictments of former FirstEnergy executives, ex-CEO Chuck Jones and ex-VP Michael Dowling are moving forward, with the state trial scheduled for January 2026.

FUKUSHIMA STATUS REPORT

OVERVIEW OF ONSITE AND OFFSITE CHALLENGES

Fourteen years after the disaster began at the Fukushima Daiichi nuclear power plant, Tokyo Electric Power Company (TEPCO) for the first time removed bits of radioactive debris from a heavily contaminated unit—a significant milestone in the plant’s decommissioning that at the same time underscores how immense the task ahead is. The two removals took place three years later than initially scheduled and gleaned a total of just 0.9 grams of material, out of an estimated 880 tons that need to be cleared out. There is no plan yet for how to remove the bulk of the material.

Offsite, decontamination efforts are inching along, with the government aiming to complete around summer 2025 a plan to store or reuse the millions of cubic meters of radioactive soil removed from contaminated areas thus far. Japan appears to have largely kept its food supply free of radioactive contamination and most countries have now lifted bans on Japanese agricultural and seafood imports. China, one of the holdouts, agreed last year to gradually resume seafood purchases. It partially lifted its ban at the end of June 2025. But a WNISR dive into Japan’s **Food Contamination Monitoring** reveals an opaque and apparently disorganized system that makes it difficult for outside observers to understand or feel comfortable with the data.

ONSITE CHALLENGES

Removing Highly Radioactive Nuclear Fuel Debris⁸²⁵

To understand just how massive the challenge of decontaminating and dismantling Fukushima Daiichi is, it is instructive to look at TEPCO’s struggle to remove its first pinch of fuel debris last year (see **Table 12**).

Fuel debris is the mess left after fuel assemblies in three reactor cores overheated and melted, boring through the steel pressure vessel that surrounded them, carving a path through layers of metal, wiring and electronic equipment and eating into the steel-and-concrete foundation in the primary containment vessel below.

The resulting debris, a hardened mix of nuclear fuel, metals, and minerals, is highly radioactive and thus continues to generate heat. It has to be kept cool—the regulatory limit for the bottom of the pressure vessel is 80°C⁸²⁶—to ward off any possibility that the nuclear fuel in the mixture

⁸²⁵ - The following sources were used throughout this section for background on fuel-debris removal: Nuclear Accident Response Office, “Fukushima Daiichi Nuclear Power Station The Challenge of Retrieving ‘Fuel Debris’ Article No.1: What Is Fuel Debris?”, Provisional Translation, Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (METI), Government of Japan, 6 April 2020, Original in Japanese released 14 February 2020, see <https://www.enecho.meti.go.jp/en/category/special/article/fukushima.html>, accessed 4 April 2025; and Nuclear Accident Response Office, “Fukushima Daiichi Nuclear Power Station The Challenge of Retrieving ‘Fuel Debris’ Article No.2: What Obstacles Will We Face?”, Provisional Translation, METI, 21 May 2021, Original published 21 February 2020, see https://www.enecho.meti.go.jp/en/category/special/article/detail_148.html, accessed 3 April 2025; also Kaida Naoe, “The First Small Steps: Debris Removal at Fukushima Daiichi”, *nippon.com*, 27 March 2025, see <https://www.nippon.com/en/japan-topics/g02501/>, accessed 4 April 2025.

⁸²⁶ - TEPCO, “福島第一原子力発電所2号機 原子炉圧力容器底部温度計測状況”, Tokyo Electric Power Company, 14 May 2025, see https://www.tepco.co.jp/decommission/data/plant_data/unit2/rpv_index-j.html, accessed 14 May 2025.

could overheat again or start a thermal runaway reaction. TEPCO says that even without cooling, the debris temperature should plateau at around 240°C, well below the 1,200°C that would spur a thermal runaway reaction.⁸²⁷ TEPCO keeps the debris cool by maintaining a continuous injection of water into the reactors. For the past year, that has kept the temperature at the bottom of the pressure vessels of all three of the damaged units below 40°C.⁸²⁸ TEPCO also injects nitrogen into the damaged pressure vessels to prevent the buildup and combustion of hydrogen, something that had led to explosions in the days after the meltdowns.

TEPCO estimates there is around 880 tons of fuel debris in the three units. It is the source of the continuing radioactive contamination that seeps out of the plant through water, air, and dust. To end that threat and stabilize the onsite situation, the debris must ultimately be removed, packaged, and sealed off somehow from the outside world.

Debris Sampling

Step one in the debris removal process is taking a small sample and assessing its composition, in order to help gauge the radiation risks to workers and figure out how to remove larger quantities and store it safely at scale.⁸²⁹ TEPCO decided to start with Unit 2, since radiation levels inside its reactor building are relatively low compared to the other two units that experienced meltdowns—Units 1 and 3—and the building itself is in relatively good shape, meaning there is less chance of scattering radioactive particles to the outside during removal.⁸³⁰

The primary containment and pressure vessels of all three units are far too radioactive for human workers to enter for any length of time, with lethal dose-rate levels estimated at between several Sieverts per hour (Sv/h) to several hundreds of Sv/h, thousands of times the regulatory *annual* dose limit.^{831,832} But TEPCO has been surveying the inside of the vessels with robots and had more information on the location of the debris in Unit 2 than for the other units.

Initially, the sampling was supposed to have started by 2021 but was delayed until the fall of 2024 by the COVID-19 pandemic and unexpected problems in gaining access to the

827 - Fukushima Daiichi Decontamination & Decommissioning Engineering Company, “福島第一原子力発電所における燃料デブリ取り出しの安全確保策のあり方”, TEPCO, as presented at the 24th Technical Meeting on Examination of Implementation Plans for Nuclear Facilities, TEPCO’s Fukushima Daiichi Nuclear Power Station Accident Countermeasures Office, Nuclear Regulatory Authority of Japan, 4 February 2025, see <https://www.da.nra.go.jp/view/NRA100007837?contents=NRA100007837-002-003>.

828 - Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, “廃炉・汚染水・処理水対策の概要”, as released on 24 April 2025, 30 January 2025, 31 October 2024 and 25 July 2024; see Ministry of Economy Trade and Industry, “廃炉・汚染水・処理水対策チーム会合／事務局会議（アーカイブ）”, Government of Japan, see https://www.meti.go.jp/earthquake/nuclear/decommissioning_team_archive.html, last accessed 6 June 2025.

829 - Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, “Outline of Decommissioning, Contaminated Water and Treated Water Management”, Ministry of Economy, Trade and Industry, Government of Japan, 28 November 2024, see <https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/mp202411.pdf>, accessed 21 May 2025.

830 - Nuclear Accident Response Office, “Fukushima Daiichi Nuclear Power Station The Challenge of Retrieving ‘Fuel Debris’ Article No.2: What Obstacles Will We Face?”, METI, 21 May 2021, op. cit.

831 - A measure of the effect of radiation on the body. Japanese regulations limit exposure to workers to 50 milli-Sievert per year capped at 100 milli-Sievert over the course of five years.

832 - Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods, “Report on ‘Sub-committee for the Evaluation of Fuel Debris Retrieval Methods’”, Nuclear Damage Compensation and Decommissioning Facilitation Corporation, 7 March 2024, see <https://dd-ndf.s2.kuroco-edge.jp/files/user/pdf/en/committee/pdf/report/20240308reportFT.pdf>, accessed 21 May 2025.

containment vessel.⁸³³ TEPCO and partner engineering companies decided the best way to take the first sample was with a piece of equipment shaped like a fishing pole. To get to the debris, engineers guided a telescoping rod into a narrow shaft in Unit 2's containment vessel that was normally used for equipment installation. The rod then extended and lowered a cable equipped with a camera, light, and grasping pincers to the bottom of the vessel to take the sample.⁸³⁴ The whole process was expected to take three weeks as the equipment navigated obstacles.⁸³⁵

There were problems. Workers installing the sampling equipment in the Unit 2 reactor building had to wear full protective gear and were restricted to 15- to 30-minute shifts in order to limit radiation exposure. In August 2024, they realized they had installed sections of the rod in the wrong order, leading to a redo. They also had to replace two cameras,⁸³⁶ which failed in the highly radioactive environment.⁸³⁷

Eventually, TEPCO extracted 0.7 grams of debris on 7 November 2024,⁸³⁸ and another 0.2 grams from a different spot closer to the center of the vessel on 23 April 2025.⁸³⁹ There is around a billion times that amount left to take out from the three reactors.

What Happens Next

Now, as research labs analyze the composition of the sampled debris—a process expected to take 12 to 18 months⁸⁴⁰—TEPCO is also mulling plans for removing the bulk of the material, much of it far more radioactive than the samples. The company is planning to keep pecking at the debris pile in Unit 2, testing and honing the equipment and trying to figure out ways to take out more than just a few grams at a time.⁸⁴¹ For its next tries, TEPCO is hoping to use a

833 - Nuclear Damage Compensation and Decommissioning Facilitation Corporation, “Technical Strategic Plan 2024 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.”, 27 September 2024, see https://dd-ndf.s2.kuroco-edge.jp/files/user/pdf/en/strategic-plan/book/20241216_SP2024eFT.pdf; and *Kyodo News*, “Fukushima Nuclear Fuel Debris Retrieval to Begin on Aug. 22”, 9 August 2024, see <https://english.kyodonews.net/news/2024/08/884be1cc521b-fukushima-nuclear-fuel-debris-retrieval-to-begin-on-thursday.html>, both accessed 21 May 2025.

834 - TEPCO, “福島第一原子力発電所 廃炉作業の取り組みに関するご報告—資料2”, October 2024, see https://www.tepco.co.jp/decommission/information/committee/kenminkaigi/pdf/2024/k241008_01-j.pdf; and International Research Institute for Nuclear Decommissioning, “Fukushima Daiichi Nuclear Power Station Unit 2 PCV Internal Investigation/Status of Fuel Debris Trial Retrieval”, TEPCO, 27 February 2025, see https://www.tepco.co.jp/en/hd/decommission/information/newsrelease/reference/pdf/2025/reference_20250227_02-e.pdf; both accessed 21 May 2025.

835 - *Kyodo News*, “Fukushima Nuclear Fuel Debris Retrieval to Begin on Aug. 22”, 9 August 2024, op. cit.

836 - TEPCO, “Fukushima Daiichi Nuclear Power Station Replacing the Cameras for the Unit 2 Fuel Debris Trial Retrieval”, 7 October 2024, see https://www.tepco.co.jp/en/hd/decommission/information/newsrelease/reference/pdf/2024/reference_20241007_01-e.pdf; and *Jiji Press*, “Tepco Resumes Attempt to Remove Nuclear Fuel Debris from Fukushima Plant”, as published by *The Japan Times*, 28 October 2024, see <https://www.japantimes.co.jp/news/2024/10/28/japan/tepco-debris-removal-trial/>; both accessed 9 July 2025.

837 - Mari Yamaguchi, “‘Nervous and Rushed’: Massive Fukushima Plant Cleanup Work Involves High Radiation and Stress”, *The Associated Press*, 11 March 2025, see <https://apnews.com/article/japan-fukushima-plant-radiation-safety-4efe204a48f952137cac5a44b41f93ae>, accessed 21 May 2025.

838 - *Jiji Press*, “Nuclear Debris from Fukushima Reactor Weighs 0.7 Gram”, as published by *The Japan Times*, 9 November 2024, see <https://www.japantimes.co.jp/news/2024/11/09/japan/fukushima-tepco-nuclear-debris/>, accessed 21 May 2025; and TEPCO, “Seventh Press Conference for Overseas Media—Update on the Status of the Discharge of ALPS Treated Water into the Sea and Decommissioning Work at the Fukushima Daiichi Nuclear Power Station”, November 2024, see <https://www.tepco.co.jp/en/decommission/progress/watertreatment/images/20241121-e.pdf>, accessed 5 June 2025.

839 - International Research Institute for Nuclear Decommissioning, “Fukushima Daiichi Nuclear Power Station Unit 2 PCV Internal Investigation/Status of Fuel Debris Trial Retrieval”, TEPCO, 24 April 2025, see https://www.tepco.co.jp/en/hd/decommission/information/newsrelease/reference/pdf/2025/reference_20250424_02-e.pdf, accessed 21 May 2025.

840 - Ibidem.

841 - Nuclear Damage Compensation and Decommissioning Facilitation Corporation, “Technical Strategic Plan 2024 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.”, 27 September 2024, op. cit.

robotic arm for the sampling, rather than pincers hanging from a cable, since it is able to move around more and can take out greater quantities. TEPCO is aiming for a first trial of the arm in the second half of FY2025.⁸⁴²

The company is also slowly building structures that will let it remove the 615 intact spent-fuel assemblies sitting in a cooling pool atop the Unit 2 reactor building. TEPCO aims to start removing the Unit 2 spent fuel by FY2026 and the 392 spent-fuel assemblies from the highly contaminated Unit 1 by FY2027–28.⁸⁴³ TEPCO moves fuel assemblies from the pools atop each unit to a common pool. When they have cooled enough, the assemblies are transferred to dry storage casks in a temporary facility onsite.⁸⁴⁴

TEPCO finished removing the 1,456 spent-fuel assemblies from the relatively unscathed Unit 6's spent-fuel pool on 16 April 2025, leaving 428 new-fuel assemblies at the unit, 198 in the spent-fuel pool and 230 in a storage facility in the reactor building.⁸⁴⁵ The company plans to ship 56 of those assemblies back to their manufacturer in the U.S. starting in the latter part of FY2025.⁸⁴⁶

TEPCO plans to start removing fuel assemblies from Unit 5 in July 2025. Units 5 and 6 are located about 500 meters from Units 1–4. TEPCO completed unloading the spent-fuel assemblies from Unit 3 in 2021 and Unit 4 in 2014.⁸⁴⁷ Units 4, 5, and 6 were not operating when the tsunami hit and did not suffer fuel meltdowns. TEPCO aims to have all the fuel assemblies removed from Units 1–6 by 2031.

TEPCO's success in removing the spent-fuel assemblies from Unit 3 is making that reactor the prime candidate for the first large-scale debris removal. TEPCO is looking at three potential methods (see Japan Focus in *WNISR2024*) and is expected to finish the studies by the middle of FY2025.⁸⁴⁸ The biggest challenge is figuring out how to shield workers and the outside world from extreme levels of radiation while shoveling tons of debris past obstacles like broken equipment and damaged metal scaffolding, then into storage. The latest mid-to-long-term decommissioning plan envisions that work starting some time before 2036.⁸⁴⁹

842 - *The Nihon Keizai Shimbun*, “福島第一原発のデブリ採取、2回目が成功 次回はロボット式に”, 23 April 2025, see <https://www.nikkei.com/article/DGXZQOUA22AD00S5A420C2000000/>, accessed 21 May 2025; and Keitaro Fukuchi, “Robotic Arm Struggles to Take Fuel Sample from Fukushima Plant”, *The Asahi Shimbun*, 28 April 2025, see <https://www.asahi.com/ajw/articles/15704793>, accessed 7 June 2025.

843 - Nuclear Damage Compensation and Decommissioning Facilitation Corporation, “Technical Strategic Plan 2024 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.”, 27 September 2024, op. cit.

844 - TEPCO, “Things You Should Know More About Decommissioning—What Happens to ‘Spent Fuel’ After it Is Removed?”, see https://www.tepco.co.jp/en/hd/decommission/towards_decommissioning/Things_you_should_know_more_about_decommissioning/answer-16-e.html, accessed 9 July 2025.

845 - TEPCO, “福島第一原子力発電所 6号機使用済燃料プールからの使用済燃料取り出し完了について”, 16 April 2025.

846 - TEPCO, “6号機新燃料の搬出について”, 3 July 2025, see https://www4.tepco.co.jp/decommission/information/committee/roadmap_progress/pdf/2025/d250703_24-j.pdf, accessed 9 July 2025.

847 - Ibidem; and Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, “Outline of Decommissioning, Contaminated Water and Treated Water Management”, TEPCO, 24 April 2025, see https://www.tepco.co.jp/en/hd/decommission/information/committee/pdf/2025/roadmap_20250424_01-e.pdf, accessed 6 June 2025.

848 - Nuclear Damage Compensation and Decommissioning Facilitation Corporation, “Technical Strategic Plan 2024 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.”, 27 September 2024, op. cit.

849 - TEPCO, “燃料デブリ取り出し準備 スケジュール”, 24 April 2025, see <https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2025/04/3-3-1.pdf>, accessed 22 May 2025.

The vision is to finish debris removal and the rest of the decommissioning work by 2051, a goal Prime Minister Shigeru Ishiba reaffirmed on the 14th anniversary of the Fukushima events in March 2025.⁸⁵⁰ Given the difficulties ahead and TEPCO's track record so far, many observers are skeptical.

“With this debris sample removal, we move into the third [and final] stage of the [decommissioning] process,” the *Nihon Keizai Shimbun* wrote in a 13 November 2024 editorial, “But no expert thinks we will be able to revert the land back to its untouched state in 27 years.”⁸⁵¹

Contaminated Water⁸⁵²

TEPCO is slowly making headway in the battle against contaminated water at the Fukushima Daiichi compound, although gains remain hard-fought and incremental. In the latest sign of progress, TEPCO in FY2024 released to the sea twice as much treated water as the site generated in newly contaminated water, according to WNISR calculations. In February 2025, the company started dismantling some of the 1,000-plus tanks—most containing 1,000 tons or more of contaminated water—in order to make room for facilities to eventually store fuel debris, although it only has firm plans to remove 12 tanks this fiscal year.⁸⁵³

Contamination largely results when water injected to cool the reactors comes into contact with the highly radioactive fuel debris and leaks into the basements of the buildings, where it mixes with groundwater or rainwater and seeps out into the environment.

To keep that contamination from spreading, TEPCO has installed a seawall and a massive underground wall of ice that surrounds the damaged units. It took steps to keep groundwater around the units relatively low and clean by digging wells to pump out water and covering around 1.4 million m² of land with asphalt.

Those steps have helped TEPCO bring down the amount of contaminated water generated each day from 540 m³ in May 2014 to an average 70 m³ in FY2024, and 50 m³ in the first quarter of 2025.

Still, the amount of contaminated water on the site continued to increase until August 2023, when TEPCO started its controversial step of releasing into the ocean water filtered to remove radioactive elements aside from tritium, a radioactive isotope of hydrogen. In FY2024, TEPCO released 55,000 m³ of treated water,⁸⁵⁴ while the site generated around 25,550 m³ of contaminated water, calculating from the daily average reported by TEPCO.

850 - *The Nihon Keizai Shimbun*, “石破茂首相「原発廃炉、支障ない」 51年までの工程見直さず”, 11 March 2025, see <https://www.nikkei.com/article/DGXZQOUA117REoR1oC25A3000000/>, accessed 22 May 2025.

851 - *The Nihon Keizai Shimbun*, “〔社説〕デブリ初回収を機に実効性ある廃炉を”, 13 November 2024, see <https://www.nikkei.com/article/DGXZQODK13oV4oT11C24A1000000/>, accessed 22 May 2025.

852 - Unless noted otherwise, the sources for this section are: Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, “廃炉・汚染水・処理水対策の概要”, 24 April 2025 and 3 July 2025, see <https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2025/04/04/2-1.pdf>, accessed 21 May 2025.

853 - TEPCO, “Fukushima Daiichi Nuclear Power Station—Dismantling of the J8/J9 area tanks”, 6 February 2025, see https://www.tepco.co.jp/en/hd/decommission/information/newsrelease/reference/pdf/2025/reference_20250206_01-e.pdf, accessed 22 May 2025.

854 - TEPCO, “Treated Water Portal Site—Discharge History”, see https://www.tepco.co.jp/en/decommission/progress/watertreatment/performance_of_discharges/2024/index-e.html, accessed 10 July 2025.

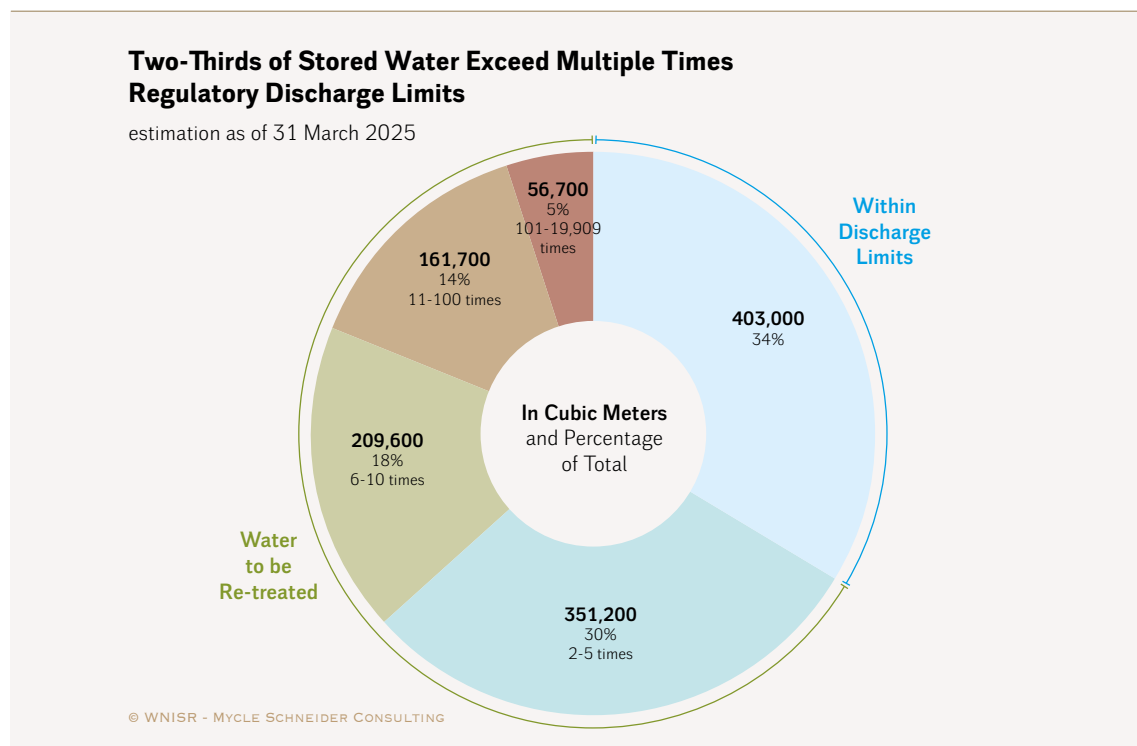
By 28 April 2025, TEPCO had discharged a cumulative 94,000 m³ of treated water. That left roughly 1.3 million m³ of contaminated and treated water on site as of 19 June 2025,⁸⁵⁵ stored in nearly 1,100 tanks.⁸⁵⁶ TEPCO plans to treat and discharge all the contaminated water that collects on the site by the targeted decommissioning deadline of 2051.

*A similar volume of water as in the previous year
but with a 20 percent higher tritium content*

For FY2025, TEPCO plans to release around 54,600 m³ of water, representing roughly 15.3 trillion becquerels (Bq)⁸⁵⁷ of tritium—a similar volume of water as in the previous year but with a 20 percent higher tritium content.⁸⁵⁸

The water-treatment system, Advanced Liquid Processing Systems (ALPS), continues to underperform, with only 34 percent of the 1.18 million m³ of the water it had processed satisfying regulatory standards as of March 2025—little changed from the previous year. The rest needs to be repurified (see Figure 52).⁸⁵⁹

Figure 52 · Percentages of Treated Water and Water to be Re-purified



Source: TEPCO Contaminated Water Portal Site, May 2025

855 - TEPCO, “滞留水の貯蔵状況6月19日時点”, 3 July 2025, see <https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2025/06/06/1-2.pdf>, accessed 10 July 2025.

856 - TEPCO, “各エリア別タンク一覧 (2025年6月19日 現在)”, 3 July 2025, see <https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2025/06/06/1-3.pdf>, accessed 10 July 2025.

857 - A measure of the rate of radioactive decay, one disintegration per second.

858 - TEPCO, “FY2024 Financial Results”, 30 April 2025, see https://www.tepco.co.jp/en/hd/about/ir/library/presentations/pdf/250430_01-e.pdf, accessed 23 May 2025.

859 - Treated Water Portal Site, “Alps Treated Water, Etc.—Reduction Status”, TEPCO, Updated 8 May 2025, see <https://www.tepco.co.jp/en/decommission/progress/watertreatment/alpsstate/index-e.html>, accessed 22 May 2025.

Worker Safety

Worker radiation exposure remains reportedly low overall, with an average exposure of 2.08 mSv/person for FY2024—far below the regulatory limit of 100 mSv over a five-year period and 50 mSv annually, as well as TEPCO’s own annual limit of 20 mSv.⁸⁶⁰

However, in a worker survey conducted between September and October 2024, concerns about contamination—particularly bodily contamination—increased compared to the previous survey.⁸⁶¹ TEPCO speculates this might have to do with an accident in October 2023, when workers cleaning ALPS pipes were sprayed with radioactive water, resulting in contamination levels high enough to send two people to the hospital. The Ministry of Economy, Trade and Industry said after their discharge that “there were no physical problems with any of the workers, and no trouble were observed at the skin of the contaminated area.”⁸⁶²

Other worker-safety concerns are accidents and heat stroke. Fifteen people were injured in workplace accidents at Fukushima Daiichi in FY2024, one seriously enough to require a leave of absence of more than two weeks. Eight people suffered heat stroke or other heat-related stress. Both those numbers are up from the previous fiscal year.⁸⁶³ On 13 June 2024, one worker was found collapsed in a rest area in the compound; he was taken to a hospital and confirmed dead. TEPCO said there was no radioactive contamination on his body and the cause of death was unclear.⁸⁶⁴

OFFSITE CHALLENGES

Approximately 165,000 people evacuated from Fukushima Prefecture after the nuclear disaster began. As of 1 February 2025, the prefecture still officially recorded 24,644 evacuees, 19,673 of them living outside Fukushima.⁸⁶⁵ The total number of people who have returned to former evacuation zones is uncertain and varies widely between locations.

Decontamination work has allowed the government to chip away at Fukushima Prefecture’s “Difficult-to-Return Zones”—areas considered hazardous to live in because annual radiation dosage levels are higher than 50 mSv per year, and are likely to remain above 20 mSv per year even after five years. On 31 March 2025, the government lifted the designation on pieces of

⁸⁶⁰ - Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, “廃炉・汚染水・処理水対策の概要”, 29 May 2025, see <https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2025/05/05/2-1.pdf>, accessed 9 July 2025.

⁸⁶¹ - TEPCO, “Outline of Decommissioning, Contaminated Water and Treated Water Management”, 30 January 2025, see https://www.tepco.co.jp/en/hd/decommission/information/committee/pdf/2025/roadmap_20250130_01-e.pdf, accessed 22 May 2025.

⁸⁶² - METI, “Follow Up News Release Regarding Situation About Splash of Cleaning Water Onto Workers at Additional ALPS Building in Fukushima Daiichi Nuclear Power Station”, Press Release, Ministry of Economy, Trade and Industry, Government of Japan, 28 October 2023, see https://www.meti.go.jp/english/press/2023/1028_001.html, accessed 22 May 2025.

⁸⁶³ - Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, “廃炉・汚染水・処理水対策の概要”, 24 April 2025, op. cit.

⁸⁶⁴ - *The Mainichi Shimbun*, “Worker at Fukushima Nuclear Plant Dies During Decommission Work; Radiation Exposure Denied”, 14 June 2024, see <https://mainichi.jp/english/articles/20240614/p2a/oom/ona/002000c>, accessed 10 July 2025; and Fukushima Daiichi Decommissioning & Engineering Company, “福島第一原子力発電所の状況について（日報）”, TEPCO, June 2024, see <https://www.tepco.co.jp/press/report/2024/pdf/240614j0101.pdf>, accessed 11 July 2025.

⁸⁶⁵ - Fukushima Revitalization Information Portal Site, “Transition of the number of evacuees”, Fukushima Prefectural Government, 11 March 2025, see <https://www.pref.fukushima.lg.jp/site/portal-english/en-1-4-1.html>, accessed 22 May 2025.

Iitate and Katsurao villages,⁸⁶⁶ leaving around 2.2 percent of the prefecture still categorized as “Difficult-to-Return Zones”, as of December 2024.⁸⁶⁷

Disposal of Contaminated Soil⁸⁶⁸

The soil, leaves, timber, and other waste removed in decontamination efforts—mostly in Fukushima Prefecture—is currently stored in interim facilities in two towns bordering the Fukushima Daiichi power plant site. There was around 14 million cubic meters of it as of the end of December 2024, enough to fill 5,600 Olympic swimming pools, even though much of the heavily forested prefecture remains untouched. See [WNISR2024](#) for a discussion of the effectiveness of decontamination in Fukushima Prefecture.

The government is legally mandated to move that contaminated soil and waste out of Fukushima Prefecture by 2045. Japan’s Nuclear Emergency Response Headquarters, a group under the Cabinet Secretariat, created a new committee in December 2024⁸⁶⁹ to take responsibility for planning and implementing that removal, supported by the Ministry of the Environment. The committee released its basic policy for the removal and reuse of the contaminated soil in May 2025 and plans to put together a roadmap for implementation around summertime.⁸⁷⁰ Broadly, the government plans to use, e.g., in a range of construction applications, the soil that is judged safe for reuse, with radiation levels below 8,000 Bq per kilogram. Around three-quarters of the contaminated soil and waste falls into that category.

The Japanese government has decided the rest is to be shipped and stored permanently outside Fukushima Prefecture, in view of the already extreme burden of the nuclear accident on the area’s residents.⁸⁷¹ In early 2025, the Ministry of the Environment released various scenarios for dealing with that heavily contaminated material, including processes for concentrating it into a smaller, more radioactive mass.

Between 2023 and 2024, the International Atomic Energy Agency (IAEA) reviewed the ministry’s approach for recycling and disposal of contaminated soil and deemed it “consistent

⁸⁶⁶ - Ministry of Economy, Trade and Industry, “飯館村・葛尾村における避難指示解除について”, Government of Japan, Updated 7 March 2025, see https://www.meti.go.jp/earthquake/nuclear/kinkyu/hinanshiji/2025/20250307iitatemura_katsuraomura_hinansjikaijo.html, accessed 22 May 2025.

⁸⁶⁷ - Fukushima Revitalization Information Portal Site, “Damage in Fukushima Prefecture”, Fukushima Prefectural Government, 8 January 2025, see <https://www.pref.fukushima.lg.jp/site/portal-english/en-m1.html>, accessed 22 May 2025; and Fukushima Revitalization Information Portal Site, “Transition of the evacuation zones -Explanation-”, Updated 16 February 2024, see <https://www.pref.fukushima.lg.jp/site/portal-english/en-1-3-1.html>, accessed 5 June 2025.

⁸⁶⁸ - Unless noted otherwise, the source for this section is: Ministry of the Environment, “県外最終処分に向けた これまでの取組の成果と 2025 年度以降の進め方”, Government of Japan, 7 March 2025, see <https://www.env.go.jp/content/000302878.pdf>, accessed 22 May 2025.

⁸⁶⁹ - Nuclear Emergency Response Headquarters, “福島県内除去土壌等の県外最終処分の実現に向けた 再生利用等の推進に関する体制の強化について”, 20 December 2024, see https://www.cas.go.jp/jp/seisaku/saisei_riyou/pdf/konkyo.pdf, accessed 14 July 2025.

⁸⁷⁰ - 福島県内除去土壌等の県外最終処分の実現に向けた再生利用等推進会議, “福島県内除去土壌等の県外最終処分の実現に向けた再生利用等の推進に関する基本方針”, Nuclear Emergency Response Headquarters, 27 May 2025, see https://www.cas.go.jp/jp/seisaku/saisei_riyou/pdf/kihon_houshin.pdf; and Prime Minister’s Office, “福島県内除去土壌等の県外最終処分の実現に向けた再生利用等推進会議”, Government of Japan, 27 May 2025, see https://www.kantei.go.jp/jp/pages/20250527choukan_kaigi.html; both accessed 14 July 2025.

⁸⁷¹ - Momo Takada, Muchio Murakami et al., “Public Attitudes toward the Final Disposal of Radioactively Contaminated Soil Resulting from the Fukushima Daiichi Nuclear Power Station Accident”, National Institute of Advanced Industrial Science and Technology, Osaka University, and Hokkaido University, *Environmental Management*, 2 February 2024; and Environment Committee, “第187回国会 衆議院 環境委員会 第5号 平成26年10月31日 | テキスト表示 | 国会会議録検索システム シンプル表示”, House of Representatives, National Diet, 31 October 2014, see <https://kokkai.ndl.go.jp/simple/detail?minId=118704006X00520141031>, accessed 6 June 2025.

with the IAEA Safety Standards.”⁸⁷² The ministry has been conducting its own trials of reusing contaminated soil, including one in Fukushima where the soil was used as filler under rice paddies. The resulting rice had radiation levels well below Japan’s food limits, the ministry says.

However, the soil-recycling idea has gotten a lot of pushback from communities where other trials have been proposed, with activists raising concerns that dust from construction or other reuse projects could be inhaled by those nearby and lead to dangerous internal radiation exposure.⁸⁷³ In early 2025, Tokyo residents protested a plan to use contaminated soil under a flower bed in the popular Shinjuku Gyoen National Garden, while residents of Tokorozawa, Saitama denounced a trial planned for their city.⁸⁷⁴ The government has scrapped those trials, according to local media.⁸⁷⁵

At the end of May 2025, the government committee overseeing the contaminated waste removal proposed leading the way by using some of it at the prime minister’s residence, potentially under a garden; construction is reported to be starting in July.⁸⁷⁶

Meanwhile, an investigative piece in *the Bulletin of the Atomic Scientists* from January 2025 serves as a reminder of the challenges of tracking radioactive contamination and its effects. The article describes the discovery around 2016 that highly radioactive cesium microparticles had wafted to Tokyo following the Fukushima Daiichi meltdowns—and how the research detailing those findings was kept out of publication for three years amid academic infighting and wariness over a politically sensitive topic.⁸⁷⁷

Food Contamination Monitoring

One of the thorniest issues facing Japan following the Fukushima Daiichi nuclear accident has been controlling, monitoring, and communicating about potential radioactive contamination in its food supply.

Testing for radionuclides has shown vanishingly few food samples that exceed contamination limits—at least among cultivated plants and animals where farmers can better control the

⁸⁷² - IAEA, “Japan’s Fukushima Soil Recycling and Disposal Plan Meets Safety Standards, IAEA Says”, Press Release 84/2024, International Atomic Energy Agency, 10 September 2024, see <https://www.iaea.org/newscenter/pressreleases/japans-fukushima-soil-recycling-and-disposal-plan-meets-safety-standards-iaea-says>, accessed 16 May 2025.

⁸⁷³ - Citizens’ Commission on Nuclear Energy, “「声明：除去土壌の「復興再生利用」は、放射能に汚染された土の無秩序な拡散につながり、許されない 一省令案は趣旨が変質しており、改正の正当性がない」を発表しました | 原子力市民委員会”, 18 February 2025, see <https://www.ccnejapan.com/?p=16029>, accessed 22 May 2025.

⁸⁷⁴ - Ryo Takeda, “Tokyo, Saitama Residents Say ‘No’ to Living Near Fukushima Soil”, *The Asahi Shimbun*, 25 February 2023, see <https://www.asahi.com/ajw/articles/14848079>, accessed 22 May 2025.

⁸⁷⁵ - Akira Hatano, “Local Pushback Halted Plans to Reuse Soil from Fukushima”, *The Asahi Shimbun*, 23 April 2025, see <https://www.asahi.com/ajw/articles/15722037>, accessed 22 May 2025.

⁸⁷⁶ - NHK, “首相官邸敷地内での除染土再生利用 7月中にも工事開始へ”, 1 July 2025, see <https://www3.nhk.or.jp/news/html/20250701/k10014849681000.html>; and Justin McCurry, “Fukushima Soil Headed to Japan PM’s Flower Beds to Allay Nuclear Safety Fears”, *The Guardian*, 28 May 2025, see <https://www.theguardian.com/world/2025/may/28/fukushima-radioactive-soil-japan-pm-garden>; both accessed 14 July 2025

⁸⁷⁷ - François Diaz-Maurin, “How Fukushima’s Radioactive Fallout in Tokyo Was Concealed from the Public”, *The Bulletin of the Atomic Scientists*, 13 January 2025, see <https://thebulletin.org/premium/2025-01/how-fukushimas-radioactive-fallout-in-tokyo-was-concealed-from-the-public/>, accessed 23 July 2025.

environment.⁸⁷⁸ When products do exceed those limits, the Japanese government pulls them off the market.

Most of the 55 countries and regions that initially halted imports of food from Japan have lifted those bans, with only China, Russia, South Korea, Taiwan, Hong Kong, and Macau still restricting some products as of mid-2025.⁸⁷⁹

China, which had banned all imports of Japanese seafood following Japan's decision to start releasing treated water from the Fukushima nuclear plant into the ocean, agreed in September 2024 to gradually lift that ban in return for expanded cooperation in monitoring the releases.⁸⁸⁰ At the end of June 2025, China agreed to lift its import ban on seafood products from all but Fukushima and nine other prefectures, as long as exporters provided government certificates of origin and tests for a range of radionuclides.⁸⁸¹

TEPCO has been discharging the water in batches since August 2023,⁸⁸² and the IAEA has declared it “in line with international safety standards.”⁸⁸³ The European Union, Norway, Iceland, Switzerland, and Liechtenstein lifted their remaining food import bans that same month, shortly before the water discharges began.⁸⁸⁴ (See also [section on Contaminated Water](#).)

Still, parts of the Japanese countryside remain significantly contaminated, especially forested areas and streams in Fukushima which are nearly impossible to scrub of radioactive elements. Wild game, fish, and plants from those areas are still showing high levels of radioactivity.

In FY2024, 29 percent of the wild boar meat from Fukushima Prefecture that was tested exceeded radiation limits,⁸⁸⁵ with one specimen caught in February 2025 in the heavily contaminated village of Futaba registering a radioactive cesium level of 13,000 Bq/kg, 130 times

878 - Naomi Hayashida and Itsuko Horiguchi, “The Summary of Risk Response on Radioactive Substances Contained in Food Items in the Aftermath of the Fukushima Nuclear Accident”, Nagasaki University, and Keio University, *Journal of Radiation Research*, 16 December 2024, see https://academic.oup.com/jrr/article/65/Supplement_1/i97/7924268, accessed 2 April 2025; and Tanimura Nobuko, “Radioactive Cesium Contamination of Food After the Fukushima Nuclear Accident Summary up to Fiscal Year 2019”, Citizens’ Nuclear Information Center, 11 February 2021, see <https://cnic.jp/english/?p=5326>, accessed 6 May 2025.

879 - Ministry of Agriculture, Forestry and Fisheries, “Status of Countries and Regions Introduced Import Measures on Japanese Food After the TEPCO Fukushima Daiichi Nuclear Power Station Accident”, Government of Japan, 29 June 2025, see https://www.maff.go.jp/j/export/e_info/attach/pdf/hukushima_kakukokukensa-83.pdf, accessed 11 July 2025.

880 - Daisuke Wakabayashi, Kiuko Notoya, and Claire Fu, “China Says It Will ‘Gradually’ Resume Imports of Japanese Seafood”, *The New York Times*, 20 September 2024, see <https://www.nytimes.com/2024/09/20/world/asia/china-japan-seafood-ban-fukushima.html>, accessed 12 May 2025.

881 - Tokuhiko Saito, “China Resumes Japan Seafood Imports, but not from Fukushima”, *The Asahi Shimbun*, see <https://www.asahi.com/ajw/articles/15873891>; and Ministry of Agriculture, Forestry and Fisheries, “原発事故及びALPS処理水の海洋放出に伴う諸外国・地域の規制措置（2025年6月29日現在）”, Government of Japan, 29 June 2025, see https://www.maff.go.jp/j/export/e_info/attach/pdf/hukushima_kakukokukensa-86.pdf; both accessed 11 July 2025.

882 - TEPCO, “Commencement of the Discharge of Water Treated with Multi-nuclide Removal Equipment (ALPS Treated Water) into the Sea”, Press Release, 22 August 2023, see https://www.tepco.co.jp/en/hd/newsroom/press/archives/2023/20230822_01.html, accessed 12 May 2025.

883 - IAEA, “Latest IAEA Reports Confirm Japan’s ALPS Treated Water Release Continues to Meet International Safety Standards”, Press Release 23/2025, 24 March 2025, Updated 7 May 2025, see <https://www.iaea.org/newscenter/pressreleases/latest-iaea-reports-confirm-japans-alps-treated-water-release-continues-to-meet-international-safety-standards>, accessed 12 May 2025.

884 - Ministry of Agriculture, Forestry and Fisheries, “List of Countries and Regions That Have Lifted Import Measures on Japanese Food Imposed after the TEPCO Fukushima Daiichi Nuclear Power Plant Accident”, Government of Japan, 30 May 2024, see https://www.maff.go.jp/j/export/e_info/attach/pdf/hukushima_kakukokukensa-70.pdf, accessed 11 July 2025.

885 - National Institute of Health Sciences, “食品中の放射性物質検査データ(Database of Radioactive Substances in Food)”, Ministry of Health, Labour and Welfare, Government of Japan, see <https://www.radioactivity-db.niph.go.jp/>, accessed 19 May 2025.

the legal limit of 100 Bq/kg.⁸⁸⁶ Scientists are still researching the ways in which different organisms, from mushrooms to fish, absorb radioactive elements.

Other prefectures such as Miyagi and Gunma also see high levels of contamination in boars and other wild game, while foraged plants and mushrooms from prefectures as far away from Fukushima as Nagano and Shizuoka have logged radioactivity levels exceeding limits during the past year.⁸⁸⁷

Japan's radionuclide testing regime remains opaque and appears disorganized, making it challenging for the government to convince many international observers, and even its own citizenry, that it has control over the situation.

Contamination and Response

The meltdowns and explosions at Fukushima Daiichi spread radioactive particles over a wide and uneven swathe of the surrounding countryside, much carried northwest by winds. Japan has focused its attention on radioactive cesium, which was released in large quantities. In particular, it has concentrated on the isotope Cesium-137 which has a half-life of around 30 years and whose effects can linger for decades or even centuries.

Testing after the meltdowns found high levels of radioactive elements in products like spinach and milk from regions near the nuclear plant. It also found significant contamination in tea leaves hundreds of miles from the accident site and in cattle around the country that had eaten tainted rice straw, showing that radioactivity could be transferred in unexpected ways and pop up in surprising parts of the food chain.⁸⁸⁸ The Japanese government scrambled to establish contamination limits and radionuclide-testing programs to keep unsafe food off shelves and plates.

Japan's current contamination limits went into effect in 2012, the year after the initial events. Like many other international guidelines set by groups such as the European Union or the Codex Alimentarius, a Joint Venture of the United Nations' Food and Agriculture Organization (FAO) and the World Health Organization (WHO) that oversees food safety, Japan's standards aim to limit the maximum exposure to radionuclides through food to 1 mSv per year for adults.⁸⁸⁹ That is a level considered appropriate by expert groups such as the International Commission

⁸⁸⁶ - Database of Radioactive Substances in Food, “詳細表示 > No.505700479”, National Institute of Health Sciences, Ministry of Health, Labour and Welfare, Government of Japan, see <https://www.radioactivity-db.niph.go.jp/detail/505700479>, accessed 10 July 2025.

⁸⁸⁷ - Ministry of Health, Labour and Welfare, “Sum up of Radionuclide Test Results Reported in FY2024”, Government of Japan, as of 31 March 2025, see https://www.mhlw.go.jp/english/topics/2011eq/dl/Sum_up_March_2025_updated_01.pdf, accessed 13 May 2025.

⁸⁸⁸ - Phred Dvorak and Juro Osawa, “Radiation Threat Rattles Japan's Food Chain”, *The Wall Street Journal*, 6 August 2011, see <http://online.wsj.com/article/SB10001424053111904772304576466641695180326.html>, accessed 7 April 2025.

⁸⁸⁹ - Sources for the various exposure limits are: Public Health Bureau, “Radionuclides in Foods -Current Situation and Protective Measures-”, Ministry of Health, Labour and Welfare, Government of Japan, Undated, see <https://www.mhlw.go.jp/content/001327508.pdf>, accessed 2 April 2025; and Council of the European Union, “Council Regulation (Euratom) 2016/52 of 15 January 2016”, *Official Journal of the European Union*, L 13/2, enacted 20 January 2016, see <https://eur-lex.europa.eu/eli/reg/2016/52/oj/eng>, accessed 22 May 2025; also Codex Secretariat, “Fact Sheet—Codex Guideline Levels for Radionuclides in Foods Contaminated Following a Nuclear or Radiological Emergency”, Codex Alimentarius Commission, May 2011, see https://www.fao.org/fileadmin/user_upload/agns/pdf/codex_guideline_for_radionuclides_contaminated_food.pdf, accessed 12 May 2025.

on Radiological Protection,⁸⁹⁰ although scientists are still studying how low levels of radiation exposure affect the body, particularly over time.

For most foods, Japan caps the amount of allowable radioactivity at 100 Bq/kg, under an assumption that as much as 50 percent of what is eaten could be contaminated due to the Fukushima nuclear accidents. Drinking water, milk, and infant food have lower limits.

The E.U. caps levels of cesium in most foods at 1,250 Bq/kg and the UN-backed Codex Alimentarius at 1,000 Bq/kg, for a scenario involving the import of contaminated food comprising around 10 percent of total consumption. Both bodies note that guidelines may be revised if those assumptions change.

Japan's Nuclear Emergency Response Headquarters, a group under the cabinet office, issues and updates guidelines for testing food products. The tests themselves are conducted by a variety of local governments, largely at the stage of production, before anything is sold or distributed. A Fukushima Prefecture-backed association of farmers, retailers, and consumers, for example, voluntarily tested all bags of rice grown prior to 2020—screening more than 11 million bags per year at one point.⁸⁹¹ The blanket testing found 71 bags of rice that exceeded Japan's radioactivity limit in 2012, 28 in 2013, two in 2014, and none in subsequent years.⁸⁹² The prefecture still bans shipments or requires blanket testing of rice grown in areas that were more heavily contaminated.⁸⁹³

Items found to have exceeded the limits are pulled from distribution or consumption until subsequent tests show them to be clear.⁸⁹⁴

The government also conducts twice yearly tests of baskets of foodstuffs—chosen to mimic local diets—sold at retail outlets in 15 locations.⁸⁹⁵

Japanese farmers in affected areas have been attempting to lower radiation levels on their land by, for instance, spreading fields with fertilizers that limit cesium absorption by plants and using high-pressure sprays to cleanse trees in orchards.⁸⁹⁶

⁸⁹⁰ - ICRP, “The 2007 Recommendations of the International Commission on Radiological Protection”, International Commission on Radiological Protection, Vol. 37, Nos 2–4, 2007, see <https://journals.sagepub.com/doi/pdf/10.1177/ANIB-37-2-4>, accessed 22 May 2025.

⁸⁹¹ - Ryota Koyama and William D. Y. McMichael, “Radioactive Contamination Countermeasures, Food Inspection Systems, and the Issue of Reputational Damage in the Early Stages of the Nuclear Disaster in Fukushima Prefecture”, Faculty of Food and Agricultural Sciences, and International Center, Fukushima University, *Journal of Disaster Research*, Vol. 18, No. 8, December 2021, see <https://www.fujipress.jp/jdr/dr/dsstro01600081274>, accessed 10 April 2025; and Ministry of the Environment, “Chapter 8 Radioactive Materials in Foods— Radioactivity Inspection of All Rice Bags by Fukushima Prefecture”, in “Booklet to Provide Basic Information Regarding Health Effects of Radiation (5th edition)”, Government of Japan, Updated 31 March 2024, see <https://www.env.go.jp/en/chemi/rhm/basic-info/1st/o8-o2-o3.html>, accessed 6 June 2025.

⁸⁹² - Fukushima Association for Securing Safety of Agricultural Products, “Inspection Data by Year”, see https://fukumegu.org/ok/contentsV2/each_year_inspection.html accessed 11 July 2025.

⁸⁹³ - Ministry of the Environment, “第8章 食品中の放射性物質—8.2 米—2024年産米の作付制限等の対象区域” in “放射線による健康影響等に関する統一した基礎資料 (令和6年度版)”, Government of Japan, Updated 31 March 2025, see <https://www.env.go.jp/chemi/rhm/current/o8-o2-o2.html>, accessed 12 May 2025.

⁸⁹⁴ - Public Health Bureau, “Radionuclides in Foods -Current Situation and Protective Measures-”, MHLW, Undated, op. cit.

⁸⁹⁵ - Food Safety Standards and Evaluation Division, “Radioactive Materials in Foods - Current Situation and Protective Measures -”, Consumer Affairs Agency, Undated, see https://www.caa.go.jp/policies/policy/standards_evaluation/food_pollution/criterion/assets/standards_cms105_241220_002.pdf, accessed 7 June 2025.

⁸⁹⁶ - Ryota Koyama and William D. Y. McMichael, “Radioactive Contamination Countermeasures, Food Inspection Systems, and the Issue of Reputational Damage in the Early Stages of the Nuclear Disaster in Fukushima Prefecture”, *Journal of Disaster Research*, 2021, op. cit.

There have been only a handful of reported instances of contamination exceeding maximums for Japanese vegetables, fruit, livestock, and fish for the past decade, with most of those coming from Fukushima Prefecture.⁸⁹⁷

Puzzling Out the Data on Contamination

A closer look at Japan's testing regime, however, reveals a system that appears messy and very hard to understand.

The government's testing guidelines apply to the 17 eastern prefectures or municipalities in the vicinity of the nuclear disaster. Other areas and organizations conduct tests on a voluntary basis; some are included in the government's overall testing tally and some are not.

The guidelines focus testing on food categories and locations where products have exceeded contamination limits and reduce monitoring for products that have shown little or no radioactive exposure. In the most recently revised guidelines, for instance, the items subject to testing are:

- ➔ products that have recorded cesium contamination levels of more than half the maximum during the past fiscal year;
- ➔ milk, beef, and log-grown mushrooms, which could be contaminated through feed or the wood on which they are cultivated;
- ➔ fish;
- ➔ some processed foods like dried mushrooms or seaweed; and
- ➔ products where restrictions were lifted in the past fiscal year or which will be produced for the first time following the accident, with no record of testing.⁸⁹⁸

In line with the focus on contaminated items, the government in 2017 started separating most products into those whose feeding and cultivation was “possible to manage”—generally farmed vegetables and livestock—versus “difficult to manage”—largely wild game, fish, and foraged plants, where the vast majority of high radiation readings were found.⁸⁹⁹

In FY2024, of the 193 items that exceeded contamination limits, 189, or 98 percent, were in the “difficult to manage” category, according to figures released by the Ministry of Health, Labour and Welfare (MHLW).⁹⁰⁰

⁸⁹⁷ - Ministry of the Environment, “第8章 食品中の放射性物質”, Government of Japan, April 2025, see <https://www.env.go.jp/content/000301969.pdf>, accessed 23 May 2025.

⁸⁹⁸ - Nuclear Emergency Response Headquarters, “The Revision of the ‘Concepts of Inspection Planning and the Establishment and Cancellation of Items and Areas to which Restriction on Distribution and/or Consumption of Foods concerned Applies’ (Developed by the Nuclear Emergency Response Headquarters)”, Press Release, Provisional Translation, Public Health Bureau, Ministry of Health, Labour and Welfare, Government of Japan, 31 March 2025, see https://www.mhlw.go.jp/content/food_revision_31_March_2025.pdf, accessed 7 June 2025.

⁸⁹⁹ - Naomi Hayashida and Itsuko Horiguchi, “The Summary of Risk Response on Radioactive Substances Contained in Food Items in the Aftermath of the Fukushima Nuclear Accident”, *Journal of Radiation Research*, 16 December 2024, op. cit.; and Public Health Bureau, “Radionuclides in Foods -Current Situation and Protective Measures-”, MHLW, Government of Japan, Undated, op. cit.

⁹⁰⁰ - MHLW, “令和6年度検査結果”, Ministry of Health, Labour and Welfare, Government of Japan, March 2025, see <https://www.mhlw.go.jp/content/11135000/001477843.pdf>, accessed 7 June 2025.

The approach has led to an overall decline in the number of testing samples as decontamination of farmland progressed, from a peak of more than 340,000 in FY2015⁹⁰¹ to just under 46,000 in FY2024⁹⁰²—with a sharp drop in FY2020, when four prefectures switched from blanket testing of cattle to random sampling, according to MHLW figures. The MHLW does not include results from Fukushima Prefecture’s blanket testing of rice.

The focus on contaminated items has also meant that the “difficult to manage” category is a growing proportion of the overall sampling data as testing concentrates there. In FY2020, around 60 percent of test samples were in the “possible to manage” category versus 34 percent that were in the “difficult to manage” category. By FY2023 that had flipped to 37 percent in “possible to manage” versus 58 percent in “difficult to manage.”⁹⁰³

In FY2024, the number of wild plants, mushrooms, and game samples shot up to more than 16,000, around 35 percent of the total.⁹⁰⁴

Still, the growing concentration of testing in the most contaminated categories makes overall contamination ratios difficult to parse: the share of food samples that exceeded contamination limits has actually been increasing as a percentage of the overall, by a factor of six from 0.06 percent in FY2019 to 0.42 percent in FY2024, according to MHLW figures.⁹⁰⁵

A Hodgepodge of Results Difficult to Interpret⁹⁰⁶

An even bigger challenge is that the testing guidelines are relatively vague, leaving details such as where and how much of various products are tested to the local governments, which implement them in different ways. That leads to a hodgepodge of results that are impossible to interpret without checking with each locality.

The local testing entities too are split up in odd ways and often do not integrate their reports. Fukushima Prefecture’s main radionuclide monitoring report for agricultural products, for instance, does not include results from two of the prefecture’s biggest cities, Koriyama and Iwaki, which do their own testing. Nor does it include tests of wild fish and game or processed foods, which are overseen by different prefectural divisions and reported separately.⁹⁰⁷ Until FY2020, it also did not include the results of most of the prefecture’s rice tests, which were reported separately before Fukushima largely switched to spot from blanket testing.⁹⁰⁸

901 - Public Health Bureau, “Radionuclides in Foods -Current Situation and Protective Measures-”, MHLW, Undated, op. cit.

902 - MHLW, “令和6年度検査結果”, Government of Japan, March 2025, op. cit.

903 - Consumer Affairs Agency, “食品中の放射性物質の最近の検出状況”, Food Safety Commission of Japan, Ministry of Agriculture, Forestry and Fisheries, and Ministry of Health, Labour and Welfare, August 2024, see https://www.maff.go.jp/j/syouan/seisaku/radio_nuclide/240813_siryo.pdf, accessed 12 July 2025.

904 - MHLW, “Sum up of radionuclide test results reported in FY2024”, Government of Japan, February 2025, op. cit.

905 - MHLW, “令和6年度検査結果”, Government of Japan, March 2025, op. cit.; and Public Health Bureau, “Radionuclides in Foods -Current Situation and Protective Measures-”, MHLW, Government of Japan, Undated, op. cit.

906 - Analysis in this section is drawn from assessing reports, test results, testing plans and annually updated guidelines issued by the Nuclear Emergency Response Headquarters, the Ministry of Health, Labour and Welfare, the Ministry of Environment, Fukushima Prefecture and other prefectural governments as well as a national database of radioactive substances in food. Further insights were gained through personal communications with officials from Fukushima Prefecture, the Ministry of Health, Labour and Welfare and Katsumi Shozugawa, Assistant Professor at the University of Tokyo.

907 - Personal communication with an official from the Environmental Preservation Agriculture Division of Fukushima Prefecture, 18 and 25 April 2025.

908 - Environmental Conservation Agriculture Division, “農林水産物の緊急時環境放射線モニタリング実施状況”, Fukushima Prefecture, 31 March 2021, see <https://www.pref.fukushima.lg.jp/uploaded/attachment/454966.pdf>, accessed 23 May 2025.

The only comprehensive compilation of testing data is put out by the MHLW, which releases monthly and annual numbers broken down by prefecture and category of product. But it often takes months for the ministry to process and release test results, meaning the figures the ministry puts out may not match those released by the local governments, and may not reflect what was actually collected during each period.

Testing data released by the MHLW for FY2022, for instance, showed only 5,963 samples taken in Fukushima Prefecture, less than half the amount sampled in the previous or following years, an anomaly noted by WNISR. Fukushima Prefecture's FY2022 radionuclide monitoring report for agricultural products, however, shows 11,208 samples, even though it reflects a smaller subset of tests.

An official overseeing the Fukushima report told WNISR that the MHLW's delayed release of test results could explain some of that difference.⁹⁰⁹ For instance, one test result for beef that the prefecture had published on 1 August 2022 was not released by MHLW until 11 April 2023, pushing that entry into the next fiscal year's report, the official explained. An official from the Food Inspection and Safety Division of the MHLW also mentioned that delay, telling WNISR that the ministry's data was compiled by the date test results were reported rather than when the samples were taken, which could push some entries into a subsequent year.⁹¹⁰

A WNISR search of the raw data used by the ministry, contained in the Database of Radioactive Substances in Foods, indicates that 12,311 samples of food produced in Fukushima Prefecture were tested in FY2022.

“Nobody Can Confirm the Data”

Yet even that database is riddled with errors and not reliably updated, said Katsumi Shozugawa, an assistant professor at the University of Tokyo who specializes in environmental analytical chemistry, and has co-authored many studies on contamination in food and the environment after the Fukushima accident.⁹¹¹

Japan has conducted a massive amount of radiation measurements, but the tests have been done by a medley of organizations without an integrated approach or a readily accessible way to figure out what is going on, he said. The Fukushima government as well as organizations in the prefecture that conduct independent food tests have done a good job of monitoring to ensure highly contaminated products do not go to market; other prefectures have not been so thorough, he said. The opaque and uneven testing landscape has left outside observers uneasy and without a way of checking how thorough and reliable Japan's radiation testing is, he said.

Shozugawa coauthored a study on the safety of the 2020 Tokyo Olympics, prompted by concerns from international athletes worried about exposure risks.⁹¹² He concluded the game venues were very safe, but said it took an immense amount of effort to find the data

⁹⁰⁹ - Personal communication with official from the Environmental Preservation Agriculture Division of Fukushima Prefecture, 18 and 25 April 2025.

⁹¹⁰ - Personal communication, with an official from the Ministry of Health, Labour and Welfare, 11 June 2025.

⁹¹¹ - Interview with Katsumi Shozugawa, Assistant Professor, Graduate School of Arts and Sciences, University of Tokyo, 25 April 2025.

⁹¹² - Rebecca Querfeld, Mayumi Hori et al., “Radioactive Games? Radiation Hazard Assessment of the Tokyo Olympic Summer Games”, Leibniz University Hannover, University of Tokyo, and VKTA – Radiation Protection, Analytics & Disposal, *Environmental Science & Technology*, Vol 54, Issue 18, 15 September 2020, see <https://pubs.acs.org/doi/10.1021/acs.est.0c02754>, accessed 23 May 2025.

he needed. “It takes an incredible amount of work to grasp the entire picture” of radioactive contamination post Fukushima, said Shozugawa. “This is the biggest problem: nobody can confirm the data.”⁹¹³

Legal Cases, Compensation

A spate of recent court rulings found TEPCO executives or the government were not to blame for failing to prepare better for risks at Fukushima Daiichi.

Japan’s Supreme Court on 5 March 2025 upheld decisions by lower courts that found two former TEPCO top executives not guilty of criminal negligence leading to the Fukushima Daiichi accidents and the subsequent death of Fukushima evacuees. A third executive, TEPCO chair in March 2011, Tsunehisa Katsumata, died in October 2024, and the charges against him were dismissed at that time.⁹¹⁴

The decision by the top court puts a period on the only case to try to assign criminal responsibility for the nuclear disaster. The prosecution had argued that TEPCO could have prevented the accident if it had heeded a long-term tsunami risk assessment and installed proper countermeasures. The Supreme Court agreed with lower courts’ views that the assessment was not considered reliable and the executives could not have forecast the magnitude of the 2011 tsunami based on them. (See also [past WNISR editions](#) and [Judicial Decisions on Damages and Criminal Liability for the Fukushima Nuclear Accidents](#) in [WNISR2021](#).)

On 6 June 2025, the Tokyo High Court overturned a 2022 lower court decision ordering four former TEPCO executives to pay ¥13 trillion in damages (US\$₂₀₂₂ 98.8 billion) to the company. That decision also revolved around the long-term tsunami risk forecasts, with the High Court ruling the forecasts were not seen as pressing, and so the executives should not be held accountable for not acting immediately.⁹¹⁵

And the Osaka High Court on 18 December 2024 overruled a 2018 decision by the Kyoto District Court that ordered the government to pay compensation to some Fukushima residents who had evacuated to other prefectures. The Kyoto court had ordered both the government and TEPCO to pay around ¥110 million (~US\$₂₀₁₈ 996,000) in compensation to 110 claimants. The Osaka court revised that to ¥110 million (~US\$₂₀₂₄ 727,000) paid by TEPCO alone to 92 plaintiffs, in the latest decision to shield the Japanese government from responsibility for the accident.⁹¹⁶

Meanwhile, the government’s official estimate of the cost of compensation, decontamination, the interim storage facility for contaminated soil and waste, and the decommissioning

913 - Interview with Katsumi Shozugawa, Assistant Professor, Graduate School of Arts and Sciences, University of Tokyo, 25 April 2025.

914 - Mari Yamaguchi, “Japan’s Top Court Upholds Ex-TEPCO Leaders’ Acquittal on Negligence Over Fukushima Nuclear Crisis”, *The Associated Press*, 6 March 2025, see <https://apnews.com/article/japan-fukushima-nuclear-ruling-criminal-9fcc04408f37e9cb1a0605ecc8d03c22>, accessed 22 May 2025.

915 - Mari Yamaguchi, “Japanese Court Rejects Damage Claims Against Utility Executives Over Fukushima Disaster”, *The Associated Press*, 6 June 2025, see <https://apnews.com/article/japan-nuclear-fukushima-tsunami-safety-ruling-87b56c42c1c2ead5fd2f3ecac44d25d2>, accessed 15 July 2025.

916 - *Jiji Press*, “Government Not Liable for Nuclear Evacuations, Osaka High Court Rules”, as published by *The Japan Times*, 18 December 2024, see <https://www.japantimes.co.jp/news/2024/12/18/japan/crime-legal/fukushima-nuclear-plant-evacuees/>, accessed 22 May 2025.

of Fukushima Daiichi remains unchanged from its latest revision at the end of 2023, at ¥23.4 trillion (US\$₂₀₂₃166.6 billion).⁹¹⁷ When various administrative costs are added, that estimate rises to ¥26.2 trillion (US\$182 billion).⁹¹⁸ Other groups have estimated far higher costs. See *Estimated Costs of Fukushima Disaster: Official and Independent Assessments in WNISR2021* for various cost estimates.

As of 11 July 2025, the total compensation amount that has already been paid out by TEPCO is ¥11.58 trillion (US\$80.3 billion).⁹¹⁹ TEPCO's compensation costs have been rising recently, in part because it is paying for damages suffered by fisheries and other businesses that have seen earnings drop after the company started releasing treated water into the ocean in 2023.⁹²⁰ The releases caused some consumers to shun marine products from the area and a handful of countries like China to ban purchases of Japanese seafood, although some of those restrictions are now coming off.

In March 2025, TEPCO revised its Fourth Comprehensive Special Business Plan, bumping up the cumulative amount of compensation it expects it needs to pay by around ¥180 billion (US\$1.2 billion), to ¥13.4 trillion (US\$94 billion), which includes the ¥11.5 trillion (US\$80 billion) in compensation it had already paid as of March 2025.⁹²¹

In April 2025, TEPCO released its latest three-year plan for the reserve fund from which it pays its decommissioning expenses, budgeting a total of ¥260.5 billion (US\$1.8 billion) for FY2025, including around ¥30 billion (US\$208 million) for water management, ¥31 billion (US\$215 million) on removing spent fuel, ¥18.7 billion (US\$130 million) for the program to retrieve fuel debris, and ¥19.8 billion (US\$137 million) on tackling waste. It is budgeting gradual increases for that total over the following two years, with the largest increases in spending on water and waste management.⁹²²

917 - TEPCO, “FY2024 Financial Results”, April 2025, see https://www.tepco.co.jp/en/hd/about/ir/library/presentations/pdf/250430_01-e.pdf, accessed 23 May 2025; and Ministry of Economy, Trade and Industry, “東京電力の賠償費用等の見直しと交付国債の発行限度額の見直しについて”, Government of Japan, December 2023, see <https://www.meti.go.jp/earthquake/nuclear/kinkyu/pdf/2023/r20231222baisyoutou.jissi.sankousiryoku.pdf>, accessed 15 July 2025.

918 - 発電コスト検証ワーキンググループ, “発電コスト検証に関するとりまとめ”, Ministry of Economy, Trade and Industry, Government of Japan, February 2025, see https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/mitoshi/cost_wg/pdf/cost_wg_20250206_01.pdf, accessed 15 July 2025.

919 - TEPCO, “賠償金のお支払い状況—原子力損害賠償のご請求・お支払い等”, 11 July 2025, see https://www.tepco.co.jp/fukushima_hq/compensation/results/, accessed 15 July 2025.

920 - TEPCO, “ALPS処理水放出に伴い風評被害等が発生した場合の賠償のご案内 | 東京電力”, Undated, see https://www.tepco.co.jp/fukushima_hq/compensation/alps/index-j.html; and TEPCO, “特別事業計画の変更の概要”, 17 March 2025, see <https://www.tepco.co.jp/press/release/2025/pdf/250317j0103.pdf>; both accessed 23 May 2025.

921 - TEPCO, “FY2024 Financial Results”, April 2025, see https://www.tepco.co.jp/en/hd/about/ir/library/presentations/pdf/250430_01-e.pdf, accessed 23 May 2025; and TEPCO, “特別事業計画の変更の概要”, 17 March 2025, op. cit.

922 - Nuclear Damage Compensation and Decommissioning Facilitation Corporation, “取り戻そうとする廃炉等積立金の額、廃炉等の実施内容及び廃炉等の実施時期”, TEPCO, April 2025, see <https://www.tepco.co.jp/press/release/2025/pdf/250407j0102.pdf>, accessed 23 May 2025.

Table 12 · Overview of Status of the Decommissioning (as of mid-2025)

	Spent Fuel Remaining in Pools (in tons)					Contaminated Water Generated (m ³ /day)	Debris Removal (cumulated)	Number of Evacuees	Estimated Total Cost (¥ Trillion)
	Unit 1	Unit 2	Unit 3	Unit 4	Total				
2011	392	615	566	1,535	3,108	900	0	159,168	5.7
2015	392	615	566	Removal Completed in 2014	1,573	540	0	120,300	11.6
2020	392	615	Removal Completed in 2017	0	1,007	140	0	41,099	21.5
2025	392	615	0	0	1,007	50	0.9 grams	24,644	23.4

Sources: compiled by WNISR with TEPCO and METI, Various years

DECOMMISSIONING STATUS REPORT

INTRODUCTION

In mid-2025, 218 nuclear power reactors were closed, corresponding to about 110 GW of permanently retired capacity. This compares with 408 reactors in operation and 33 in Long-Term Outage (LTO). Thus, almost one-third of the reactors ever connected to the grid in the past 70 years have been retired.

Decommissioning nuclear power plants is an important, and often overlooked, element of the nuclear electricity system. Defueling, deconstruction, and dismantling—summarized by the term decommissioning—are the final steps in the operational cycle of a nuclear power plant (excluding waste management and disposal). The process is technically complex and poses major challenges in terms of long-term planning, implementation, and financing. In the first decades of the nuclear age, decommissioning was hardly considered in the reactor design. The costs for decommissioning at the end of a reactor's the lifetime were usually discounted away, and thus largely ignored. However, as a growing number of nuclear facilities either reach the end of their operational lifetimes or have already been closed, the challenges of reactor decommissioning are increasingly attracting stakeholder and public attention.

Elements of National Decommissioning Policies

When analyzing decommissioning policies, one needs to distinguish between the process (in the sense of the actual implementation) and the financing. To provide a general and globally applicable overview of the progress of nuclear decommissioning, WNISR has been classifying technical decommissioning into three main stages since WNISR2018. This is necessary due to the heterogeneous nature of decommissioning regulations around the world.⁹²³ The three stages are defined as follows:

- ➔ The **warm-up stage** comprises the post-operational stage and the dismantling of systems that are not needed for the decommissioning process. In addition, the dismantling of system parts with higher contamination begins, including the defueling of the reactor, which is crucial for any further undertakings and means removing the spent fuel from the reactor core and the spent-fuel pools.
- ➔ The **hot-zone stage** comprises the dismantling activities in the hot zone, i.e., the dismantling of highly contaminated or activated parts, e.g., the reactor pressure vessel (RPV) and its internals (RVI) and the biological shield.

⁹²³ - IAEA and European Commission, "A Taxonomy for the Decommissioning of Nuclear Facilities", International Atomic Energy Agency, with Nuclear Energy Agency, Organization for Economic Co-Operation and Development, December 2023, see <https://www-pub.iaea.org/MTCD/Publications/PDF/TE-2029web.pdf>, accessed 24 July 2024.

- The **ease-off stage** comprises the removal of operating systems as well as the decontamination of the buildings. This stage concludes with the end of physical demolition work.

After physical demolition is completed—as far as reported by the owner or the licensing authorities—WNISR classifies decommissioning as “completed”. This does not necessarily reflect the license termination of the site. Generally, a site can be qualified as a brownfield site in which some infrastructure remains for further nuclear or other industrial use, or it can be released from regulatory oversight as a greenfield site for unrestricted use. Different countries require different types of end-states for complete license termination.⁹²⁴ WNISR classifies sites that have been partially released from regulatory oversight but still operate nuclear facilities on site, e.g., interim spent-fuel and waste-storage infrastructure, as brownfield sites.

The technical procedure of physically dismantling nuclear reactors, following the three stages described above, can begin after varying amounts of time following nuclear power plant closure. This depends on the strategy the operator chooses. The options include:

- **immediate dismantling**, which is characterized by a seamless transition to decommissioning activities after reactor closure
- **deferred dismantling**, where reactors are placed into Long-Term Enclosure (LTE) for several years to decades to allow for radiation levels to decline before decommissioning begins
- **entombment**, characterized by LTE (50 years or more) that can sometimes become permanent (e.g., Chernobyl Unit 4)

Most countries have adopted variations of these strategies, although some, like France or Germany, have placed restrictions on which strategy may be applied.⁹²⁵

With respect to financing, five main approaches are observable: public budget, external segregated fund, internal non-segregated fund, internal segregated fund, and surety methods such as guarantees or insurances (for more details, see [WNISR2018](#)).⁹²⁶

The goal of this chapter is to provide a global overview of the current state of nuclear decommissioning. However, information on the status and progress at individual sites can be inaccessible, and available data can change over time. This may lead to simplifications regarding the classification of individual sites and reactors into different stages of the decommissioning process. WNISR aims to provide full access to the basis of our assessments and has in the

924 - Rebekka Bärenbold, Muhammad Maladoh Bah et al., “Decommissioning of Commercial Nuclear Power Plants: Insights From a Multiple-Case Study”, *Renewable and Sustainable Energy Reviews*, Vol. 201, September 2024, see <https://linkinghub.elsevier.com/retrieve/pii/S1364032124003472>, accessed 24 July 2024.

925 - Ibidem; and Stefan Thierfeldt, “Safe Enclosure and Entombment Strategies in Nuclear Decommissioning Projects”, Brenk Systemplanung, in “Nuclear Decommissioning—Planning, Execution and International Experience”, ed. Michele Laraia, Woodhead Publishing, 2012, see <https://linkinghub.elsevier.com/retrieve/pii/B9780857091154500117>, accessed 6 May 2024; also Tim Scherwath, Ben Wealer and Roman Mendelevitch, “Nuclear Decommissioning after the German Nuclear Phase-Out an Integrated View on New Regulations and Nuclear Logistics”, *Energy Policy*, 2020, see <https://linkinghub.elsevier.com/retrieve/pii/S0301421519307128>, accessed 8 January 2020.

926 - Alexander Wimmers, Rebekka Bärenbold et al., “Decommissioning of Nuclear Power Plants: Regulation, Financing, and Production”, Data Documentation 104, DIW Berlin, Deutsches Institut für Wirtschaftsforschung/German Institute for Economic Research, January 2023, see https://www.diw.de/documents/publikationen/73/diw_01.c.864222.de/diw_datadoc_2023-104.pdf, accessed 26 January 2023.

past, when uncertainty arose, communicated individual classification decisions and potential statistical changes and will continue to do so.

GLOBAL OVERVIEW

Decommissioning Worldwide

As of 1 July 2025, a worldwide total of 218 reactors, corresponding to about 110 GW of capacity, have been closed. Since the reporting period covered in WNISR2024, five additional reactors have been closed: Doel-1 in Belgium (445 MW), the Canadian heavy-water reactors Pickering-1 and -4 (515 MW each), and both reactors at the Maanshan plant in Taiwan (938 MW each).

Of the total number of closed units, 61 percent are located in Europe (106 in Western Europe and 26 in Central and Eastern Europe), 22 percent in North America (49), and 17 percent in Asia (37).

More than three quarters or 171 reactors used one of these three technologies:

- ➔ Pressurized Water Reactors (PWRs) with 72 units or 33 percent,
- ➔ Boiling Water Reactors (BWRs) with 55 units or 25 percent, and
- ➔ Gas-Cooled Reactors (GCRs) with 44 units or 20 percent, the majority (33 units) of which are located in the U.K.

Table 13 provides an overview of the closed reactors worldwide. The table also includes the number of defueled reactors and those that are released from regulatory supervision, i.e., either as ‘full’ greenfield sites or as brownfield. The Decommissioning Status Report, as the WNISR in general, exclusively covers reactors that have generated electricity and were connected to the grid. Thus, it does not cover research reactors that were not connected to the grid.

Decommissioning plays an important and increasing role in nuclear politics, both in the timing and production process, and the financing thereof. The number of facilities that will be affected will increase significantly in the coming years: assuming a 40-year lifetime, a further 93 reactors will close by 2030 (reactors connected to the grid between 1985 and 1990), and an additional 158 will be closed by 2065 (reactors connected 1991–2025). This does not account for the 157 reactors that have already been operating for more than 40 years (connected to the grid before 1985), an additional 33 reactors in Long-term Outage (LTO), and the 63 reactors under construction as of mid-2025. It should be noted, however, that the current general trend is to extend operational lifetimes beyond 40 years, often with the aim of 60 years and in some cases 80 years of operation. (See Figure 21.)

Table 13 · Overview of Reactor Decommissioning Worldwide (as of 1 July 2025)

Country	Closed Reactor	Decommissioning Status						
		Warm-up (of which defueled)		Hot Zone	Ease-off	LTE	Completed (of which released as greenfield sites ^(a))	Completed Share of Total Closed (share of total closed released as greenfield sites ^(a))
U.S.	41	4	(4) ^(b)	6	5	9	17 (5)	41% (12%)
Germany	36	10	(4)	10	11	1	4 (3)	11% (8%)
U.K.	36	19	(12)	11	0	6	0	0%
Japan	27	25	(4)	1	0	0	1 (1)	4% (4%)
France	14	3	(2)	3	0	8	0	0%
Russia	11	6	(5)	0	0	5	0	0%
Canada	8	3	(1)	0	0	5	0	0%
Sweden	7	2	(2)	0	5	0	0	0%
Taiwan	6	6	(0)	0	0	0	0	0%
Bulgaria	4	4	(4)	0	0	0	0	0%
Italy	4	3	(3)	1	0	0	0	0%
Belgium	4	3	(0)	0	1	0	0	0%
Ukraine	4	0	(0)	0	0	4	0	0%
Spain	3	1	(0)	0	0	1	1 (0)	33%
Slovakia	3	1	(1)	0	2	0	0	0%
Lithuania	2	2	(2)	0	0	0	0	0%
South Korea	2	2	(0)	0	0	0	0	0%
Armenia	1	0	(0)	0	0	1	0	0%
Kazakhstan	1	0	(0)	0	0	1	0	0%
Netherlands	1	0	(0)	0	0	1	0	0%
Switzerland	1	0	(0)	1	0	0	0	0%
India	1	1	(1)	0	0	0	0	0%
Pakistan	1	1	(0)	0	0	0	0	0%
Total	218	96	(45)	33	24	42	23 (9)	11% (4%)

Sources: Various, compiled by WNISR, 2025

Notes:

LTE: Longt-Term Enclosure.

(a) As of WNISR2024, the “released” category only contains “greenfield released” reactors, whereas it also contained “brownfield released” reactors in previous editions (see [definitions](#) in the introduction of the chapter).

(b) Three reactors in the U.S. are currently undergoing preparations or are being considered for a restart. These are Palisades, Three Mile Island-1 (now called Christopher M. Crane Clean Energy Center or CCEC), and Duane-Arnold-1. Until the reactors are restarted and this is officially confirmed, WNISR classifies them in their respective last known decommissioning phases (warm-up for Palisades and LTE for the others).

(c) In WNISR2024, the Trino reactor in Italy was erroneously placed into the hot-zone stage and is therefore listed in the warm-up stage in this edition (see [section on Italy](#) below).

Overview of Reactors with Completed Decommissioning

As of mid-2025, 195 units globally are awaiting or in various stages of decommissioning, five more than in WNISR2024. This number includes three units in the U.S. that might restart.

Of the 23 decommissioned reactors, 21 have been released from regulatory oversight, nine of those as greenfield sites (see Figure 52). All other sites were released as brownfield sites, and apart from the Shoreham reactor in the U.S., all currently host interim waste storage facilities.

The average duration of the decommissioning process, independent of the chosen strategy, is around 20 years, with a very high variance: the minimum being six years for the 22-MW Elk River plant and the maximum 45 years for the 63-MW reactor at Humboldt Bay, both in the U.S.

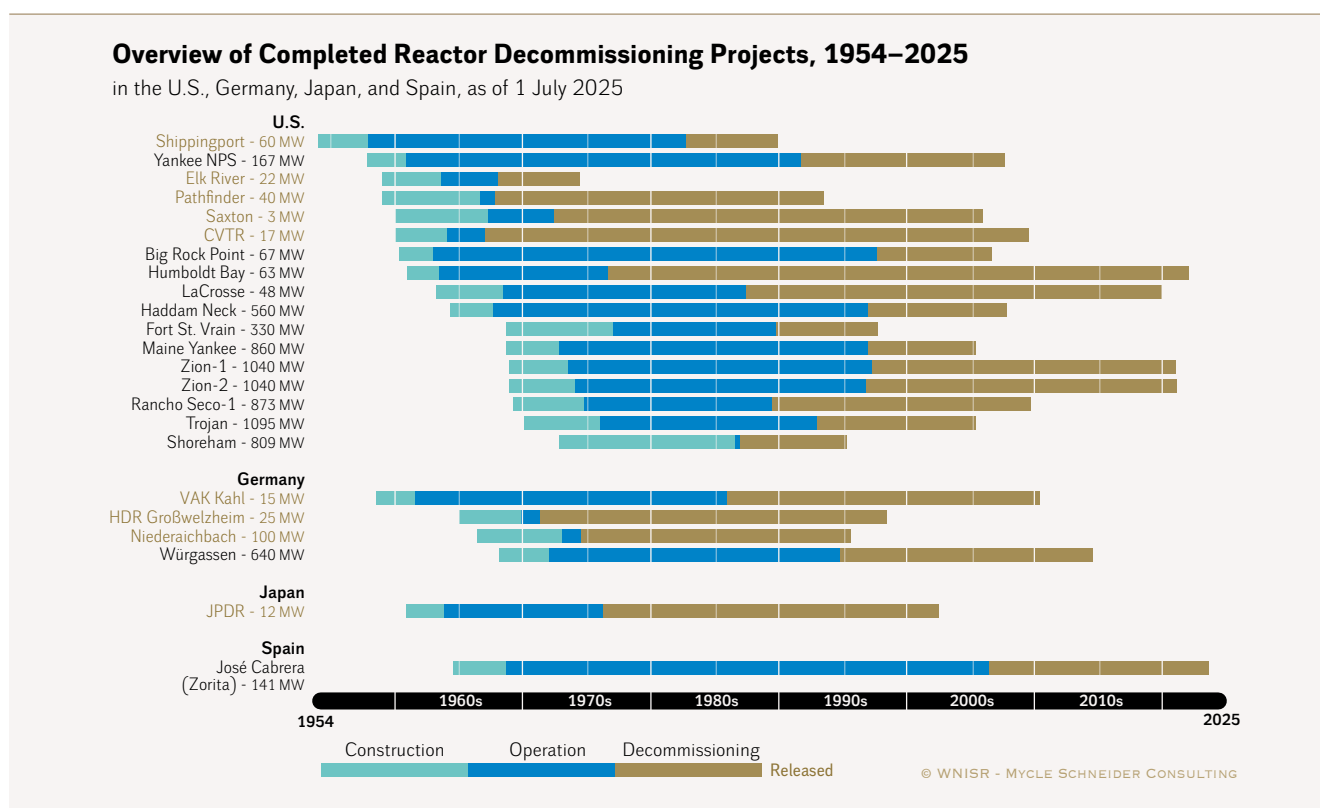
Only four countries amongst the 23 with closed power reactors have completed the technical decommissioning process of at least one reactor: the U.S. (17 units), Germany (4), Japan (1), and Spain (1). Some of the reactors that were most rapidly decommissioned are located in the U.S. In Germany, the HDR (Heißdampfreaktor, a superheated-steam reactor) Großwelzheim was only on the grid for one year, but decommissioning lasted well over 20 years. The German Würgassen reactor has de facto completed the technical decommissioning process but, legally, cannot be released from regulatory control as the buildings are being used for interim storage of wastes.⁹²⁷ In Japan, the only reactor to be decommissioned was a small 10-MW demonstration plant (JPDR), whereas none of the large commercial reactors have been decommissioned yet.⁹²⁸ It took over 17 years to decommission the José Cabrera reactor, Spain's first PWR that operated from 1968 to 2006.⁹²⁹ Figure 53 provides the timelines of the 23 reactors that have completed the decommissioning process.

⁹²⁷ - BASE, "Auflistung kerntechnischer Anlagen in der Bundesrepublik Deutschland - Anlagen in 'Stilllegung'", Bundesamt für die Sicherheit der nuklearen Entsorgung/Federal Office for the Safety of Nuclear Waste Management, December 2024, see https://www.base.bund.de/shareddocs/downloads/de/berichte/kt/kernanlagen-stilllegung.pdf?__blob=publicationFile&v=4, accessed 20 May 2025.

⁹²⁸ - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 8 July 2025, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2025/07/jp-npps-operation20250708_en.pdf, accessed 11 July 2025.

⁹²⁹ - Enresa, "Dismantling of the Jose Cabrera Nuclear Power Plant", Empresa Nacional de Residuos Radiactivos S.A./National Radioactive Waste Management Agency of Spain, 2024, see <https://www.enresa.es/eng/index/activities-and-projects/dismantling-and-environmental-restoration/dismantling-of-the-jose-cabrera-nuclear-power-plant>, accessed 18 August 2024.

Figure 53 · Overview of Completed Reactor Decommissioning Projects



Sources: Various, compiled by WNISR, 2025

Note: As of WNISR2024, the “released” category only mentions “greenfield released” reactors, whereas it also contained “brownfield released” reactors in previous editions (see definitions in the introduction of the chapter). The LaCrosse and Shoreham reactors had in previous WNISR editions been classified as “greenfield released”. However, the site at LaCrosse still contains an interim spent-fuel storage facility and is thus reclassified as a brownfield site, and while the Shoreham reactor was released from regulatory oversight, it was never entirely dismantled, and most buildings have remained intact.

Overview of Ongoing Reactor Decommissioning

This section contains a brief overview of the decommissioning status in the countries that have not been analyzed in more detail in the [Country Case Studies](#) of this WNISR edition.

Armenia

Following a partnership agreement with the European Union, the Armenian Metsamor nuclear power plant is to be completely closed as soon as possible due to safety concerns because the plant “cannot be upgraded to fully meet internationally accepted safety standards.”⁹³⁰ Both units were closed in 1989 after an earthquake, but Unit 2 was restarted in November 1995 and still operates to this day, with ongoing lifetime extension plans aiming for it to run until 2036 (see section on [Armenia](#)).⁹³¹ At Unit 1, the decommissioning status remains unclear. While the Armenian government adopted a decommissioning strategy in November 2007, at the time

930 - High Representative of the Union for Foreign Affairs and Security Policy, “Partnership Implementation Report on Armenia”, Joint Staff Working Document, European Commission, 16 December 2020, see https://www.eeas.europa.eu/sites/default/files/armenia_partnership_implementation_report_2020.pdf, accessed 8 June 2022.

931 - Onnik James Krikorian, “Armenia’s Nuclear Dilemma”, Osservatorio balcani e caucaso transeuropa, 9 February 2024, see <https://www.balcanicaucaso.org/eng/Areas/Armenia/Armenia-s-nuclear-dilemma-233054>, accessed 14 April 2025.

aiming for a deferred dismantling strategy to conclude in 2048,⁹³² and an EU-funded project “to support the Decommissioning Planning and Licensing for general decommissioning activities” ran from 2013 to 2018,⁹³³ there still seems to be no officially selected strategy. International Atomic Energy Agency (IAEA) data from 2024 shows the strategy as “other,”⁹³⁴ but data from 2019 suggest a deferred dismantling strategy with ongoing defueling activities.⁹³⁵ Since there have been no publicly communicated updates regarding the progress at Unit 1, WNISR considers the reactor to be in LTE.

Belgium

In Belgium, the prototype 10-MW BR-3 reactor in Mol, which was closed in 1987, is currently undergoing decommissioning. The reactor is in the ease-off stage⁹³⁶ and is used as a lead-and-learn site for future decommissioning projects.⁹³⁷ In November 2024, the dismantling of the biological shield was completed.⁹³⁸ Apart from Doel-4 and Tihange-3, whose state-funded lifetime extensions to 2035 were approved by the European Commission in February 2025,⁹³⁹ all remaining power reactors are scheduled to be closed by the end of 2025 (see section on **Belgium**). Tihange-1 and Doel-2 are to close by October and December 2025, respectively,⁹⁴⁰ and three reactors (Doel-1, Doel-3, and Tihange-2) have already been closed. WNISR considers Doel-3 and Tihange-2 to be in the warm-up stage, with all the fuel removed from the two

⁹³² - ARKA News Agency, “Decommissioning of Armenian NPP Starts”, 12 July 2007, see <https://arka.am/en/news/economy/7305/>, accessed 14 April 2025.

⁹³³ - European Commission, “Decommissioning Planning and Licensing Development at ANPP& Pilot Decommissioning Project at ANPP (A1.01/09 C & D)”, as of 14 April 2025, see https://nuclear-safety-cooperation.ec.europa.eu/contracts/decommissioning-planning-and-licensing-development-anpp-pilot-decommissioning-project-anpp-a10109-c_en, accessed 14 April 2025.

⁹³⁴ - IAEA, “Nuclear Power Reactors in the World—2024 Edition”, International Atomic Energy Agency, July 2024, see https://www-pub.iaea.org/MTCD/Publications/PDF/p15748-RDS-2-44_web.pdf, accessed 14 April 2025.

⁹³⁵ - IAEA, “Country Nuclear Power Profiles—2019 Edition—Armenia”, Updated 2019, see <https://www-pub.iaea.org/MTCD/publications/PDF/cnpp2019/countryprofiles/Armenia/Armenia.htm>, accessed 14 April 2025.

⁹³⁶ - Belgian Nuclear Energy Research Center, “Pioneering Work with Demolition Plan and International Expertise”, 2022, see <https://www.sckcen.be/en/about-sck-cen/annual-reports/highlights-2022/highlights-2022-dismantling-and-waste/pioneering-work-demolition-plan-and-international-expertise>, accessed 30 August 2023.

⁹³⁷ - Wouter Broeckx, Sven Boden et al., “Decommissioning of the BR3 Biological Shield: How a Proper Data Analysis Facilitates the D&D Process”, 15 September 2021, presented at “DEM 2021 International Conference on Decommissioning Challenges: Industrial Reality, Lessons Learned and Prospects”, Société française d’énergie nucléaire/French Society for Nuclear Power, European Nuclear Society, 13–15 September 2021, see [https://publications.sckcen.be/portal/en/publications/decommissioning-of-the-br3-biological-shield-how-a-proper-data-analysis-facilitates-the-dd-process\(b1c1354d-e0ac-47d2-9784-595b60c12fob\).html](https://publications.sckcen.be/portal/en/publications/decommissioning-of-the-br3-biological-shield-how-a-proper-data-analysis-facilitates-the-dd-process(b1c1354d-e0ac-47d2-9784-595b60c12fob).html); and SCK CEN, “Dismantling and decontamination”, Undated, see <https://www.sckcen.be/en/expertises/technology/dismantling-and-decontamination>; both accessed 8 June 2022.

⁹³⁸ - Belgian Nuclear Energy Research Center, “A Major Milestone For BR3: Final Concrete Blocks Removed From Bioshield”, 18 November 2024, see <https://www.sckcen.be/en/news/major-milestone-br3-final-concrete-blocks-removed-bioshield>, accessed 14 April 2025.

⁹³⁹ - European Commission, “Commission approves Belgian State aid measure to support lifetime extension of two nuclear reactors”, Press Release, 21 February 2025, see https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_25_565/IP_25_565_EN.pdf, accessed 15 April 2025.

The regulator has approved the restart of the two reactors in early July 2025; see Federal Agency for Nuclear Control, “L’AFCN approuve le redémarrage et la poursuite de l’exploitation de Tihange 3”, 4 July 2025, see <https://afcn.fgov.be/fr/actualites/lafcn-approuve-le-redemarrage-et-la-poursuite-de-l-exploitation-de-tihange-3>, accessed 10 July 2025.

⁹⁴⁰ - Federal Agency for Nuclear Control, “Cessation des activités et démantèlement des centrales nucléaires belges”, 14 February 2025, see <https://afcn.fgov.be/fr/dossiers/centrales-nucleaires-en-belgique/cessation-des-activites-et-demanterement-des-centrales>, accessed 15 April 2025.

reactor vessels and currently stored in the spent-fuel pool.⁹⁴¹ Dismantling of reactor internals necessitates a separate decommissioning license to be granted; this phase is expected to begin for both reactors in 2026.⁹⁴² Doel-1 was closed on 14 February 2025 and is considered in the warm-up stage. However, decommissioning activities will only begin once Doel-2 has also been closed because the reactors are considered “Siamese twins” as they “share a control room, machine room, and also a lot of common safety systems.”⁹⁴³

Bulgaria

Decommissioning of all four closed reactors at the Bulgarian Kozloduy plant is partly funded by the Kozloduy International Decommissioning Support Fund managed by the European Bank for Reconstruction and Development. The fund had raised more than €1.2 billion (US\$₂₀₂₃ 1.3 billion) by the end of 2023 and supports the plan to decommission all four units to a brownfield state by 2030.⁹⁴⁴ In its program review, the E.U. states that “the timely achievement of the objectives for 2021-2027 is [...] at risk.”⁹⁴⁵ The most recent report on the whole program was published in April 2024 and refers to activities conducted in 2022,⁹⁴⁶ but the European Commission tracks the project on a dedicated website that is more up to date.⁹⁴⁷ Primary decontamination work has been completed at all four units, removing up to 99 percent of activated material. While the official completion target remains at 2030, the operator is likely to postpone it to 2032. In late 2024, the Bulgarian regulator renewed the decommissioning license for Units 1 and 2 until 2034.⁹⁴⁸ Until information on hot zone dismantling becomes available, WNISR considers all four units to be in the warm-up stage. According to Bulgaria’s latest report to the Joint Convention on the Safety of Spent Fuel Management and on the Safety

941 - FANC, “Mise à l’arrêt et démantèlement de Doel 3”, Federal Agency for Nuclear Control, 14 February 2025, see <https://afcn.fgov.be/fr/dossiers/centrales-nucleaires-en-belgique/cessation-des-activites-et-demantelement-des-centrales-o>; and FANC, “Mise à l’arrêt et démantèlement de Tihange 2”, 14 February 2025, see <https://afcn.fgov.be/fr/dossiers/centrales-nucleaires-en-belgique/cessation-des-activites-et-demantelement-des-centrales-1>; both accessed 15 April 2025.

942 - ENGIE Electrabel, “The Shutdown of our Nuclear Power Plants—Shutdown of Doel 3 and Tihange 2”, Undated, see <https://nuclear.engie-electrabel.be/en/nuclear-energy/shutdown-our-nuclear-power-plants/shutdown-doel-3-and-tihange-2>, accessed 22 July 2025.

943 - ENGIE Electrabel, “Final Shutdown of Doel 1”, as of 22 July 2025, see <https://nuclear.engie-electrabel.be/en/nuclear-energy/shutdown-our-nuclear-power-plants/final-shutdown-doel-1>, accessed 22 July 2025.

944 - EBRD, “Kozloduy International Decommissioning Support Fund”, European Bank for Reconstruction and Development, Undated, see <https://www.ebrd.com/what-we-do/sectors-and-topics/nuclear-safety/kozloduy.html>, accessed 18 April 2024.

945 - European Commission, “Nuclear Decommissioning – Performance—Financial Programme for the Decommissioning of Nuclear Facilities and the Management of Radioactive Waste (Bulgaria, Slovakia and the Joint Research Centre)”, Undated, see https://commission.europa.eu/strategy-and-policy/eu-budget/performance-and-reporting/programme-performance-statements/nuclear-decommissioning-performance_en, accessed 15 April 2025.

946 - European Commission, “Report from the Commission to the European Parliament and the Council on the Implementation of the Work under the Nuclear Decommissioning Assistance Programme to Bulgaria, Slovakia and Lithuania and JRC Programme in 2022 and Previous Years”, April 2024, see <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52024DC0181>, accessed 15 April 2025.

947 - European Commission, “Nuclear Decommissioning – Performance—Financial Programme for the Decommissioning of Nuclear Facilities and the Management of Radioactive Waste (Bulgaria, Slovakia and the Joint Research Centre)”, Undated, op. cit.

948 - BNRA, “ДП РАО—Специализирано поделение ‘ПХРАО – Нови Хан’”, Bulgarian Nuclear Regulatory Agency, 2025, see <https://bnra.bg/bg/yadreni-saorazheniya/dp-rao/>, accessed 15 April 2025; and BNRA, “Издадена лицензия за извеждане от експлоатация на първи и втори енергийни блокове на АЕЦ „Козлодуй“”, 13 November 2024, see <https://bnra.bg/bg/novini-bnra/izdadena-litsenziya-za-izvezhdane-ot-eksplotatsiya-na-parvi-i-vtori-energiyni-blokov-na-aets-kozloduy/>, accessed 20 July 2025; also BNRA, “Annual Report 2024”, 2025, see https://bnra.bg/wp-content/uploads/Annual_Report_2024_EN_WEB.pdf, accessed 22 July 2025.

of Radioactive Waste Management, “the entire amount of nuclear fuel has been removed from the reactors;”⁹⁴⁹ all four reactors are thus considered defueled.

Canada

As of mid-2025, Canada had eight closed CANDU (Canada Deuterium Uranium) and one Heavy-Water Moderated Boiling Light-Water Reactor (HW BLWR) to decommission. The most recent closures were those of the Pickering-1 and -4 reactors, which ceased operations in October and December 2024, respectively. So far, no commercial reactor has been fully decommissioned. The 250-MW Gentilly-1 prototype HW BLWR reactor was closed in 1977 after only 183 full-power-equivalent days of operation and was subsequently defueled in 1984 and placed into LTE in 1986, where it has remained since. The current license will terminate in 2034.⁹⁵⁰ The prototype CANDU reactor at Douglas Point operated from 1967 to 1984 and was subsequently placed into LTE. Active dismantling began in 2021 with plans to complete decommissioning by 2070, though mention of that deadline has since been removed from the official webpage.⁹⁵¹ In March 2025, the demolition of the administrative building and the ancillary facilities was completed; the project is now moving on to demolishing the turbine hall, before beginning decommissioning work of the reactor internals and respective buildings, which is to be completed after 2030.⁹⁵²

The other six closed reactors are former commercially operated CANDU reactors. The Gentilly-2 reactor was closed in 2012 and defueled in 2013. It was subsequently placed into LTE with dismantling to begin in 2057. The site is planned to be remediated by 2064, while an environmental follow-up is scheduled to conclude by 2074.⁹⁵³ In 2023, owner-operator Hydro-Québec had toyed with potentially restarting the reactor,⁹⁵⁴ but any plans seem to have been scrapped with the application in April 2025 for a decommissioning license renewal, including for “the early dismantling of buildings and structures containing little or no radioactive contamination.”⁹⁵⁵ Two reactors of Pickering-A, Units 2 and 3, were already closed in 1997 and have been defueled, while Units 1 and 4 were closed in September and December 2024, respectively.⁹⁵⁶ Once defueling is completed, these units will join Units 2 and 3 in LTE for concrete planning for dismantling to begin in a yearly staggered approach from 2050 onwards, with practical work expected to begin in 2051. LTE is scheduled to start in 2029. Until then,

⁹⁴⁹ - Government of Bulgaria, “Eighth National Report on Fulfilment of the Obligations under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management”, 2024, see https://www.iaea.org/sites/default/files/jc_8_nat_report_bg1.pdf, accessed 22 August 2025.

⁹⁵⁰ - Government of Canada, “Shut-Down and Decommissioned Reactors—Gentilly-1 Waste Facility”, 26 February 2025, see <https://www.cnsccsn.gc.ca/eng/reactors/research-reactors/other-reactor-facilities/gentilly-1-facility/>, accessed 15 April 2025.

⁹⁵¹ - CNL, “Douglas Point Prototype Reactor”, Canadian Nuclear Laboratories, Undated, see <https://www.cnl.ca/environmental-stewardship/decommissioning-the-douglas-point-prototype-reactor/>, accessed 1 November 2023 and 22 July 2025.

⁹⁵² - CNL, “Administration Building Demolition At Canada’s First Full-Scale Nuclear Power Plant”, 3 March 2025, see <https://www.cnl.ca/administration-building-demolition-at-canadas-first-full-scale-nuclear-power-plant/>, accessed 15 April 2025.

⁹⁵³ - Hydro-Québec, “Decommissioning of the Gentilly-2 Facilities”, Undated, see <https://www.hydroquebec.com/projects/decommissioning-gentilly-2/>, accessed 15 April 2025.

⁹⁵⁴ - Hydro-Québec, on X (formerly Twitter), 10 August 2023, see <https://x.com/hydroquebec/status/1689658373384622080>, accessed 19 August 2024.

⁹⁵⁵ - Hydro Québec, “Licence Renewal: Decommissioning of the Gentilly-2 Facilities—What’s New?”, Undated, see <https://www.hydroquebec.com/projects/decommissioning-gentilly-2/whats-new.html>, accessed 15 April 2025.

⁹⁵⁶ - OPG, “Pickering Nuclear Station”, Ontario Power Generation, Undated, see <https://www.opg.com/power-generation/our-power/nuclear/pickering-nuclear/>, accessed 15 April 2025.

Units 1 and 4 are considered to be in the warm-up stage. The four still operational reactors of the Pickering-B plant are scheduled to follow this approach from 2054. Pickering-A is to be released as a brownfield site by 2063.⁹⁵⁷

France

The closed reactor fleet in France is diverse compared to the largely standardized operational PWR fleet. In total, 14 reactors (8 GCRs, 3 PWRs, 1 HWGCR, 2 FBRs), corresponding to approximately 5.5 GW, have been closed. Decommissioning progress is slow in France (see [previous WNISR editions](#)). All GCRs, the six UNGG-type (Uranium Naturel Graphite Gaz) reactors, Bugey-1, Chinon A-1, A-2, A-3, and St. Laurent A-1 & A-2, as well as the G-2 and G-3 reactors at Marcoule are considered as being in LTE by WNISR.⁹⁵⁸ For its six UNGG-GCR reactors, EDF initially adopted an immediate dismantling strategy in 2001 to flood the reactor vessel with water, followed by plans to perform decommissioning procedures underwater.⁹⁵⁹ Following a regulatory change, this strategy was changed to in-air dismantling in 2016, prompting the need for new decommissioning licenses for each reactor. These were submitted in December 2022 and are expected to be granted in 2026, at the earliest. Based on the revised plans, the first dismantling work of reactor internals and graphite blocks will begin at Chinon A-2 in 2044 after the first opening of the reactor casing in 2034. All other UNGG reactors will remain in LTE until at least 2056. Completion of decommissioning is planned for “between 2063 and 2093, depending on the reactors.”⁹⁶⁰

The EL-4 reactor at Brennilis (Monts d’Arrée) was closed in 1985 and is in the hot-zone stage. With additional regulatory approval, dismantling of the reactor block and demolition of the containment building began in November 2024. Site remediation is expected for 2041.⁹⁶¹

The 305-MW PWR reactor at Chooz-A was closed in 1991 and has been undergoing decommissioning work since 2007. In 2023 and 2024, preparatory work for reactor internal dismantling was ongoing, including pool drainage and primary circuit segmentation. Reactor vessel dismantling is scheduled to begin in 2027 (two years later than last year’s estimate, see [Decommissioning Status Report—Country Case Studies: France in WNISR2024](#)).⁹⁶²

The two PWRs at Fessenheim were closed in 2020. EDF planned for a five-year preparatory phase until the decommissioning license is obtained, which was expected to be issued in

957 - OPG, “Pickering Nuclear Site Preliminary Decommissioning Plan”, Ontario Power Generation, January 2022, see <https://www.opg.com/documents/pickering-nuclear-site-preliminary-decommissioning-plan-pdf/>, accessed 18 April 2024.

958 - ASN, “Rapport de l’ASN sur l’état de la sûreté nucléaire et de la radioprotection en France en 2024”, Autorité de sûreté nucléaire et de radioprotection/French Nuclear Safety and Radiation Protection Authority, May 2025, see <https://www.asn.fr/information/publications/rapports-de-l-asnr/la-surete-nucleaire-et-la-radioprotection-en-france-en-2024>, accessed 25 May 2025; and ASN, “ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2024”, July 2025, see <https://www.french-nuclear-safety.fr/content/download/204898/file/ASN-Report-on-the-State-of-nuclear-safety-and-radiation-protection-in-France-in-2024.pdf>, accessed 22 July 2025.

959 - Ibidem; and ASN, “ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2020”, August 2021, see <https://www.french-nuclear-safety.fr/content/download/179293/file/ASN%20Report%20on%20the%20state%20of%20nuclear%20safety%20and%20radiation%20protection%20in%20France%20in%202020.pdf>, accessed 19 August 2024.

960 - EDF, “Consolidated Financial Statements at 31 December 2024”, March 2025, op. cit.; and EDF, “Consolidated Financial Statements at 31 December 2022”, 2023, see <https://www.edf.fr/sites/groupe/files/2023-02/annual-results-2021-consolidated-financial-statements-2023-02-17.pdf>, accessed 22 June 2023.

961 - EDF, “Consolidated Financial Statements at 31 December 2024”, Électricité de France, March 2025, see <https://www.edf.fr/sites/groupe/files/2025-03/annual-results-2024-consolidated-financial-statements-2025-03-05.pdf>, accessed 15 April 2025.

962 - EDF, “Consolidated Financial Statements at 31 December 2024”, March 2025, op. cit.

mid-2025 and take effect in early 2026. In the meantime, both reactors have been defueled, full system decontamination has been completed, and dismantling work in the turbine hall is ongoing.⁹⁶³

The FBR Super-phenix at Creys-Malville, closed in 1996, has been undergoing decommissioning since 2006. Currently, reactor vessel internals are being dismantled, with the neutron shield support (the first part of the vessel internals) having been removed in 2024 and dismantling continuing in the reactor pit. The current decommissioning finalization target is 2034.⁹⁶⁴ Decommissioning at the FBR Phénix at Marcoule continued with defueling activities in 2024, after which further dismantling shall begin. The reactor's sodium will be transferred to the storage facility of the NOAH⁹⁶⁵ sodium treatment plant, scheduled to become operational in 2028.⁹⁶⁶

Since 2020, there have been no publicly announced updates regarding dismantling progress at the remaining GCR plants, G-2 and G-3, formerly operated by CEA at Marcoule.⁹⁶⁷ Thus, WNISR considers these reactors to be in LTE.

India

Rajasthan-1 in India—in LTO (Long-Term Outage) status since 2004 and considered as closed by WNISR since 2014—has apparently not moved beyond complete defueling and is reportedly “maintained under dry preservation.”⁹⁶⁸ WNISR considers this PHWR to be in the warm-up phase.

Italy

Since 1988, Italian nuclear power plants have not produced any electricity, and the last two reactors were officially closed in 1990. Since then, decommissioning at all four facilities has been underway. The work is conducted by Italian company Società Gestione Impianti Nucleari SpA (Sogin). The smallest reactor, Garigliano, a 150-MW BWR, was officially closed in 1982 and is considered in the hot-zone stage.⁹⁶⁹ According to the 2024 report of Italy to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste

963 - Ibidem.

964 - Ibidem.

965 - Play on words, the process produces sodium hydroxide or NaOH.

966 - ASNR, “Rapport de l’ASN sur l’état de la sûreté nucléaire et de la radioprotection en France en 2024”, May 2025, op. cit., and ASNR, “ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2024”, July 2025, op. cit.

967 - Cour des comptes, “L’arrêt et le démantèlement des installations nucléaires”, French Court of Accounts, February 2020, see https://www.ccomptes.fr/system/files/2020-03/20200304-rapport-arret-demantelement-installations-nucleaires-2_0.pdf, accessed 31 August 2023.

968 - NPCIL, “Rawatbhata Rajasthan Site”, Nuclear Power Corporation of India Limited, Department of Atomic Energy, Undated, see https://www.npcil.nic.in/content/501_1_rawatbhatarajasthansite.aspx, accessed 6 May 2025 and 22 July 2025.

969 - Sogin, “Sogin, terminata la prima fase di smantellamento del vessel della centrale nucleare del Garigliano”, Press Release, 30 July 2024, see <https://www.sogin.it/SiteAssets/uploads/2024/notizie/com-stampa-Sogin-terminata-la-prima-fase-di-smantellamento-del-vessel-della-centrale-nucleare-del-Garigliano.pdf>; and Sogin, “Sogin, iniziato lo smantellamento del radwaste della centrale del Garigliano”, Press Release, 23 April 2025, see <https://www.sogin.it/SiteAssets/uploads/2025/Notizie/CS-SOGIN-INIZIATO-LO-SMANTELAMENTO-DEL-RADWASTE-DELLA-CENTRALE-DEL-GARIGLIANO.pdf>; both accessed 22 July 2025.

Management, brownfield is to be achieved in 2028 and greenfield in 2042⁹⁷⁰ (see Table 14); however, the Italian project website claims a target year of 2031.⁹⁷¹ At the Enrico Fermi (Trino) plant, decommissioning work has been ongoing since 1999. Tenders for dismantling reactor internals are being prepared.⁹⁷² Official reports note that most of the work that happened at Trino in 2024 were preliminary activities to the actual dismantling, such as the design, commissioning and licensing preparations for the project, and that in 2024, “no dismantling operations with significant impacts were carried out,”⁹⁷³ which stands in contrast to a February 2024 news report that claims that reactor internals dismantling has begun.⁹⁷⁴ Until more information becomes available, WNISR classifies Trino in the warm-up stage. At Italy’s largest reactor, the 860-MW BWR Caorso, Sogin reported in November 2024 that it had begun dismantling external components of the reactor building.⁹⁷⁵ Since there have been no updates on any hot zone work, WNISR considers Caorso to be in the warm-up stage. The Latina GCR is awaiting the operation of Italy’s planned waste repository for reactor dismantling to begin, currently envisioned for 2039.⁹⁷⁶ Until then, auxiliary buildings are being demolished during the so-called “Phase 1” of decommissioning.⁹⁷⁷ The reactor core is defueled.⁹⁷⁸

970 - National Inspectorate for Nuclear Safety and Radiation Protection, “Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management—7th Italian National Report”, Government of Italy, August 2024, see <https://www.iaea.org/sites/default/files/italy-national-report-8rm.pdf>, accessed 22 August 2025.

971 - Sogin, “Smantellamento del reattore”, Centrale del Garigliano, Undated, see <https://www.sogin.it/it/chiusuradelciclounucleare/sitinucleariitaliani/centraledigarigliano/progettidedecommissioning/smantellamento-del-reattore.html>, accessed 6 May 2025 and 22 July 2025.

972 - Sogin, “Trino Nuclear Power Plant—Decommissioning Projects—Reactor Dismantling”, Undated, see <https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/trinonuclearpowerplant/decommissioningprojects/reactor-dismantling.html>, accessed 23 June 2023 and 23 July 2025.

973 - Sogin, “Dichiarazione Ambientale: Centrale nucleare di Trino—IV Edizione Triennio 2024-2026”, Revised February 2025, see <https://www.sogin.it/SiteAssets/uploads/2025/dichiarazioni-ambientali/dichiarazione-ambientale-trino-agg-2025.pdf>, accessed 11 August 2025.

974 - Vanni Caratto, “Decommissioning nucleare, a Trino si è arrivati allo ‘smontaggio’ del reattore”, *Radiotelevisione Italiana*, 23 February 2024, see <https://www.rainews.it/tgr/piemonte/video/2024/02/viaggio-nella-centrale-di-trino-ca4c9555-f619-42a2-b9b5-aa305146516b.html>, accessed 16 May 2024.

975 - Sogin, “Sogin, iniziato a Caorso lo smantellamento dei componenti dell’edificio reattore”, Press Release, 5 November 2024, see <https://www.sogin.it/SiteAssets/uploads/2024/notizie/Com-stampa-Sogin-iniziato-a-Caorso-lo-smantellamento-dei-componenti-dell-edificio-reattore-05112024.pdf>, accessed 6 May 2025.

976 - Sogin, “Latina Nuclear Power Plant—Decommissioning Projects—Dismantling of the Reactor Building”, Undated, see <https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/latinanuclearpowerplant/decommissioningprojects/dismantling-of-the-reactor-building.html>, accessed 23 July 2025; and Linda De Benedetto, “La pesante eredità dell’ex centrale nucleare di Latina”, *L’Espresso*, 2 April 2025, see <https://lespresso.it/c/economia/2025/4/2/ex-centrale-nucleare-latina-pesante-eredita/53452>, accessed 6 May 2025.

977 - Sogin, “Centrale di Latina—Progetti di decommissioning—Smantellamento dell’edificio reattore”, Undated, see <https://www.sogin.it/it/chiusuradelciclounucleare/sitinucleariitaliani/centraledilatina/progettidedecommissioning/smantellamento-dell%E2%80%99edificio-reattore.html>, accessed 6 May 2025.

978 - Sogin, “Latina Nuclear Power Plant—Decommissioning Projects—Dismantling of the Reactor Building”, 23 July 2025, see <https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/latinanuclearpowerplant/decommissioningprojects/dismantling-of-the-reactor-building.html>, accessed 23 July 2025.

Table 14 · Target Dates for Decommissioning Milestones in Italy

Reactor (Net Capacity)	Operating	Decommissioning Authorization	Brownfield	Complete Transfer of Radioactive Waste	Greenfield
Garigliano (150 MW)	1964–1978	2012	2028	2041	2042
Latina (153 MW)	1963–1986	2020	2042	2042	2043
Caorso (860 MW)	1978–1986	2014	2031	2037	2039
Trino (260 MW)	1964–1987	2012	2030	2038	2040

Sources: Reactor data compiled by WNISR with IAEA-PRIS, 2025; and Decommissioning data from Italy's 7th National Report to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, 2024

Japan

As of mid-2025, 27 reactors (17.1 GW) were permanently disconnected from the Japanese grid. Almost all currently closed reactors remain in the warm-up stage as of now, except Hamaoka-2 that entered the hot-zone stage. The country, one of the early adopters of nuclear power, has not completed the decommissioning of a single commercial reactor. The only completed decommissioning project is the small 12-MW research reactor, Japan Power Demonstration Reactor (JPDR), which was released as a greenfield site in October 2002.⁹⁷⁹

Cleanup at the Fukushima Daiichi plant is slowly advancing as fuel is being removed from the reactors. Fuel removal from the spent-fuel pools has been completed at Units 3 and 4, and this step is expected to begin for Units 1 and 2—which both suffered meltdowns along with Unit 3—in FY2027–2028 and FY2026, respectively. Spent-fuel assemblies from Unit 6 have already been retrieved, although some fresh fuel is still stored in the pool and reactor building, while the defueling of Unit 5 is to begin in July 2025.⁹⁸⁰ The aim is for all spent-fuel pools to be empty by 2031.⁹⁸¹ Fuel debris removal however is in its preliminary stages. TEPCO retrieved a first sample in late 2024—0.9 grams in total—and is still to determine how to remove and safely store the estimated remaining 880 tons. Actual dismantling is yet to begin, and the official target for completion of decommissioning is 2051. See [Fukushima Status Report](#) for details.

At the other plant in the Fukushima prefecture, Fukushima Daini, all four BWRs are in the process of being defueled,⁹⁸² with decommissioning scheduled to conclude in FY2064.⁹⁸³

Dismantling work on Hamaoka-1 and -2 began in late 2009, and the planned finalization for both BWRs is FY2042.⁹⁸⁴ In March 2025, the dismantling of the Reactor Pressure Vessel (RPV)

979 - Satoshi Yanagihara, “Outcome of the Japan Power Demonstration Reactor Decommissioning Project”, Research Institute of Nuclear Engineering, University of Fukui, presented at “2019 Sino-Japanese Workshop on NPP Decommissioning Technology”, Atomic Energy Council 3F, 29–30 October 2019.

980 - Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, “Outline of Decommissioning, Contaminated Water and Treated Water Management”, Tokyo Electric Power Company Holdings, 24 April 2025, see https://www.tepco.co.jp/en/hd/decommission/information/committee/pdf/2025/roadmap_20250424_01-e.pdf, accessed 6 June 2025.

981 - Ibidem; and TEPCO, “6号機新燃料の搬出について”, Tokyo Electric Power Company Holdings, 3 July 2025, see https://www4.tepco.co.jp/decommission/information/committee/roadmap_progress/pdf/2025/d250703_24-j.pdf, accessed 9 July 2025.

982 - TEPCO, “福島第二原子力発電所における廃止措置等の進捗状況について”, Tokyo Electric Power Company Holdings, December 2024, see <https://www.tepco.co.jp/2f-np/information/handouts/pdf/2024/j241220a-j.pdf>, accessed 6 May 2025.

983 - JAIF, “Current Status of Nuclear Power Plants in Japan”, as of 8 July 2025, op. cit.

984 - Ibidem.

began at Hamaoka-2 and will be followed by that of Unit 1; the process is expected to take about six years per unit.⁹⁸⁵ Thus, Unit 2 is in the hot-zone stage, while Unit 1 is still in warm-up. The decommissioning of the Magnox reactor Tokai-1 began in 2001. The dismantling of auxiliary components and buildings has begun, and in some cases, such as for the turbines, it has been completed. Decommissioning activities are scheduled to end in 2035.⁹⁸⁶ According to a news report, the completion date was initially set for FY2017 and has already been postponed four times.⁹⁸⁷ At all other closed reactors, no meaningful progress has been reported since the *Decommissioning Status Report in WNISR2024*. Decommissioning completion dates for all Japanese reactors range from FY2030 to FY2064, with most planned in the late 2040s and early 2050s.⁹⁸⁸

Kazakhstan

Decommissioning has been underway since 1998 at Aktau BN-350, a sodium-cooled fast reactor in Kazakhstan. The reactor is currently being transferred into LTE status, where it will remain for 50 years, after which dismantling shall begin.⁹⁸⁹ A publication by the Institute of Atomic Energy of Kazakhstan's National Nuclear Center in early July 2025 stated that

recently, the work on decommissioning the BN-350 reactor has significantly decreased. The main reason is associated with insufficient financing of this project. Consequently, activities related to the completion of the second, third, and fourth stages [of decommissioning] were almost suspended. At the same time, the reactor facility is maintained in a safe state to prevent dangerous situations for people and the environment.⁹⁹⁰

According to a July 2024 report, part of the KZT125 billion (US\$₂₀₂₀303 million) decommissioning budget, funded through an electricity tariff on local residents, is proposed to be used for the construction of a museum whose building would “replicate the main building of the BN-350.” As of July 2024, KZT16 billion (US\$₂₀₂₄34 million) had reportedly been paid for design work alone.⁹⁹¹

985 - Chubu Electric Power Company, “浜岡原子力発電所2号機 廃止措置第3段階の解体撤去工事の開始”, 17 March 2025, see <https://www.chuden.co.jp/resource/ham/250317%202udaig3dankaikojinokaishi.pdf>; and Chubu Electric Power Company, “Hamaoka Nuclear Power Station Units 1 and 2 Entering Decommissioning Phase 3”, Press Release, 18 December 2024, see https://www.chuden.co.jp/english/corporate/releases/pressreleases/1215188_5163.html; both accessed 23 July 2025; also Fumi Yada, “Dismantling Work Begins at Hamaoka Nuclear Plant”, *The Asahi Shimbun*, 17 March 2025, see <https://www.asahi.com/ajw/articles/15671904>, accessed 6 May 2025.

986 - JAPC, “東海発電所の廃止措置—廃止措置工事のスケジュール”, The Japan Atomic Power Company, December 2023, see <http://www.japc.co.jp/tokai/haishi/construction.html>, accessed 16 May 2024.

987 - Fumi Yada and Keitaro Fukuchi, “Era of Reactor Decommissioning Starts, but Waste Sites Still Elusive”, *The Asahi Shimbun*, 11 April 2025, see <https://www.asahi.com/ajw/articles/15675177>, accessed 6 May 2025.

988 - JAIF, “Current Status of Nuclear Power Plants in Japan”, as of 8 July 2025, op. cit.

989 - Kamen Kraev, “Rosatom to Help with BN-350 Fast Neutron Reactor Decommissioning”, *NucNet*, 29 July 2020, see <https://www.nucnet.org/news/rosatom-to-help-with-bn-350-fast-neutron-reactor-decommissioning-7-3-2020>, accessed 24 July 2023.

990 - Nurzhan Mukhamedov, Kuanyshbek Toleubekov et al., “Decommissioning of the BN-350 Fast Neutron Reactor: History Review and Current Status”, Institute of Atomic Energy, National Nuclear Center, as published in *Energies*, 2 July 2025, see <https://www.mdpi.com/1996-1073/18/13/3486>, accessed 23 July 2025.

991 - *NEI Magazine*, “Open Museum Planned in Kazakhstan for World’s First Fast Reactor”, 9 July 2024, see <https://www.neimagazine.com/news/open-museum-planned-in-kazakhstan-for-worlds-first-fast-reactor/>, accessed 7 May 2025. Yearly average exchange rate applied as published by the National Bank of Kazakhstan.

Lithuania

In Lithuania, the two Ignalina Soviet-designed Chornobyl-type RBMK units with 1185 MW capacity each have been closed since 2004 and 2009, respectively. Both reactors and their spent-fuel pools have been defueled. In 2024, dismantling activities advanced, with 24 demolished buildings. By the end of the year, 44 percent of the total planned volume of equipment and structures had been dismantled.⁹⁹² Hot-zone works, i.e., reactor internals dismantling, are scheduled to begin in 2028, with brownfield remediation of the site planned for 2038.⁹⁹³ (See [WNISR2019](#) for details on decommissioning in Lithuania.)

Netherlands

In the Netherlands, the 55-MW reactor Dodewaard was defueled in 2003 and placed into LTE in 2005 to begin actual dismantling activities from around 2045 onwards, with the objective to return the site to greenfield status.⁹⁹⁴ With the former operator Gemeenschappelijke Kernenergiecentrale Nederland (GKN), owned by Nederlands Elektriciteit Administratiekantoor (NEA), having mismanaged dedicated decommissioning funds (see earlier [WNISR editions](#)), the ownership of the plant was transferred to the Dutch state-owned radioactive waste management company COVRA for the symbolic fee of €1 in December 2024.⁹⁹⁵

Pakistan

Pakistan closed its first reactor Karachi Nuclear Power Plant-1 (KANUPP-1) in 2021, with a decommissioning license granted in 2022, marking the beginning of preparatory work to place the reactor into LTE for 20–30 years, after which dismantling to a brownfield status is planned.⁹⁹⁶ With LTE preparations ongoing—expected to last about 15 years—and no published changes or updates since last year’s edition, WNISR considers the reactor to be in the warm-up stage, to be later transferred to an LTE status.

Russia

As of mid-2025, Russia accounts for 11 closed reactors with a combined capacity of 4.9 GW, consisting of two different reactor types: eight first-generation Light-Water Gas-cooled

⁹⁹² - Ignalina Nuclear Power Plant, “IAE Performance in 2024: Record-breaking Progress in Decommissioning and Efficient Management”, Press Release, 6 March 2025, see <https://www.iaea.lt/en/news/press-releases/iae-performance-in-2024-record-breaking-progress-in-decommissioning-and-efficient-management/1161>, accessed 7 May 2025.

⁹⁹³ - Ignalina Nuclear Power Plant, “Summary of the Environmental Impact Assessment Programme (Scoping Document)—Decommissioning of the Ignalina Nuclear Power Plant”, 2023, see https://am.lrv.lt/uploads/am/documents/files/Scoping_document_decommissioning_EN.pdf, accessed 23 July 2025.

⁹⁹⁴ - OECD/NEA, “Radioactive Waste Management Programmes in OECD/NEA Member Countries—Netherlands”, Nuclear Energy Agency, Organisation for Economic Co-operation and Development, 2008, see https://www.oecd-neo.org/jcms/pl_33758/netherlands-profile-web, accessed 8 June 2022; and COVRA, “Jaarrapport 2024”, June 2025, see <https://www.covra.nl/app/uploads/2025/06/COVRA-jaarrapport2024.pdf>, accessed 24 July 2025.

⁹⁹⁵ - NOS Nieuws, “Overname kerncentrale Dodewaard door staat is een feit: aandelen overgekocht”, 12 December 2024, see <https://nos.nl/artikel/2548062-overname-kerncentrale-dodewaard-door-staat-is-een-feit-aandelen-overgekocht>, accessed 7 May 2025; and COVRA, “Jaarrapport 2024”, June 2025, op. cit.

⁹⁹⁶ - Javed Iqbal, “Issuance of Decommissioning License to Karachi Nuclear Power Plant (KANUPP) - PNRA Experience”, Pakistan Nuclear Regulatory Authority, presented at the International Conference on Nuclear Decommissioning: Addressing the Past and Ensuring the Future, 15 May 2023, see <https://conferences.iaea.org/event/288/contributions/26603/>, accessed 17 May 2024.

Reactors (LWGR)—among them four RBMK Chornobyl-type reactors—and three Soviet-designed PWRs. Kursk-2 was the latest reactor to close in Russia in January 2024.⁹⁹⁷ Kursk-1 and -2 and Leningrad-1 and -2 are the four closed RBMK reactors that pose substantial challenges for decommissioning because of the large volume of irradiated graphite stacks. While robotic dismantling techniques were being tested before Russia invaded Ukraine, the research progress remains uncertain.⁹⁹⁸ The two closed reactors at the Leningrad plant shall be turned into pilot sites for RBMK dismantling.⁹⁹⁹ Both reactors were defueled as of December 2024,¹⁰⁰⁰ and they are awaiting the dedicated decommissioning licenses to be approved, which is expected sometime during 2025, before actual dismantling can begin. In the meantime, additional onsite waste storage and treatment facilities are to be built by 2026.¹⁰⁰¹ All four RBMKs are considered in warm-up stage. At the Novovoronezh plant, the initial deferred dismantling strategy was changed to an immediate dismantling approach in 2017 for Units 1 and 2 as a pilot project for Soviet/Russian PWR dismantling.¹⁰⁰² In 2024, the project apparently moved on to active dismantling and decontamination of material and components; WNISR thus considers the units to be in the warm-up stage.¹⁰⁰³ Considering the lengthy estimated decommissioning duration of 50 years and unclear decommissioning strategies at the other sites,¹⁰⁰⁴ WNISR considers all other Russian reactors to be in LTE as long as there is no documented evidence of decommissioning progress. (See [WNISR2019](#) for details on decommissioning in Russia.)

Slovakia

Slovakia's decommissioning efforts are advancing, with both 408-MW VVER-230 reactors Bohunice-1 and -2 in the ease-off stage.¹⁰⁰⁵ The decommissioning company Jadrová a vyrad'ovacia spoločnosť (JAVYS) estimates total costs for both reactors at €1.22 billion

⁹⁹⁷ - Rosenergoatom, "Power Unit No. 2 of the Kursk NPP Was Taken Out of Power Generation Mode After 45 Years of Successful Operation", Rosatom, 1 February 2024, see <https://www.rosenergoatom.ru/en/for-journalists/highlights/45620/>, accessed 7 August 2024.

⁹⁹⁸ - Bellona, "Russia's Chernobyl-style Reactors to Keep Operating until the End of the Decade", 9 April 2025, see <https://bellona.org/news/nuclear-issues/2025-04-russias-chernobyl-style-reactors-to-keep-operating-until-the-end-of-the-decade>, accessed 12 May 2025.

⁹⁹⁹ - *NEI Magazine*, "Leningrad NPP to Be Pilot Site for RBMK Decommissioning", 30 June 2023, see <https://www.neimagazine.com/news/newsleningrad-npp-to-be-pilot-site-for-rbm-decommissioning-10978741>, accessed 24 July 2023.

¹⁰⁰⁰ - Rosenergoatom, "С остановленных для вывода из эксплуатации энергоблоков №1 и 2 Ленинградской АЭС полностью вывезено ядерное топливо", 17 December 2024, see <https://www.rosenergoatom.ru/zhurnalistam/news/47660/>, accessed 24 July 2025.

¹⁰⁰¹ - *NEI Magazine*, "Leningrad NPP Prepares Used Fuel Handling Complex to Support Decommissioning", 31 January 2024, see <https://www.neimagazine.com/news/newsleningrad-npp-prepares-used-fuel-handling-complex-to-support-decommissioning-11476895>, accessed 17 May 2024.

¹⁰⁰² - Igor Anatol'evich Engovatov et al., "Main Provisions of the Block Concept of Decommissioning of NPP Buildings and Facilities", *Izvestiya Vysshikh Uchebnykh Zawedeniy, Yadernaya Energetika*, December 2023.

¹⁰⁰³ - Андрей Волок and Юрий Холодов, "Непростые выводы: какие работы проведут на окончательно остановленных энергоблоках", *Страна РОСАТОМ*, 22 October 2024, see <https://strana-rosatom.ru/2024/10/22/rosenergoatom-gotovitsya-k-utilizatsii/>, accessed 11 August 2025.

¹⁰⁰⁴ - Дмитрий Анохин, "Блок вопросов: сколько времени, сил и средств займет вывод АЭС из эксплуатации", *Страна РОСАТОМ*, 7 December 2023, see <https://strana-rosatom.ru/2023/12/07/blok-voprosov-skolko-vremeni-sil-i-s/>, accessed 20 August 2025.

¹⁰⁰⁵ - European Commission, "Nuclear Decommissioning - Performance", Undated, see https://commission.europa.eu/strategy-and-policy/eu-budget/performance-and-reporting/programme-performance-statements/nuclear-decommissioning-performance_en, accessed 24 July 2025. On 21 July 2025, the European Bank for Reconstruction and Development (EBRD) announced the completion of the dismantling of the two Bohunice reactors; see EBRD, "Two Old Nuclear Reactors in Slovak Republic Successfully Dismantled", European Bank for Reconstruction and Development, 21 July 2025, see <https://www.ebrd.com/home/news-and-events/news/2025/two-old-nuclear-reactors-in-slovak-republic-successfully-dismant.html>, accessed 24 July 2025.

(US\$1.4 billion), but project performance is not updated regularly, complicating an assessment of the accuracy of this estimate and of the project timeline.¹⁰⁰⁶

Bohunice A1, a 93-MW heavy water GCR-type reactor, began decommissioning in 1999. All fuel has been removed from the site since 2009.¹⁰⁰⁷ Currently, the reactor is in the fourth of five decommissioning phases, which was planned to conclude in 2024.¹⁰⁰⁸ Decommissioning will continue with the dismantling of reactor internals in the fifth phase. As of the time of writing in mid-2025, there have been no official updates on the completion of the fourth phase,¹⁰⁰⁹ and the licensing process for the fifth stage is yet to be completed. The whole project is expected to be completed by 2033.¹⁰¹⁰

South Korea

As of mid-2025, two commercial reactors were closed in South Korea. The first reactor, South Korea's oldest unit, Kori-1, a 576-MW PWR, was closed in 2017. At the time, defueling was envisioned for end-2025 and the completion of plant dismantling by 2032.¹⁰¹¹ Operator Korea Hydro & Nuclear Power (KHNP) applied for a decommissioning license in 2021. As of early 2025, the license was expected to be granted “in the first half of [2025].”¹⁰¹² The regulator issued its approval in late June 2025. Cost of decommissioning was estimated at KRW1.7 trillion (US\$1.2 billion), for a 12-year implementation duration.¹⁰¹³ Meanwhile, preparatory work, such as chemical decontamination, has already begun.¹⁰¹⁴ Wolsong-1, a 661-MW Pressurized Heavy-Water Reactor (PHWR), ceased generating power in May 2017 and was officially closed in December 2019.¹⁰¹⁵ KHNP submitted the final decommissioning plan for the Wolsong-1 reactor

1006 - Javys, “Activities of the Company—V1 NPP Decommissioning”, Jadrová a vyrad'ovacia spoločnosť, Undated, see <https://www.javys.sk/en/activities-of-the-company/decommissioning-of-the-v1-npp>, accessed 24 July 2025.

1007 - Javys, “Annual Report 2023”, 2024, see <https://www.javys.sk/data/web/dokumenty/spravy-o-zp/javys-annual-report-2023.pdf>, accessed 16 August 2024.

1008 - Javys, “Activities of the Company—A1 NPP Decommissioning”, Undated, see <https://www.javys.sk/en/activities-of-the-company/a1-npp-decommissioning>, accessed 24 July 2025; and National Nuclear Fund of Slovakia, “Decommissioning of the Nuclear Power Plant A1”, Undated, see <https://www.njf.sk/en/financial-management/providing-the-financial-resources/decommissioning-of-the-nuclear-power-plants/decommissioning-of-npp-a1/>, accessed 12 May 2025.

1009 - Nuclear Regulatory Authority of the Slovak Republic, “Jadrové elektrárne”, Updated 6 February 2025, see <https://www.ujd.gov.sk/jadrovyy-program/jadrove-zariadenia-na-slovensku/jadrove-elektrarne/>, accessed 24 July 2025.

1010 - Javys, “Výročná Správa 2024”, June 2025, see <https://www.javys.sk/data/web/dokumenty/vyrocnne-spravy/2024/vyrocnna-sprava-2024-250722-id-zmensene.pdf>, accessed 24 July 2025.

1011 - Daeyong Kim, “Status of Decommissioning Preparation for Kori #1”, Korea Hydro & Nuclear Power, presented at the Eleventh Annual Meeting of the International Decommissioning Network (IDN), 6 December 2017, see https://nucleus.iaea.org/sites/connect/IDNpublic/IDN%20Annual%20Forum%202017/SESSION%205_KHNP%20Status%20of%20Decommissioning%20Preparation%20for%20Kori1_KIM.pdf, accessed 5 August 2024.

1012 - Ho-jun Lee, “Korea Initiates Dismantling Process for Wolsong Unit 1 Amid 500 Trillion Won Market”, *ChosunBiz*, 27 February 2025, see <https://biz.chosun.com/en/en-science/2025/02/28/VFIU5U7ZARD35BHO4BMBT635PY/>, accessed 12 May 2025.

1013 - NSSC, “고리 1호기 해체 승인(안)”, Nuclear Safety and Security Commission, 26 June 2025, see https://www.nssc.go.kr/attach/namo/files/000003/20250626215020353_2RA6WSUV.pdf; and NSSC, “원안위, 국내 첫 원전 고리 1호기 해체 승인”, Press Release, Nuclear Safety and Security Commission, 26 June 2025, see https://www.nssc.go.kr/ajaxfile/FR_SVC/FileDown.do?GBN=Xo1&BOARD_SEQ=5&SITE_NO=2&BBS_SEQ=46772&FILE_SEQ=2, both accessed 24 July 2025.

1014 - *Yonhap*, “Korea begins process to decommission country's first commercial Kori-1 nuclear reactor”, as published by *The Korea Times*, 8 May 2024, see https://www.koreatimes.co.kr/www/nation/2024/05/281_374144.html, accessed 21 May 2024.

1015 - KHNP, “Nuclear Power Operation – Plant Status”, Korea Hydro & Nuclear Power, 31 December 2018, see <http://cms.khnp.co.kr/eng/content/529/main.do?mnCd=EN03020101>, accessed 27 March 2019; and KHNP, “Overview”, Undated, see <https://www.khnp.co.kr/eng/contents.do?key=414>, accessed 5 November 2023.

in June 2024 and is awaiting final approval by the end of 2026 at the earliest.¹⁰¹⁶ Until then, preparatory work is underway, with the current schedule aiming for site remediation in 2034.¹⁰¹⁷

Spain

Current Spanish legislation plans to close all seven still operating units by 2035. In February 2025, a non-binding proposal to extend reactor lifetimes passed the Spanish Congress,¹⁰¹⁸ and the Iberian blackout in late April 2025 has rekindled the debate on the Spanish phaseout (see [section on Spain](#)).¹⁰¹⁹ Regardless, decommissioning at the three closed reactors is continuing.

Since WNISR2024, the José Cabrera (Zorita) reactor, which was closed in 2006, is considered fully decommissioned. Currently, final remediation work is underway with the site reportedly planned to be released as a greenfield site by “the end of 2027 or early 2028.”¹⁰²⁰

The GCR Vandellós-1 is scheduled to remain in LTE until 2030, after which reactor internals dismantling will begin.¹⁰²¹ Earlier versions of the program envisioned the start of these activities and the end of LTE in 2028.¹⁰²² As of 2024, Empresa Nacional de Residuos Radiactivos S.A (Enresa) indicated that the last phase of dismantling would last about 15 years, and the site would be released of regulatory oversight after a maximum of ten years following the end of works, meaning around 2055 at the latest.¹⁰²³

The 446-MW BWR Santa Maria de Garona (Garona-1) that last produced electricity in 2012, suspended operations in 2013 and was officially closed in 2017. The first decommissioning phase, planned from 2023 to 2026, is underway. It includes defueling procedures and dismantling of the first auxiliary components, such as the turbines.¹⁰²⁴ According to a news report from November 2024, this phase is delayed by two years.¹⁰²⁵ It remains unclear whether this delay

¹⁰¹⁶ - 이병구, “월성 1호기 원전 해체 본심사 착수...1년반 뒤 결론”, *Dong-A Science*, 27 February 2025, see <http://m.dongascience.com/news.php?idx=70284>, accessed 12 May 2025.

¹⁰¹⁷ - 손대성, “월성1호기 해체계획서 공청회 열려...안전성.기술 확보에 관심”, *Yonhap News Agency*, 9 May 2025, see <https://www.yna.co.kr/view/AKR20240509151500053>, accessed 12 May 2025.

¹⁰¹⁸ - Congreso de los Diputados, “El Congreso insta al Gobierno a ampliar la vida útil y mejorar la seguridad en las centrales nucleares”, Press Release, Parliament of Spain, 12 February 2025, see https://www.congreso.es/en/notas-de-prensa?p_p_id=notasprensa&p_p_lifecycle=o&p_p_state=normal&p_p_mode=view&_notasprensa_mvcPath=detalle&_notasprensa_notalId=48111, accessed 24 July 2025.

¹⁰¹⁹ - Victor Jack, Max Griera and Gabriel Gavin, “Atomic Lobby Seizes on Spanish Blackout”, *Politico*, 8 May 2025, see <https://www.politico.eu/article/nuclear-power-push-europe-spain-portugal-outage-energy-security/>, accessed 12 May 2025.

¹⁰²⁰ - Paco Campos, “¿Que se está haciendo para que el suelo de la nuclear de Zorita quede como estaba en 1968?”, *Nueva Alcarria*, 12 December 2024, see <https://nuevaalcarria.com/articulos/que-se-esta-haciendo-para-que-el-suelo-de-la-central-de-zorita-quede-como-estaba-en-1968>, accessed 12 May 2025.

¹⁰²¹ - Enresa, “Dismantling of Vandellós I Nuclear Power Plant”, Undated, see <https://www.enresa.es/eng/index/activities-and-projects/dismantling-and-environmental-restoration/dismantling-of-vandellos-i-nuclear-power-plant>, accessed 24 July 2025.

¹⁰²² - Enresa, “Decommissioning Report 1998 – 2003—Vandellós I Nuclear Power Plant”, December 2007, see https://www.enresa.es/phocadownload/divulgacion/vandellos_report.pdf, accessed 24 July 2025.

¹⁰²³ - Enresa, “7th General Radioactive Waste Plan”, 2024, approved 27 December 2023, see https://www.enresa.es/documentos/EN_7-plan-general-residuos-radiactivos.pdf, accessed 24 July 2025.

¹⁰²⁴ - Ibidem; and Enresa, “Dismantling of the Santa María de Garoña Nuclear Power Plant”, Undated, see <https://www.enresa.es/eng/index/activities-and-projects/dismantling-and-environmental-restoration/dismantling-of-the-santa-maria-de-garona-nuclear-power-plant>, accessed 24 July 2025.

¹⁰²⁵ - *Diario de Burgos*, “Garoña alargará de 3 a cerca de 5 años la primera fase de su desmantelamiento”, 16 November 2024, see <https://www.diariodeburgos.es/noticia/ze6e55134-d09b-9aae-b78a61c7d83867f6/202411/la-primera-fase-para-desmantelar-garona-se-alargara-hasta-2028>, accessed 12 May 2025.

will impact the target of site remediation by 2033, as Enresa's website has not been updated accordingly as of mid-2025. (See [WNISR2019](#) for details on the Spanish decommissioning process.)

Sweden

In Sweden, the closed reactor fleet comprises seven reactors, corresponding to 4.1 GW, and consists of five BWRs, one PWR, and one PHWR. With the completion of RPV dismantling in late 2023,¹⁰²⁶ and the removal of the steam generators from the reactor building in January 2025,¹⁰²⁷ the Ågesta PHWR, which was closed in 1974, has moved on to the ease-off stage. The plan is for the project to conclude in 2027.¹⁰²⁸

Reactors at Barsebäck and Oskarshamn (two BWRs each) have moved to the ease-off stage with the completion of RPV segmentation by a consortium of German companies Nukem and Uniper Nuclear Services in December 2024.¹⁰²⁹ Remaining dismantling and demolition is expected to be completed at both sites by 2028.¹⁰³⁰ The plan is to release both plants as brownfield sites subsequently.¹⁰³¹

Ringhals-1 and -2 were closed in 2020 and 2019, respectively. Defueling was completed in May 2022, when all spent fuel was transported to the Swedish interim waste storage facility CLAB.¹⁰³² In late 2023, Nuvia, a subsidiary of French construction company Vinci, was awarded the contract to dismantle both plants. The projects are to be completed by 2031, and reactor internals will be dismantled by Westinghouse following a 2021 tender award.¹⁰³³ First dismantling work began in 2024, seemingly limited to external components; thus, both reactors

¹⁰²⁶ - Vattenfall, "Avveckling Ågestaverket—Ågesta Decommissioning Program", 10 September 2024, see <https://karnkraft.vattenfall.se/siteassets/agesta/presentation-fran-informationsmote-2024.pdf>, accessed 13 May 2025.

¹⁰²⁷ - Malin Brikell, "Ågestas ånggeneratorer – de sista stora föremålen lämnar berget", Press Release, Vattenfall, 21 January 2025, see <https://group.vattenfall.com/se/nyheter-och-press/nyheter/2025/agestas-anggeneratorer--de-sista-stora-foremalen-lamnar-berget>, accessed 13 May 2025.

¹⁰²⁸ - Vattenfall, "Avveckling Ågestaverket—Ågesta Decommissioning Program", 10 September 2024, op. cit.

¹⁰²⁹ - Nukem Technologies, "Safe Decommissioning with Cutting-Edge Technology: NUKEM and UNS Complete Fleet Dismantling in Sweden with Final Reactor Pressure Vessel Successfully Dismantled at Oskarshamn", Press Release, 5 February 2025, see <https://www.nukemtechnologies.de/en/news/safe-decommissioning-with-cutting-edge-technology-nukem-and-uns-complete-fleet-dismantling-in-sweden-with-final-reactor-pressure-vessel-successfully-dismantled-at-oskarshamn>, accessed 13 May 2025.

¹⁰³⁰ - Swedish Radiation Safety Authority, "Anläggningar under avveckling", Updated 9 April 2025, see <https://www.stralsakerhetsmyndigheten.se/omraden/karnkraft/avveckling-av-karntekniska-anlaggningar-i-sverige/anlaggningar-under-avveckling/>, accessed 13 May 2025.

¹⁰³¹ - Rebekka Bärenbold, "Nuclear Decommissioning Profile: Sweden", Center of Business Economics, University of Basel, January 2023, see <https://hdl.handle.net/10419/278349>, accessed 13 May 2025.

¹⁰³² - Anna Wallrud, "Ringhals 1 och 2 är nu bränslefria", Vattenfall, 2 May 2022, see <https://group.vattenfall.com/se/nyheter-och-press/nyheter/2022/ringhals-1-och-2-ar-nu-branslefria>, accessed 13 May 2025.

¹⁰³³ - Nuvia Nordic, "NUVIA Signs a Major Contract in Sweden for Nuclear Decommissioning", Nuvia Group, 22 December 2023, see <https://www.nuvia.com/news/nuvia-signs-major-contract-sweden-nuclear-decommissioning/>; and VINCI Construction, "VINCI Construction Wins Contract to Dismantle Nuclear Reactors in Sweden", Press Release, 5 February 2024, see <https://vinci-construction.com/en/blog/2024/02/05/vinci-construction-wins-contract-to-dismantle-nuclear-reactors-in-sweden/>; also Vattenfall, "Vattenfall Signs Decommissioning Agreement for Radioactive Components at Ringhals 1 and Ringhals 2", Press Release, 17 August 2021, see <https://group.vattenfall.com/press-and-media/pressreleases/2021/vattenfall-signs-decommissioning-agreement-for-radioactive-components-at-ringhals-1-and-ringhals-2>; all accessed 24 July 2025.

remain in the warm-up stage until further notice.¹⁰³⁴ In June 2025, three steam generators were removed from Unit 2.¹⁰³⁵

Switzerland

Switzerland has some decommissioning experience, having completed technical decommissioning of the research reactor at Lucens in 2004.¹⁰³⁶ Decommissioning of the commercial reactor at Mühleberg began shortly after its closure in 2019. The site has been defueled since September 2023.¹⁰³⁷ In 2024, the control rods in the reactor core were dismantled, and work was ongoing to empty the spent-fuel pond.¹⁰³⁸ The reactor is therefore considered to be in the hot-zone stage. Dismantling of nuclear components is expected to be completed in 2031, with the site being released for further use by 2034.¹⁰³⁹ Per latest announcements, operator BKW is considering the construction of a battery storage facility or a “low-emission gas power plant.”¹⁰⁴⁰ An application to repurpose the site must be submitted before the end of 2027, and as of late 2024, BKW was still reviewing its options.¹⁰⁴¹

Ukraine

In Ukraine, the three reactors Chornobyl 1–3 completed defueling activities in 2016,¹⁰⁴² and following the chosen deferred dismantling strategy, they are to be placed into LTE from approximately 2028 to 2045. They will then be dismantled for regulatory release in 2065.¹⁰⁴³ At the damaged Unit 4, the so-called New Safe Confinement was completed in 2016.¹⁰⁴⁴ In December 2023, the dismantling license to stabilize critical parts of the original 1986 sarcophagus—“whose collapse probability is very high”—and to subsequently demolish it was extended for another six years to 2029. The original plan had been to complete these tasks

¹⁰³⁴ - Samuel Linde, “En tugga i taget – avvecklingen når milstolpe”, Vattenfall, 3 February 2025, see <https://group.vattenfall.com/se/nyheter-och-press/nyheter/2025/en-tugga-i-taget--avvecklingen-nar-milstolpe>, accessed 13 May 2025.

¹⁰³⁵ - Nuvia, “A New Milestone in the Dismantling of Ringhals 2 Reactor in Sweden”, Nuvia Group, 19 June 2025, see <https://www.nuvia.com/news/new-milestone-dismantling-ringhals-2-reactor-in-sweden/>, accessed 11 August 2025.

¹⁰³⁶ - Swiss Federal Nuclear Safety Inspectorate, “Serie Lucens: Der Rückbau eines Pionierwerks”, 14 June 2012, see <https://www.ensi.ch/de/2012/06/14/serie-lucens-der-rueckbau-eines-pionierwerks/>, accessed 8 June 2022.

¹⁰³⁷ - BKW, “Five Years of Decommissioning and Options for the Future of the Mühleberg Nuclear Power Plant Site”, Press Release, 19 December 2024, see https://www.bkw.ch/fileadmin/bt3_news/MyConvento/2024/12/18/6494861/241219_PR_KKM_Five_years_of_decommissioning.pdf, accessed 24 July 2025.

¹⁰³⁸ - Ibidem; and *Keystone-SDA*, “AKW Mühleberg: Rückbau läuft nach Plan”, as published on *Swissinfo.ch*, 18 December 2024, see <https://www.swissinfo.ch/ger/der-r%C3%BCckbau-des-kernkraftwerks-m%C3%BChleberg-geht-gut-voran/88609372>, accessed 24 July 2025.

¹⁰³⁹ - BKW, “The Decommissioning of Mühleberg Nuclear Power Plant”, Undated, see <https://www.bkw.ch/en/energy/energy-generation/decommissioning-of-the-muehleberg-nuclear-power-plant>, accessed 24 July 2025.

¹⁰⁴⁰ - SRF, “Mega-Batterie oder Gaskraftwerk: So geht es mit AKW-Areal weiter”, *Schweizer Radio und Fernsehen*, 19 December 2024, see <https://www.srf.ch/news/schweiz/akw-muehleberg-mega-batterie-oder-gaskraftwerk-so-geht-es-mit-akw-areal-weiter>, accessed 13 May 2025.

¹⁰⁴¹ - BKW, “Five Years of Decommissioning and Options for the Future of the Mühleberg Nuclear Power Plant Site”, Press Release, 19 December 2024, op. cit.

¹⁰⁴² - Chornobyl NPP, “Important Stage for Chornobyl NPP: ChNPP Units Are Completely Free of Spent Nuclear Fuel”, 6 June 2016, see <https://chnpp.gov.ua/en/news/3773-important-stage-for-chornobyl-npp-chnpp-units-are-completely-free-of-spent-nuclear-fuel>, accessed 18 August 2024.

¹⁰⁴³ - Chornobyl NPP, “ChNPP Decommissioning”, Chornobyl Nuclear Power Plant, Undated, see <https://chnpp.gov.ua/en/activity/chnpp-decommissioning>, accessed 13 May 2025.

¹⁰⁴⁴ - EBRD, “Chernobyl’s New Safe Confinement”, European Bank for Reconstruction and Development, Undated, see <https://www.ebrd.com/what-we-do/sectors/nuclear-safety/chernobyl-new-safe-confinement.html>, accessed 9 June 2022.

by 2023.¹⁰⁴⁵ On 14 February 2025, the outer wall of the confinement was hit by a drone strike, resulting in several fires breaking out.¹⁰⁴⁶ In March 2025, the situation was downgraded to a “controlled situation” from the initial “emergency” category, but several more drone sightings had been reported.¹⁰⁴⁷

United Kingdom

In the United Kingdom (U.K.), 36 reactors, corresponding to 7.75 GW, are awaiting decommissioning. Over the past few years, the organization of nuclear decommissioning has been reintegrated into the responsibility of the Nuclear Decommissioning Authority (NDA), which will decommission all British reactors, apart from the PWRs Sizewell B and Hinkley Point C, via its various so-called “Site License Companies”.¹⁰⁴⁸

As of mid-2025, 19 reactors were in the warm-up stage (of which 12 were defueled), 11 in the hot-zone stage, and six reactors remained in LTE. The U.K. is facing the challenge of decommissioning its so-called legacy fleet, consisting mostly of Magnox GCRs, whose decommissioning had been neglected for decades. Refer to *earlier WNISR editions* for more details on decommissioning in the United Kingdom. The following paragraphs only provide examples of status and ongoing work at select sites.

The British Advanced Gas-cooled Reactors (AGR) are operated by French state-owned utility Électricité de France (EDF)’s subsidiary EDF Energy. Eight reactors remain operational but are expected to close by 2030. After defueling, all AGRs will be transferred to NDA stewardship for further dismantling.¹⁰⁴⁹ Three AGR plants are currently undergoing defueling. At Dungeness B, defueling began in 2021, but no completion date is publicly available.¹⁰⁵⁰ In contrast, defueling at Hunterston B, where two reactors were closed in 2021 and 2022, respectively, was announced as completed in April 2025.¹⁰⁵¹ The first handover to the NDA is planned for 2026, after which the site will be transferred into an LTE state for 70 years.¹⁰⁵² At Hinkley Point B, which is housing

¹⁰⁴⁵ - Chornobyl NPP, “Service life of Shelter Facility Unstable Building Structures Extended for 6 Years. Regulator Made Amendments to License”, 4 December 2023, see <https://chnpp.gov.ua/en/infocenter/news/6174-service-life-of-shelter-facility-unstable-building-structures-extended-for-6-years-regulator-made-amendments-to-license>, accessed 18 August 2024.

¹⁰⁴⁶ - IAEA, “Update 278 – IAEA Director General Statement on Situation in Ukraine”, Press Release, 27 February 2025, see <https://www.iaea.org/newscenter/pressreleases/update-278-iaea-director-general-statement-on-situation-in-ukraine>, accessed 24 July 2025; and Ian Aikman, “Chernobyl Radiation Shield Hit by Russian Drone, Ukraine says”, *BBC*, 14 February 2025, see <https://www.bbc.com/news/articles/cwyjvkkgdnqo>, accessed 13 May 2025.

¹⁰⁴⁷ - NEA, “Ukraine: Current Status of Nuclear Power Installations”, Nuclear Energy Agency, Updated 9 April 2025, see https://www.oecd-nea.org/jcms/pl_66130/ukraine-current-status-of-nuclear-power-installations, accessed 13 May 2025; and IAEA, “Update 278 – IAEA Director General Statement on Situation in Ukraine”, Press Release, 27 February 2025, op. cit.

¹⁰⁴⁸ - Alexander Wimmers and Christian Von Hirschhausen, “Organizational Models for the Decommissioning of Nuclear Power Plants: Lessons from the United Kingdom and the United States”, Technical University Berlin, and German Institute for Economic Research, in *Utilities Policy*, December 2024, see <https://linkinghub.elsevier.com/retrieve/pii/S0957178724001371>, accessed 7 October 2024.

¹⁰⁴⁹ - EDF Energy, “Nuclear Decommissioning – How Is a Power Station Decommissioned?”, Undated, see <https://www.edfenergy.com/about/nuclear/decommissioning>, accessed 13 May 2025.

¹⁰⁵⁰ - EDF Energy, “Dungeness B Nuclear Power Station”, Undated, see <https://www.edfenergy.com/energy/power-stations/dungeness-b>, accessed 13 May 2025.

¹⁰⁵¹ - EDF Energy, “Fuel Free at Hunterston B as UK’s First Advanced Gas-Cooled Reactor Nuclear Station Completes Defueling”, 23 April 2025, see <https://www.edfenergy.com/media-centre/fuel-free-hunterston-b-uks-first-advanced-gas-cooled-reactor-nuclear-station-completes>, accessed 17 May 2025.

¹⁰⁵² - EDF Energy, “Hunterston B Power Station”, Undated, see <https://www.edfenergy.com/energy/power-stations/hunterston-b>, accessed 13 May 2025.

two reactors that were both closed in 2022, the formal handover to the NDA is expected for 2026, after which an equally long LTE period shall begin in 2039.¹⁰⁵³

Decommissioning of the Magnox fleet is advancing slowly. With only the four Calder Hall units and both reactors at Bradwell remaining in LTE, most sites have moved on to active dismantling, with physical demolition target dates ranging from 2050 to 2080.¹⁰⁵⁴ The NDA's current strategy draft, open for consultation and scheduled for release in 2026, plans for all buildings to be decommissioned, demolished, or reused by 2089.¹⁰⁵⁵ Whether this target stays in the final version of the strategy remains to be seen. Since WNISR2024, only the two 195-MW reactors at Trawsfynydd have made significant advancements, moving from the warm-up into the hot-zone stage. Dismantling of the fast breeders PFR and DFR at Dounreay is expected to begin in the coming years. The Winfrith prototype AGR shall be fully decommissioned by 2036.¹⁰⁵⁶

Since the restructuring of nuclear decommissioning in the U.K., organizational improvements have been acknowledged by the government's watchdog agency National Audit Office; however, especially at Sellafield, one of the most complex nuclear sites in Europe, remaining inefficiencies have led to a 6–13-year delay of the clean-up of legacy ponds and silos, and the NDA is still failing to provide “value for money”, according to a report to Parliament in October 2024.¹⁰⁵⁷ WNISR will continue to monitor decommissioning progress in the U.K.

United States

The United States (U.S.) has not only the largest fleet of operating and closed reactors, but also the highest number of fully decommissioned units, representing nearly three-quarters of the global total. In the U.S., as of mid-2025, 41 reactors (20 GW) were closed.¹⁰⁵⁸ Of these, 17 units or 7.1 GW have been fully decommissioned. Currently, decommissioning work is ongoing at 15 units: four units are in the warm-up stage (all defueled), six are in the hot-zone stage, five in the ease-off stage, while nine remain in LTE. Refer to previous WNISR editions for more details on individual decommissioning projects.

¹⁰⁵³ - NDA, “Draft Business Plan—1 April 2025 to 31 March 2028”, Nuclear Decommissioning Authority, 10 March 2025, see https://assets.publishing.service.gov.uk/media/67cef34d1aec816cd80c585/Draft_business_plan_2025-28_FINAL.pdf, accessed 13 May 2025; and WSP UK, “Decommissioning of Hinkley Point B Nuclear Power Station—Environmental Statement Volume I: Main Text”, on behalf of EDF Energy Nuclear Generation Ltd, February 2025, see <https://www.onr.org.uk/media/rqlesujh/eiadr-hinkley-point-b-application-for-consent-environmental-statement-main-text.pdf>, accessed 24 July 2025; also NDA, “Annual Report and Accounts 2024/25”, HC 1107, 21 July 2025, see https://assets.publishing.service.gov.uk/media/687e1afa78b11bf39db8dbe7/ARAC_2024-25_210725_final.pdf, accessed 24 July 2025.

¹⁰⁵⁴ - NDA, “Draft Business Plan—1 April 2025 to 31 March 2028”, 10 March 2025, op. cit.

¹⁰⁵⁵ - NDA, “The NDA Group Draft Strategy”, published for consultation, Nuclear Decommissioning Authority, July 2025, see https://assets.publishing.service.gov.uk/media/686ba6cfao8d3a3ca3b677e0/Draft_Strategy_2025_-_July.pdf, accessed 11 August 2025.

¹⁰⁵⁶ - NDA, “Draft Business Plan—1 April 2025 to 31 March 2028”, 10 March 2025, op. cit.

¹⁰⁵⁷ - NAO, “Decommissioning Sellafield: Managing Risks From The Nuclear Legacy”, HC 233, National Audit Office, October 2024, see <https://www.nao.org.uk/wp-content/uploads/2024/10/decommissioning-sellafield-managing-risks-from-the-nuclear-legacy.pdf>, accessed 13 May 2025.

¹⁰⁵⁸ - Another closed reactor is GE ESADA Vallecitos Experimental Superheat Reactor (EVESR), which is next to the GE Vallecitos BWR. Although the reactor never produced any electricity, the site was not decommissioned and put into LTE instead; see U.S. NRC, “Status of the Decommissioning Program—Annual Report”, U.S. Nuclear Regulatory Commission, 2018. Because the reactor was non-commercial, WNISR statistics do not include it. The reactor will be actively dismantled by NorthStar after a license transfer concluded in 2025. Project completion is scheduled for 2030; see U.S. NRC, “General Electric Co. – ESADA Vallecitos Experimental Superheat Reactor (EVESR)”, Updated 17 March 2025, <https://www.nrc.gov/info-finder/decommissioning/power-reactor/general-electric-co-vesr.html>, accessed 11 August 2025.

The Dresden-1 BWR was not reopened after a 1978 routine inspection because post-TMI (nuclear accident which occurred at the Three Mile Island plant in the U.S. in 1979) safety upgrades were deemed too costly.¹⁰⁵⁹ The reactor has been in LTE since 2007. According to U.S. regulations, decommissioning must be completed within 60 years of reactor closure, i.e., 2038 for Dresden-1. In March 2024, however, operator Constellation requested an extension of this deadline from the U.S. Nuclear Regulatory Commission (NRC) because of plans to extend the operational lifetimes of the still-running reactors Dresden-2 and -3 by 20 years to 2049 and 2051, respectively, and the hopes of dismantling all three plants simultaneously.¹⁰⁶⁰ As of mid-2025, there was no official ruling on this application.¹⁰⁶¹ At the Peach Bottom-1 High Temperature Gas-Cooled Reactor (HTGR), closed since 1974 and in LTE since 1978, Constellation applied for a similar extension in 2023 to dismantle the reactor jointly with the still-operational Units 2 and 3. Here, too, additional lifetime extensions have been applied for, potentially extending operations beyond 2050.¹⁰⁶² The application for Peach Bottom-1 is yet to be approved by the NRC.¹⁰⁶³

The 24 MW BWR GE Vallecitos was closed in 1963 and was subsequently placed in LTE. No major dismantlement activities were carried out before 2007–2008.¹⁰⁶⁴ In 2023, it was announced that private decommissioning company NorthStar would acquire ownership of the plant pending regulatory approval.¹⁰⁶⁵ In November 2023, the removal of the reactor vessel was completed.¹⁰⁶⁶ The agreement to transfer ownership of the entire complex of Vallecitos Nuclear Center—where several research reactors are hosted—from GE Vernova and GE-Hitachi to NorthStar was closed in March 2025.¹⁰⁶⁷ WNISR considers the reactor to be in the ease-off stage. At the Pilgrim-1 reactor, currently being decommissioned by Holtec International, disputes between Holtec and local and state authorities regarding the discharge of radioactive wastewater into Cape Cod Bay, Massachusetts, are ongoing.¹⁰⁶⁸ According to Holtec, the dispute

¹⁰⁵⁹ - Tom Lamar, “Exelon Nuclear Marks 50 Years of Nuclear Power during Dresden Unit 1 Celebration”, *Nuclear Street*, 23 September 2010, see https://nuclearstreet.com/nuclear_power_industry_news/b/nuclear_power_news/archive/2010/09/23/exelon-nuclear-marks-50-years-of-nuclear-power-during-dresden-unit-1-celebration-092305, accessed 14 May 2025.

¹⁰⁶⁰ - Constellation Energy, “Request for Alternative Schedule to Complete Decommissioning Beyond 60 Years of Permanent Cessation of Operations [At Dresden-1]”, addressed to the U.S. Nuclear Regulatory Commission, 14 March 2024, see <https://www.nrc.gov/docs/ML2407/ML24074A437.pdf>, accessed 14 May 2025.

¹⁰⁶¹ - U.S. NRC, “Power Reactor Sites—Dresden - Unit 1”, United States Nuclear Regulatory Commission, Updated 19 August 2024, see <https://www.nrc.gov/info-finder/decommissioning/power-reactor/dresden-nuclear-power-station-unit-1.html>, accessed 14 May 2025 and 25 July 2025.

¹⁰⁶² - Constellation Energy, “Request for Alternative Schedule to Complete Decommissioning Beyond 60 Years of Permanent Cessation of Operations [At Peach-Bottom-1]”, addressed to the U.S. NRC, 20 October 2023, see <https://www.nrc.gov/docs/ML2329/ML23293A305.pdf>, accessed 14 May 2025.

¹⁰⁶³ - U.S. NRC, “Power Reactor Sites—Peach Bottom - Unit 1”, 8 May 2025, see <https://www.nrc.gov/info-finder/decommissioning/power-reactor/peach-bottom-atomic-power-station-unit.html>, accessed 14 May 2025.

¹⁰⁶⁴ - Jack Parrott, “NRC Public Meeting on the Vallecitos Boiling Water Reactor License Termination Plan”, U.S. NRC, May 2024, see <https://www.nrc.gov/docs/ML2415/ML24158A390.pdf>, accessed 25 July 2025.

¹⁰⁶⁵ - NorthStar, “NorthStar Announces Intent to Take Ownership of GE Vallecitos Nuclear Center”, Press Release, 10 May 2023, see <https://www.northstar.com/northstar-announces-intent-to-take-ownership-of-ge-vallecitos-nuclear-center/>, accessed 25 July 2025.

¹⁰⁶⁶ - NorthStar Group, “NorthStar Completes Vallecitos Boiling Water Reactor Removal and Shipment”, Press Release, as published on *PR Newswire*, 13 November 2023, see <https://www.prnewswire.com/news-releases/northstar-completes-vallecitos-boiling-water-reactor-removal-and-shipment-301986534.html>, accessed 25 July 2025.

¹⁰⁶⁷ - NorthStar, “NorthStar Closes GE Hitachi Vallecitos Nuclear Center Decommissioning Deal”, Press Release, 14 March 2025, see <https://www.northstar.com/northstar-closes-ge-hitachi-vallecitos-nuclear-center-decommissioning-deal/>, accessed 25 July 2025.

¹⁰⁶⁸ - Jennette Barnes, “Radioactive Water to Be Drained from Areas of Pilgrim Nuclear Plant”, *CapeAndIsland*, NPR, 29 March 2025, see <https://www.capeandislands.org/local-news/2025-03-29/radioactive-water-to-be-drained-from-areas-of-pilgrim-nuclear-plant>, accessed 14 May 2025.

and its regulatory fallout have already delayed decommissioning by years and are prolonging the process.¹⁰⁶⁹

In the U.S., several closed reactors are being considered for restart. The 601-MW BWR Duane Arnold-1 was closed in 2020 after equipment, including the cooling towers, was damaged by a derecho, a type of severe thunderstorm event.¹⁰⁷⁰ The reactor was moved into LTE and was scheduled to be decommissioned by 2080.¹⁰⁷¹ In March 2025, however, licensee NextEra Energy engaged in talks with the NRC regarding a potential restart of the reactor by 2028.¹⁰⁷²

Unit 1 at Three Mile Island was closed in 2019. In September 2024, operator Constellation signed a 20-year PPA with Microsoft to restart the 837-MW PWR. Current plans envision operations to begin in 2028 and for the plant to run to at least 2054.¹⁰⁷³ The reactor's name was officially changed to Christopher M. Crane Clean Energy Center (CCEC) in May 2025.¹⁰⁷⁴

In early 2023, Holtec announced its plans to restart the 805-MW PWR at Palisades (closed since May 2022) and received substantial financial support from the U.S. Department of Energy and the state of Michigan. While Holtec plans for the reactor to reopen in late 2025, several indications on steam generator pipes, found during a September 2024 NRC inspection, necessitate substantial refurbishment. The NRC might not approve Holtec's plans of "sleeving" the tubes.¹⁰⁷⁵ Alternatively, the steam generators would have to be replaced, endangering the ambitious restart plans.¹⁰⁷⁶ Holtec expects the sleeves will extend the steam generators' operating life by 30 years and is sticking to the restart of Palisades "in the fourth quarter of 2025."¹⁰⁷⁷

Until a reactor is officially restarted, WNISR considers them to be in their respective decommissioning stage (see [United States Focus](#) for further details).

¹⁰⁶⁹ - Jennifer Smith, "Holtec Considers Appeal to Discharge Water from Pilgrim Plant", *CommonWealth Beacon*, 23 July 2024, see <http://commonwealthbeacon.org/energy/holtec-considers-appeal-to-discharge-water-from-pilgrim-plant/>, accessed 14 May 2025.

¹⁰⁷⁰ - Aaron Larson, "Derecho Damage Results in Early Retirement of Duane Arnold Nuclear Power Plant", *POWER Magazine*, 26 August 2020, see <https://www.powermag.com/derecho-damage-results-in-early-retirement-of-duane-arnold-nuclear-power-plant/>, accessed 25 July 2025.

¹⁰⁷¹ - U.S. NRC, "Power Reactor Sites—Duane Arnold Energy Center", Updated 31 December 2024, see <https://www.nrc.gov/info-finder/reactors/duan.html>, accessed 14 May 2025.

¹⁰⁷² - U.S. NRC, "Summary of March 19, 2025, Observation Public Meeting with NextEra Energy Duane Arnold, LLC Regarding Regulatory Path for Potentially Requesting Reauthorization of Power Operations at Duane Arnold Energy Center (EPID L-2025-LRM-0021)", 22 April 2025, see <https://www.nrc.gov/docs/ML2509/ML25099A149.pdf>, accessed 14 May 2025.

¹⁰⁷³ - WNN, "Three Mile Island Restart Project 'Ahead Of Schedule'", 28 February 2025, see <https://world-nuclear-news.org/articles/us-reactor-restart-project-ahead-of-schedule>, accessed 14 May 2025.

¹⁰⁷⁴ - U.S. NRC, "Three Mile Island Nuclear Station, Unit 1 – Issuance Of Amendment No. 306 Re: Facility Name Change from Three Mile Island Nuclear Station, Unit 1 to Christopher M. Crane Clean Energy Center (EPID L-2025-LLA-0008)", 13 May 2025, see <https://www.nrc.gov/docs/ML2510/ML25100A006.pdf>, accessed 25 July 2025.

¹⁰⁷⁵ - On 24 July 2025, the NRC announced to have "approved a series of licensing and regulatory actions that will pave the way for restart of the Palisades Nuclear Plant," see NRC, "NRC Approves Major Licensing Actions Required for Restart of Palisades NPP", see <https://www.nrc.gov/cdn/doc-collection-news/2025/25-046.pdf>, accessed 2 August 2025.

¹⁰⁷⁶ - Carol Thompson, "Defects in Michigan Nuclear Plant's Tubes Could Complicate Reopening Plans", *The Detroit News*, 25 November 2024, see <https://www.detroitnews.com/story/news/local/michigan/2024/11/25/michigan-nuclear-plants-tubes-defects-palisades-could-complicate-reopening/76457121007/>, accessed 14 May 2025.

¹⁰⁷⁷ - Holtec, "Palisades Restart Forges Ahead with Several Key Milestones Achieved", Holtec International, 7 April 2025, see <https://holtecinternational.com/2025/04/07/hh-40-08/>, accessed 14 May 2025.

DECOMMISSIONING IN SELECTED COUNTRIES

This section provides a more detailed update on decommissioning developments in the two most recent nuclear phaseout countries, Germany and Taiwan.

Country Case Studies

Germany



Despite Germany's closure of its last three reactors, Emsland, Isar-2, and Neckarwestheim-2, in April 2023 after their planned closure dates were postponed by about three months in the wake of the energy crisis caused by Russia's invasion of Ukraine in 2022 (see [Germany Focus](#) in [WNISR2023](#)), the debate on Germany's nuclear phaseout was reignited in the run-up to the federal election held in February 2025. Most notably, the conservative Christian Democrats (CDU) together with their sister-party CSU (the conservative equivalent in the federal state of Bavaria) criticized the closure as an "ideological mistake" made by the so-called "Traffic Light" (Ampel) coalition (formed by Social Democrats (SPD, red), the Green Party, and the Liberal Democratic Party FDP (yellow)).¹⁰⁷⁸ In April 2024, CDU politicians suggested halting the ongoing decommissioning work at the three latest closed reactors. They proposed corresponding legislation in the German Parliament. The initiative was rejected against the votes of CDU, CSU, and the far-right AfD (Alternative für Deutschland).¹⁰⁷⁹ Nonetheless, in the run-up to the election, these political parties defended the proposal to halt nuclear decommissioning regardless of the stage of decommissioning and despite all three nuclear power plant operators rejecting plans to reopen closed plants and the nuclear option in general. Moreover, advocating for reintegrating nuclear power into Germany's energy supply, both CDU and CSU emphasized on SMRs, so-called "advanced reactors", and nuclear fusion.

After the election, designated Chancellor Friedrich Merz (CDU) reiterated the supposed necessity of halting decommissioning work.¹⁰⁸⁰ Although the coalition agreement between CDU, CSU, and SPD to form a government does not mention the terms "nuclear power", "decommissioning", or "nuclear waste storage" (or any synonyms except for "nuclear fusion", an entirely different topic),¹⁰⁸¹ and the propagated announcement of reactivating closed reactors seems to have evaporated,¹⁰⁸² it is useful to assess whether restarting German reactors would have been technically feasible at all or whether the announcements were made merely for election campaigning reasons.

¹⁰⁷⁸ - Klaus Stratmann, Kathrin Witsch and Silke Kersting, "Neue Chance für Atomkraft?", *Handelsblatt*, 20 November 2024.

¹⁰⁷⁹ - Deutscher Bundestag, "Antrag zur Nutzung der Kernenergie in der Energiekrise abgelehnt", April 2024, see <https://www.bundestag.de/dokumente/textarchiv/2024/kw15-de-kernenergie-997394>, accessed 17 April 2025.

¹⁰⁸⁰ - Michael Bauchmüller, "Merz' Moratorium zu Atomkraft: Wie AKW-Betreiber reagieren", *Süddeutsche.de*, 25 February 2025, see <https://www.sueddeutsche.de/wirtschaft/friedrich-merz-atomkraft-moratorium-deutschland-akw-betreiber-reaktion-li.3209188>, accessed 17 April 2025.

¹⁰⁸¹ - CDU, CSU, and SPD, "Verantwortung für Deutschland—Koalitionsvertrag zwischen CDU, CSU und SPD. 21—Legislaturperiode", April 2025, see https://www.csu.de/common/csu/Koalitionsvertrag_2025_Verantwortung_fuer_Deutschland.pdf, accessed 17 April 2025.

¹⁰⁸² - Petr Jerabek, "'Nicht mehr möglich': Söder gibt seinen Atomkraft-Plan auf", *BR24*, 10 April 2025, see <https://www.br.de/nachrichten/bayern/nicht-mehr-moeglich-soeder-gibt-seinen-atomkraft-plan-auf,UhxLRT0>, accessed 17 April 2025.

German nuclear legislation requires “immediate dismantling” of closed nuclear power plants.¹⁰⁸³ Consequently, decommissioning work began at the last three operating plants once the respective decommissioning licenses had been obtained.

One of the major steps of reactor decommissioning is the decontamination of the primary loop. Decontamination measures can be taken at operating nuclear power plants to reduce the activation content of components and reduce the radiation exposure to personnel. During in-operation decontamination, less aggressive methods are applied to ensure that components are not damaged and remain safe for continued operation. However, when a plant has been closed, so-called Full System Decontamination (FSD) takes place to substantially reduce activation and further reduce radiation exposure to workers. This includes the decontamination of the primary loop.¹⁰⁸⁴ Several decontamination techniques exist,¹⁰⁸⁵ but the most commonly used method involves injecting diluted acids into the system to dissolve deposited radioactive materials that have accumulated in the pipes and also dissolve some of the pipes’ material to remove activation that has dissipated into the pipes themselves.¹⁰⁸⁶ Consequently, once FSD has happened at a closed reactor, e.g., when the primary loop has been decontaminated, operations cannot be restarted without replacing the decontaminated components, which—as the head of EnBW (operator of Neckarwestheim-2), Georg Stamatelopoulos, also pointed out—would require substantial investment and several years to execute.¹⁰⁸⁷ Table 15 provides an overview of the decontamination status at the nine reactors closed since 2011.¹⁰⁸⁸

Since 2018, WNISR analysis has shown that decommissioning work is advancing at all German reactors. Currently, with one reactor in LTE, decommissioning work is being conducted at 31 reactors:

- ➔ Ten reactors are in the warm-up stage: Biblis-A (defueled), Brokdorf, Emsland, Grohnde, Gundremmingen-B (defueled) & -C, Isar-2, Krümmel (defueled), Lingen (defueled), and Neckarwestheim-2.
- ➔ Ten reactors are in the hot-zone stage: AVR Jülich, Biblis-B, Brunsbüttel, Grafenrheinfeld, KNK II, Mülheim-Kärlich, Neckarwestheim-1, Philippsburg-1 & -2, and Unterweser.
- ➔ Eleven reactors are in the ease-off stage: Greifswald 1–5, Gundremmingen-A, Isar-1, MZFR, Obrigheim, Rheinsberg, and Stade.

¹⁰⁸³ - Federal Ministry of Justice and Consumer Protection, “Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre Gefahren (Atomgesetz) (Nuclear Power Law) § 7 Genehmigung von Anlagen”, 2022, see https://www.gesetze-im-internet.de/atg/___7.html, accessed 17 April 2025.

¹⁰⁸⁴ - Luc Noynaert, “Decontamination Processes and Technologies in Nuclear Decommissioning Projects”, CSK/CEN, in “Nuclear Decommissioning—Planning, Execution and International Experience”, *Woodhead Publishing Series in Energy*, 2012, see <https://linkinghub.elsevier.com/retrieve/pii/B9780857091154500130>, accessed 17 April 2025.

¹⁰⁸⁵ - Felix Hübner, Georg von Grone and Frank Schultman, “Technologien zur Zerlegung und zur Dekontamination von kerntechnischen Anlagen”, Karlsruhe Institute of Technology, March 2017, see <https://publikationen.bibliothek.kit.edu/1000067419/4063878>, accessed 17 April 2025.

¹⁰⁸⁶ - Stefan Thierfeldt and Frank Schartmann, “Stilllegung und Rückbau kerntechnischer Anlagen”, Brenk Systemplanung, commissioned by the Federal Ministry of Education and Research, November 2009, see https://www.ptka.kit.edu/ptka-alt/downloads/ptka-wte-e/WTE-E-Entsorgungsforschung-Broschuere_Stilllegung-und-Rueckbau_BRENK.pdf, accessed 17 April 2025.

¹⁰⁸⁷ - Michael Bauchmüller, “Merz’ Moratorium zu Atomkraft: Wie AKW-Betreiber reagieren”, *Süddeutsche.de*, 25 February 2025, op. cit.

¹⁰⁸⁸ - Reactors closed earlier are too far advanced in decommissioning to be remotely considered for restart. However, note that Krümmel was included in this list due to the decommissioning license being granted only in June 2024, see German Bundestag, “Bericht nach § 7 des Transparenzgesetzes - Rückbau von Kernkraftwerken”, Parliament of Germany, 29 November 2024, see <https://dserver.bundestag.de/btd/20/139/2013999.pdf>, accessed 17 April 2025.

Table 15 · Overview of Decommissioning Progress for Reactors in Germany Closed, 2015–2023

Reactor	Capacity (MWe)	Closure Date ^(a)	Decommissioning Stage	Full System Decontamination
Grafenrheinfeld	1275	30 June 2015	Hot-zone	Completed in 2016
Gundremmingen-B	1284	31 December 2017	Warm-up	Planned for 2027
Philippsburg-2	1402	31 December 2019	Hot-zone	Completed in 2020
Brokdorf	1410	31 December 2021	Warm-up	Completed in 2023
Grohnde	1360	31 December 2021	Warm-up	Completed in 2023
Gundremmingen-C	1288	31 December 2021	Warm-up	Planned for 2029
Emsland	1335	15 April 2023	Warm-up	Completed in 2024
Isar-2	1410	15 April 2023	Warm-up	Completed in 2024
Neckarwestheim-2	1310	15 April 2023	Warm-up	Completed in 2023

Sources: Various, compiled by WNISR, 2025

Note: a - Last production

With the demolition of the cooling towers in early 2023, decommissioning is advancing at the Biblis plant.¹⁰⁸⁹ Both reactors are defueled, and with the start of RPV dismantling, Biblis-B has moved to the hot-zone stage.¹⁰⁹⁰

The 1410-MW reactor at Brokdorf was closed in December 2021. Although the first decommissioning license was granted only in October 2024,¹⁰⁹¹ preparatory work had been ongoing, including primary circuit decontamination which was completed in 2023.¹⁰⁹² In August 2024, operator PreussenElektra (a subsidiary of utility E.ON) applied for the second stage of decommissioning licensing to begin hot-zone works. Defueling of the site is scheduled for completion in 2025.¹⁰⁹³

The decommissioning license for the Emsland reactor, one of the last three reactors to close in Germany, was granted in September 2024. Since the reactor's closure in April 2023, preparatory work had already been ongoing, with a full system decontamination of the reactor pressure vessel and connected systems being completed in early 2024. Furthermore, spent fuel has been removed from the reactor core and placed in wet storage.¹⁰⁹⁴ The Lingen reactor, located close by, was removed from 27 years of LTE in 2015, the license for the second stage of

¹⁰⁸⁹ - *dpa*, “Zweiter Kühlturm am früheren AKW Biblis abgerissen”, as published by *Süddeutsche Zeitung*, 23 February 2023, see <https://www.sueddeutsche.de/wirtschaft/umwelt-zweiter-kuehlturm-am-frueheren-akw-biblis-abgerissen-dpa.urn-newsml-dpa-com-20090101-230222-99-698212>, accessed 16 May 2024.

¹⁰⁹⁰ - German Bundestag, “Bericht nach § 7 des Transparenzgesetzes - Rückbau von Kernkraftwerken”, 29 November 2024, op. cit.

¹⁰⁹¹ - Ministry for Energy Transition, Climate Protection, Environment and Nature of Schleswig-Holstein, “Genehmigungsbescheid für das Kernkraftwerk Brokdorf (KBR) Stilllegung und Abbau (Abbauphase 1)”, 23 October 2024, see https://www.schleswig-holstein.de/DE/fachinhalte/R/reaktorsicherheit/Downloads/genehmigungsbescheidStilllegungBrokdorf.pdf?__blob=publicationFile&v=1, accessed 17 April 2025.

¹⁰⁹² - German Bundestag, “Bericht nach § 7 des Transparenzgesetzes - Rückbau von Kernkraftwerken”, 29 November 2024, op. cit.

¹⁰⁹³ - Ministry for Energy Transition, Climate Protection, Environment and Nature of Schleswig-Holstein, “Erste Genehmigung für Stilllegung und Abbau des Kernkraftwerks Brokdorf erteilt”, 23 October 2024, see https://www.schleswig-holstein.de/DE/landesregierung/ministerien-behoerden/V/Presse/PI/2024/10/241023_SAG_Brokdorf, accessed 17 April 2025.

¹⁰⁹⁴ - Ministry of Environment, Energy and Climate Protection of Lower Saxony, “Genehmigung gemäß §7 Abs. 3 Atomgesetz zur Stilllegung und zum Abbau des Kernkraftwerkes Emsland (KKE-SAG) in der Stadt Lingen (Ems) Landkreis Emsland”, 26 September 2024, see www.umwelt.niedersachsen.de/download/211689, accessed 17 April 2025.

decommissioning was granted in 2021, and currently, preparations for RPV dismantling are underway.¹⁰⁹⁵

The Grafenrheinfeld reactor was closed in 2015, and hot-zone dismantling is underway. Recently, all water was drained from the reactor internals and the former fuel-storage pond.¹⁰⁹⁶ Primary circuit decontamination was completed in 2016.¹⁰⁹⁷

The last fuel element was removed from Grohnde's reactor core and placed into the spent-fuel pool in 2022 where it was to remain for three to four years until the fuel can be transferred into dry storage and the reactor classified as defueled. Full system decontamination at Grohnde, which closed in 2021, was completed in 2023.¹⁰⁹⁸

The reactors B and C of the Gundremmingen plant are planned to be dismantled in parallel, despite them closing several years apart, i.e., in 2017 and 2021, respectively. Gundremmingen-B has been defueled, while this step is expected to be completed for Gundremmingen-C sometime in the mid-2020s.¹⁰⁹⁹ The completion target date for the project is 2040. At both reactors, full system decontamination is yet to be carried out, and it is scheduled for 2027 and 2029, respectively.¹¹⁰⁰ Regardless, the dismantling of other components is underway, including generators, turbines, and other parts of the steam cycle, as well as parts of the fuel storage pond of Gundremmingen-B.¹¹⁰¹ Furthermore, in March 2025, operator RWE (Rheinisch-Westfälisches Elektrizitätswerk) announced plans to demolish both cooling towers in the autumn of the same year,¹¹⁰² but as of June, a date had not been published.¹¹⁰³

The power plant Isar (also referred to as Ohu) houses two reactors. The 878-MW BWR Isar-1 was closed in 2011 and has moved to the ease-off stage since WNISR2024. The 1410-MW PWR Isar-2 was closed in April 2023 and was part of Bavarian Prime Minister Markus Söder's (CSU) nuclear restart ambitions in the run-up to the federal election.¹¹⁰⁴ Isar-2

¹⁰⁹⁵ - German Bundestag, "Bericht nach § 7 des Transparenzgesetzes - Rückbau von Kernkraftwerken", 29 November 2024, op. cit.

¹⁰⁹⁶ - Ibidem.

¹⁰⁹⁷ - Ministry of the Environment and Consumer Protection of Bavaria, "Schriftliche Anfrage gemäß § 71 der Geschäftsordnung für den Bayerischen Landtag des Abgeordneten Florian von Brunn (SPD) vom 27.02.2025 betreffend Rückbau und Möglichkeit der Reaktivierung der bayerischen Atomkraftwerke", as published by the Landtag of Bavaria, 28 March 2025, see <https://bayernspd-landtag.de/workspace/media/static/anfrage-demontage-akws-67ee8c83e52ad.pdf>, accessed 17 April 2025.

¹⁰⁹⁸ - German Bundestag, "Bericht nach § 7 des Transparenzgesetzes - Rückbau von Kernkraftwerken", 29 November 2024, op. cit.

¹⁰⁹⁹ - Ibidem.

¹¹⁰⁰ - Ministry of the Environment and Consumer Protection of Bavaria, "Schriftliche Anfrage gemäß § 71 der Geschäftsordnung für den Bayerischen Landtag des Abgeordneten Florian von Brunn (SPD) vom 27.02.2025 betreffend Rückbau und Möglichkeit der Reaktivierung der bayerischen Atomkraftwerke", 28 March 2025, op. cit.

¹¹⁰¹ - Ministry of the Environment and Consumer Protection of Bavaria, "Anlage zu Frage 2 der schriftlichen Anfrage des Abgeordneten Florian von Brunn (SPD) vom 27.02.2025 betreffend Rückbau und Möglichkeit der Reaktivierung der bayerischen Atomkraftwerke—Übersicht über den Rückbaufortschritt an den bayerischen Kernkraftwerken—Stand März 2025", as of March 2025, see <https://bayernspd-landtag.de/workspace/media/static/anhang-anfrage-akw-67ee8d55b7aff.pdf>, accessed 19 April 2025.

¹¹⁰² - Tobias Bühler, "Aktuelles aus dem Gemeinderat—Sitzung vom 20. März 2025: Die Kühltürme des Kernkraftwerks werden abgebrochen", Municipality of Gundremmingen, 28 March 2025, see <https://gundremmingen.de/2025/03/28/aktuelles-aus-dem-gemeinderat-7/>, accessed 11 August 2025.

¹¹⁰³ - Thomas Jensen, "Das Kernkraftwerk Gundremmingen verabschiedet sich: Alle Infos zu Rückbau und Sprengung", *Günzburger Zeitung*, 11 June 2025, see <https://www.augsburger-allgemeine.de/guenzburg/atomkraftwerk-gundremmingen-alle-infos-zu-rueckbau-sprengung-109091726>, accessed 11 August 2025.

¹¹⁰⁴ - *dpa*, "Debatte über Kernkraft: Betreiber widerspricht Söders Aussage zur Zukunft von Isar 2", *Die Zeit*, 19 November 2024, see <https://www.zeit.de/news/2024-11/19/betreiber-widerspricht-soeders-aussage-zur-zukunft-von-isar-2>, accessed 17 April 2025.

received its decommissioning license in March 2024,¹¹⁰⁵ and the full system decontamination was completed that same year.¹¹⁰⁶

Krümmel was closed in 2015, but the decommissioning license was granted only in 2024, which allowed for reactor-internals dismantling preparations to begin.¹¹⁰⁷ Several preparatory tasks (e.g., defueling) had been completed before the approval of the license, including full system decontamination in 2016.¹¹⁰⁸

The Neckarwestheim site houses two PWRs. Neckarwestheim-1 was closed in 2011. The reactor is currently undergoing hot-zone decommissioning work, with the RPV having been removed and current demolition work focusing on the reactor building itself. At Neckarwestheim-2—one of the reactors to close in April 2023—decommissioning began right after closure with the approval of the decommissioning license. The primary circuit was decontaminated in 2023,¹¹⁰⁹ and as of 2025 further work is ongoing, such as cutting the reactor cooling system pipes.¹¹¹⁰

Since WNISR2024, Obrigheim, which closed in 2005, has moved to the ease-off stage, with work now focusing on decontaminating the buildings. This task is scheduled for completion before 2030, followed by the demolition of the remaining infrastructure to a greenfield site.¹¹¹¹

Two reactors—one BWR and one PWR—are being decommissioned at the Philippsburg plant. Philippsburg-1 was closed in 2011 and remains in the hot-zone stage, with RPV dismantling underway. Philippsburg-2 was closed in 2019, with the primary loop fully decontaminated one year later. Here, too, the RPV is currently being dismantled. The end of regulatory oversight is envisioned for early- and mid-2030s, respectively.¹¹¹²

Taiwan

On 17 May 2025, the operations of Taiwan's last reactor, Maanshan-2, ceased,¹¹¹³ enforcing the “nuclear-free homeland” (or “non-nuclear homeland”) policy.¹¹¹⁴ This makes Taiwan the first Asian country to have closed all of its commercial nuclear power plants, and the fifth country worldwide, after Germany, Italy, Kazakhstan, and Lithuania. The Nuclear-Free Homeland

1105 - German Bundestag, “Bericht nach § 7 des Transparenzgesetzes - Rückbau von Kernkraftwerken”, 29 November 2024, op. cit.

1106 - Ministry of the Environment and Consumer Protection of Bavaria, “Schriftliche Anfrage gemäß § 71 der Geschäftsordnung für den Bayerischen Landtag des Abgeordneten Florian von Brunn (SPD) vom 27.02.2025 betreffend Rückbau und Möglichkeit der Reaktivierung der bayerischen Atomkraftwerke”, 28 March 2025, op. cit.

1107 - German Bundestag, “Bericht nach § 7 des Transparenzgesetzes - Rückbau von Kernkraftwerken”, 29 November 2024, op. cit.

1108 - Luis Sempere Belda, “Decontamination in Preparation for Dismantlement—AREVA's Chemical Decontamination Technologies Projects Performed and Results Obtained in the Period 2011-2016”, Chemical Process Supervisor for Full System Decontaminations, AREVA, presented 8 February 2017, see https://www.oecd-nea.org/rwm/wpdd/halden2017/docs/3-2____ppt____SEMPERE_BELDA_Luis____Areva_Decontamination_for_Dismantling.pdf, accessed 17 April 2025.

1109 - German Bundestag, “Bericht nach § 7 des Transparenzgesetzes - Rückbau von Kernkraftwerken”, 29 November 2024, op. cit.

1110 - BASE, “Zwei Jahre nach dem Atomausstieg läuft bei allen AKW der Rückbau”, Bundesamt für die Sicherheit der nuklearen Entsorgung/Federal Office for the Safety of Nuclear Waste Management, 11 April 2025, see <https://www.base.bund.de/shareddocs/kurzmeldungen/de/2025/rueckbau-akw.html>, accessed 17 April 2025.

1111 - German Bundestag, “Bericht nach § 7 des Transparenzgesetzes - Rückbau von Kernkraftwerken”, 29 November 2024, op. cit.

1112 - Ibidem.

1113 - Taipower, “Taipower's Maanshan Nuclear Power Plant Unit 2 Ceases Operation as 40-Year License Expires Diversified Dispatch with Gas and Renewables to Secure Stable Supply”, 17 May 2025, see <https://www.taipower.com.tw/2764/2804/2805/63562/normalPost>, accessed 25 July 2025.

1114 - Carol Yang, “Taiwan Prepares to Decommission Last Nuclear Reactor”, *Taiwan News*, 12 May 2025, see <https://taiwannews.com.tw/en/news/6107698>, accessed 13 May 2025.

policy first appeared as a principle in the Basic Environment Act of 2002, but the legally binding deadline of 2025 was only enshrined in 2017 (before being reversed by referendum in 2018).¹¹¹⁵ Refer to the *Taiwan Focus* for more details on Taiwanese nuclear policies and developments.

With the closure of the Maanshan-2 reactor, the Taiwanese fleet of six closed reactors amounts to 5.05 GW. The Chinshan (or Jinshan) site hosts two 604-MW BWRs that generated their last power in 2014 and 2017, respectively. In accordance with Taiwanese regulations, the decommissioning permits were submitted three years before plant closure and were approved by the Taiwanese Nuclear Safety Commission (NSC) in July 2019.¹¹¹⁶

Decommissioning at Chinshan is planned in four stages. In Phase 1, warm-up stage activities are to be conducted. Phase 2 consists of hot-zone tasks, such as reactor internals dismantling, and is planned to begin in 2026 and go on for 12 years. Phases 3 and 4, scheduled from 2038 onwards, include final decontamination and demolition work for the site to be released in 2043. Given the unavailability of a final waste storage facility, spent fuel shall be stored at onsite interim storage facilities planned for each plant site. The construction of such a facility was completed in 2013 at Chinshan.¹¹¹⁷ However, for eleven years, a legal dispute between the operator Taiwan Power Company (Taipower) and the government of New Taipei City, which refused to approve operator's water and soil conservation plans, had hindered its commissioning. In April 2024, both parties came to an agreement according to which Taipower would improve the safety of the facility's outer walls and its drainage system.¹¹¹⁸ The final certificate was issued in October 2024, and after initial hot testing until December 2024, Taipower began transferring spent fuel from the ponds into dry storage.¹¹¹⁹ The site is considered in the warm-up stage. Per the latest reported plans, defueling is to be completed in early 2026.¹¹²⁰

At the Kuosheng power plant, which houses two 985-MW BWRs that were closed in 2021 and 2023, respectively, spent-fuel pools have almost reached their full capacity, delaying continued defueling of the reactor core until a dry storage facility becomes available onsite.¹¹²¹ As with the facility at Chinshan, the government of New Taipei City had concerns regarding the site's water and soil conservation plans. The legal conflict was mediated before the Taipei High Administrative Court in August 2024,¹¹²² and so finally, groundbreaking for the construction of

1115 - McCatherin James, Wang Jason and Huang Wen, "Taiwan's Energy Transition Outlook for 2025", European Chamber of Commerce Taiwan, *Euroview*, 20 January 2025, see <https://euroview.ecct.com.tw/category-inside.php?id=2247>, accessed 13 May 2025.

1116 - Nuclear Safety Commission of Taiwan, "Nuclear Power Plant Decommissioning Regulations", Updated 2 May 2025, see <https://www.nusc.gov.tw/english/Nuclear-Reactor-Safety/Nuclear-Power-Plant-Decommissioning-Regulations-271.html>, accessed 13 May 2025.

1117 - Chang-Lin Hsieh and Yu-Kai Huang, "Plans for Chinshan", *Nuclear Engineering International*, 6 March 2019, see <https://www.neimagazine.com/advanced-reactors/fusion/plans-for-chinshan-7025241/>, accessed 25 July 2025.

1118 - Tung Kuang-i and Jonathan Chin, "Taipower to Activate Fuel Storage Facility at Jinshan", *The Taipei Times*, 3 May 2024, see <https://www.taipeitimes.com/News/taiwan/archives/2024/05/03/2003817308>, accessed 19 August 2024.

1119 - NSC, "Welcoming the Year of the Snake: The NSC Continues Oversight of Nuclear Material Safety", Press Release, Nuclear Safety Commission of Taiwan, Updated 24 January 2025, see <https://www.nusc.gov.tw/english/newsdetail/pressrelease/264.html>, accessed 13 May 2025.

1120 - *The Taipei Times*, "Outside Storage for Power Plant Waste Gets Approved", with *Central News Agency*, 26 August 2024, see <https://www.taipeitimes.com/News/taiwan/archives/2024/08/26/2003822786>, accessed 13 May 2025.

1121 - NSC, "Oversight on NPP Decommissioning", Nuclear Safety Commission, 16 April 2025, see <https://www.nusc.gov.tw/english/Nuclear-Reactor-Safety/Oversight-of-NPP-Decommissioning-283.html>, accessed 13 May 2025.

1122 - *The Taipei Times*, "Outside Storage for Power Plant Waste Gets Approved", 26 August 2024, op. cit.

such a facility could begin in December 2024.¹¹²³ Taipower anticipates finalizing construction by 2026 but does not expect to obtain an operating license allowing it to commission the facility before 2027.¹¹²⁴ With reactor dismantling to begin in 2029, overall decommissioning activities are scheduled to conclude with full site remediation in 2048.¹¹²⁵ However, as of mid-2025, the final decommissioning permit had not yet been granted,¹¹²⁶ and the delay regarding the onsite dry waste storage facility could lead to further delays in the whole project.

The Maanshan site houses two PWRs with capacities of 936 and 938 MW, respectively. Maanshan-1, the smaller unit, closed in July 2024 and Maanshan-2 followed in May 2025. A joint decommissioning permit was submitted by Taipower in 2021. The environmental impact assessment, to be approved by the Ministry of Environment, is still under review.¹¹²⁷ Preparations for dismantling, such as radiation characterization surveys are currently being conducted.¹¹²⁸ WNISR thus counts the reactors as being in the warm-up stage. At Maanshan, the construction of an onsite dry storage facility is planned with an expected startup “five to six years” from the closure of Maanshan-1.¹¹²⁹

CONCLUSION ON REACTOR DECOMMISSIONING

Assuming a 40-year lifetime—and given that the current average world fleet age is 32.5 years—a further 93 reactors will have been closed by 2030 (reactors connected to the grid between 1985 and 1990), and an additional 158 will be closed by 2065 (reactors connected 1991–2025). This does not account for the 157 reactors that have already been operating for more than 40 years, an additional 33 reactors in Long-Term Outage (LTO), and the 63 reactors under construction as of mid-2025. It should be noted, however, that the general trend now is to extend operational lifetimes beyond 40 years, often with the aim of 60 years and in some cases 80 years. As shown in previous WNISR editions, the financial and technical challenges of reactor decommissioning are often underestimated. With more and more reactors reaching the end of their lifetimes, this underestimation will likely bring costly consequences.

Between 1 July 2024 and 1 July 2025, five reactors were closed in the world: Doel-1 (445 MW) in Belgium, Pickering-1 and -4 (515 MW each) in Canada, and Maanshan-1 and -2 (938 MW each) in Taiwan.

1123 - NSC, “Welcoming the Year of the Snake: The NSC Continues Oversight of Nuclear Material Safety”, Updated 24 January 2025, op. cit.; and Taipower, “Key Decommissioning Work at Kuosheng Nuclear Power Plant Officially Begins; Outdoor Dry Storage for Spent Nuclear Fuel Breaks Ground”, as published by the Ministry of Economic Affairs, Government of Taiwan, 31 December 2024, see https://www.moea.gov.tw/MNS/english/news/News.aspx?kind=6&menu_id=176&news_id=119042, accessed 25 May 2025.

1124 - Taipower, “Key Decommissioning Work at Kuosheng Nuclear Power Plant Officially Begins; Outdoor Dry Storage for Spent Nuclear Fuel Breaks Ground”, Press Release, as published by Ministry of Economic Affairs, Government of Taiwan, 31 December 2024, see https://www.moea.gov.tw/MNS/english/news/News.aspx?kind=6&menu_id=176&news_id=119042, accessed 25 May 2025.

1125 - Taipower, “核二廠除役計畫 - 除役”, 4 December 2023, see <https://nbmi.taipower.com.tw/decommission/16/>, accessed 13 May 2025.

1126 - NSC, “The Review Status of the Decommissioning Plans for Taiwan’s Nuclear Power Plants”, 2025, see https://www.nusc.gov.tw/share/file/e_safety/I-gOfR4Qtm4jzpNkpBkiYA_.pdf, accessed 13 May 2025.

1127 - Ibidem.

1128 - NSC, “核三廠2號機將於114年5月18日進入除役期間。核安會持續監督台電公司落實除役計畫及安全要求”, 16 May 2025, see <https://www.nusc.gov.tw/newsdetail/headline/7370.html>, accessed 12 August 2025.

1129 - NEI Magazine, “Onsite Fuel Storage Approved For Kuosheng Decommissioning”, 27 August 2024, see <https://www.neimagazine.com/news/onsite-fuel-storage-approved-for-kuosheng-decommissioning/>, accessed 13 May 2025.

Worldwide, as of mid-2025, 218 nuclear power reactors have been closed, corresponding to over 109 GW of permanently retired capacity. Only 23 of these have been fully decommissioned, although some are still awaiting release from regulatory control, and only nine have been returned to greenfield conditions, meaning the sites are available for unrestricted use. An additional 151 reactors are in some state of decommissioning—of which three units in the U.S. might restart—while 44 reactors are in a long-term enclosure (LTE) state.

In the European Union, the 132 closed reactors represent 61 percent of the world's total and decommissioning efforts are advancing sporadically. Germany, having closed its last three operating nuclear power plants in April 2023, faces the unprecedented parallel decommissioning of 31 reactors, with one additional reactor remaining in LTE. The U.K. is still implementing its new “lead-and-learn strategy” to its legacy fleet and is facing potential financial shortfalls for the decommissioning of its AGR fleet. In France, with the exception of GCRs, decommissioning is advancing to some extent, although completion dates for ongoing projects are gradually pushed back year on year, and cost projections rise continuously with their total amount remaining uncertain.

The only countries to have fully decommissioned any commercial power reactors remain the U.S. (17), Germany (4), Japan (1), and Spain (1). The latest addition to the list is the 141-MW José Cabrera reactor, also known as Zorita, located in the Spanish province of Guadalajara. This reactor was connected to the grid in 1968 and closed in 2006. Technical decommissioning was completed in September 2023, and the site is awaiting its release from regulatory oversight following greenfield remediation.

Most of these decommissioned reactors are of low power capacity, many of them first-generation designs, with an average capacity of 350 MW. Decommissioning operations of completed projects lasted over 20 years on average, sometimes years longer than operation.

The five reactors closed over the year since mid-2024 have entered the warm-up stage. In the U.K., 19 reactors are currently in the warm-up stage, trumped only by 25 reactors in Japan; in total, 96 reactors are in this stage. Two Russian reactors, Novoronezh-1 and -2, moved from LTE to the warm-up stage, while the Italian reactor Trino was erroneously classified as being in the hot-zone stage in last year's report.

Five reactors moved from the warm-up to hot-zone stage, namely Biblis-B in Germany, Hamaoka-2 in Japan, Mühleberg in Switzerland, and both reactors at the Trawsfynydd plant in the U.K. Thus, 33 reactors, located in the U.K. (11), Germany (10), the U.S. (6), France (3), Italy (1), Switzerland (1), and Japan (1), are currently in the hot-zone stage.

Several reactors have advanced to the ease-off stage. Most notably, Swedish plants Barsebäck and Oskarshamn completed hot-zone works, and a fifth reactor, Ågesta, also moved on to the ease-off stage. In Germany, dismantling work advanced at Isar-1 and Obrigheim. The U.S. reactor GE Vallecitos had been mistakenly categorized as being in LTE in previous WNISR editions and is now counted in the ease-off stage. This places a total of 24 reactors in the ease-off stage. Germany leads in this category with a total of eleven reactors, followed by Sweden (5), the U.S. (5), Slovakia (2), and Belgium (1).

As no additional reactor has been placed into LTE since WNISR2024, the number of reactors in LTE has dropped from 45 in 2024 to 42 in 2025 (+2 in warm-up, +1 reclassification).

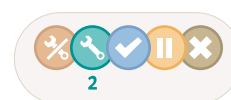
POTENTIAL NEWCOMER COUNTRIES

This chapter provides an overview of countries that have started building their first nuclear power plant or have engaged in a process aimed at the introduction of nuclear power in their respective countries. There are only three countries that do not yet operate nuclear power reactors but have invited a foreign technology provider to build them: Bangladesh, Egypt, and Türkiye. In all three cases, it is the Russian Rosatom implementing the projects.

There are many other countries that have made declarations about their ideas, intentions, strategies, plans, or even policy decisions. Most of them are too far from implementation to be covered in an annual report covering the industry. The last section provides seven examples with a wide range of progress towards national nuclear power programs.

POTENTIAL NEWCOMER COUNTRIES WITH ACTIVE REACTOR CONSTRUCTION

Bangladesh



Russia's Rosatom is building two VVER-1200 nuclear reactors at Rooppur in Bangladesh since November 2017 and July 2018, respectively.¹¹³⁰ In July 2018, Rosatom announced that commercial operations were to commence in 2023 and 2024 respectively.¹¹³¹ Since then, there have been delays due to a variety of reasons and it is not clear when the reactors will be commissioned.

In April 2024, one of Bangladesh's largest newspapers reported that "the deadline for the project's completion has been extended to 2027."¹¹³² Completion of the project, including the second unit being connected to the grid, is still expected to be 2027 according to reports after the transmission line was commissioned.¹¹³³

The project cost is estimated at US\$12.65 billion, but 90 percent of this figure (US\$11.38 billion) comes from a loan from the Russian government; the Government of Bangladesh is only

¹¹³⁰ - Rosatom, "First Concrete Poured at the Constructed Rooppur NPP Site (Bangladesh)", 30 November 2017, see <https://rosatomafrika.com/en/press-centre/news/first-concrete-poured-at-the-constructed-rooppur-npp-site-bangladesh/>, accessed 29 July 2023; and Rosatom, "Main Construction of the 2nd Unit of Rooppur NPP Begins with the 'First Concrete' Ceremony", Press Release, 14 July 2018, see <https://rosatom-mena.com/press-centre/news/main-construction-of-the-2nd-unit-of-rooppur-nuclear-power-project-begins-with-the-first-concrete-ce/>, accessed 1 August 2024.

¹¹³¹ - Rosatom, "Main Construction of the 2nd Unit of Rooppur NPP Begins with the 'First Concrete' Ceremony", July 2018, op. cit.

¹¹³² - Ahmed Humayun Kabir Topu, "Rooppur Nuclear Power Plant: First Unit to Start Production in December", *The Daily Star*, 27 April 2024, see <https://www.thedailystar.net/news/bangladesh/news/rooppur-nuclear-power-plant-first-unit-start-production-december-3596116>, accessed 3 May 2024.

¹¹³³ - Jahangir Shah, "Russia Wants to Keep Loan Repayment Money in its Custody", *Prothom Alo*, 17 November 2024, see <https://en.prothomalo.com/business/local/ywd5x39pqw>, accessed 21 February 2025.

providing the remaining 10 percent. Of this, Russia had reportedly released US\$7.33 billion by 14 August 2024.¹¹³⁴

The agreement between the Bangladesh Atomic Energy Commission and the JSC Atomstroyexport of the Russian Federation, signed on 25 December 2015, reportedly “requires semiannual payments of the loan, due on 15 March and 15 September. Each year, [US]\$379.33 million is to be paid towards the principal amount, with [US]\$189.66 million per instalment.”¹¹³⁵ But as reported in WNISR2024, due to economic challenges, the government was seeking a two-year extension on repayment of the loan from Russia for Rooppur.¹¹³⁶ According to media reports, “Although the principal repayment was initially scheduled to begin in March 2027, Russia has agreed to defer it by 18 months at Bangladesh’s request. However, Russia continues to press for regular interest payments as per the agreement.”¹¹³⁷

The other problem with repaying this loan results from Russia being forced out of the SWIFT system following its attack on Ukraine. As a consequence, Bangladesh could not send payments to Russia through this system. According to news reports, in 2023 Bangladesh agreed to repay in Chinese yuan through a bank in China.¹¹³⁸ However, that does not seem to have happened, and in 2024, Russian authorities suggested having Bangladesh open a branch of a Russian bank in Dhaka, but some commentators pointed out that this would be problematic for Bangladesh due to Western sanctions.¹¹³⁹

Finally, in December 2024, the two countries reportedly came to an agreement that would see the Russian government open a foreign currency account in Bangladesh’s state-owned Sonali Bank in Dhaka.¹¹⁴⁰ It is not clear if this arrangement actually works as in March 2025, there were media reports about blocked Sonali Bank payment attempts,¹¹⁴¹ and in June 2025, it was reported that Bangladesh “owes around \$700 million in interest arrears, which remain unpaid due to sanctions-related complications.”¹¹⁴²

The high cost of Rooppur has also led to accusations about corruption and graft.¹¹⁴³ In December 2024, Bangladesh’s Anti Corruption Commission (ACC) reportedly “alleged that

1134 - Saifuddin Saif and Shaikh Abdullah, “Russia to Get Rooppur Loan Payments Via Sonali Bank Account”, *The Business Standard*, 5 December 2024, see <https://www.tbsnews.net/economy/banking/russia-get-rooppur-loan-payments-sonali-bank-account-1010526>, accessed 21 February 2025.

1135 - Ibidem.

1136 - Shaikh Abdullah, “Bangladesh Seeks 2-year Extension for Rooppur Nuke Plant Loan Repayments”, *The Business Standard*, 26 April 2024, see <https://www.tbsnews.net/bangladesh/energy/bangladesh-seeks-2-year-extension-rooppur-nuke-plant-loan-repayments-836701>, accessed 24 July 2024.

1137 - *The Daily Observer*, “Govt Seeks US Assistance in Repaying Rooppur Nuclear Plant Loan -”, 18 April 2025, see <https://www.observerbd.com/news/521448>, accessed 15 July 2025.

1138 - Jebun Nesa Alo and Saifuddin Saif, “Dhaka, Moscow Agree to Settle Rooppur Payments in Chinese Yuan”, *The Business Standard*, 13 April 2023, see <https://www.tbsnews.net/economy/dhaka-moscow-agree-settle-rooppur-payments-chinese-yuan-616258>, accessed 26 June 2025.

1139 - Prothom Alo, “Transmission Line Commissioned, Yet Rooppur Not Ready”, 15 June 2025, op. cit.

1140 - Saifuddin Saif and Shaikh Abdullah, “Russia to Get Rooppur Loan Payments Via Sonali Bank Account”, *The Business Standard*, 5 December 2024, op. cit.

1141 - Shaikh Abdullah and Abul Kashem, “Rooppur Plant Payment Hurdle Sticks with It”, *The Business Standard*, 20 March 2025, see <https://www.tbsnews.net/economy/rooppur-plant-payment-hurdle-sticks-it-1097121>, accessed 15 July 2025.

1142 - Rejaul Karim Byron and Asifur Rahman, “Rooppur Loan Tenure to Get 3-Yr Extension”, *The Daily Star*, 19 June 2025, see <https://www.thedailystar.net/news/bangladesh/news/rooppur-loan-tenure-get-3-yr-extension-3920586>, accessed 18 June 2025.

1143 - Jack Cinamon, “The Rooppur Power Plant Scandal”, *Corruption Tracker*, 29 April 2025, see <https://corruption-tracker.org/case/the-rooppur-power-plant-scandal>, accessed 13 May 2025.

there were financial irregularities worth about \$5 billion” in the Rooppur project alone—besides a whole series of further corruption accusations—involving former Prime Minister Sheikh Hasina and members of her family, including Tulip Siddiq, her niece and now-former British Treasury Minister; prompting the ACC to launch an investigation.¹¹⁴⁴

In December 2024, Rosatom announced that the first unit had been fully built¹¹⁴⁵ and a Bangladeshi official confided in *The Daily Sun*, he was hopeful that it “would go online by March [2025].”¹¹⁴⁶ But at the end of February 2025, the head of Rosatom, Alexey Likhachev, could only announce that “the test run will commence soon.”¹¹⁴⁷ And a couple of weeks later, Likhachev vowed that “generating the first kilowatt-hours from the new nuclear power plants in Turkey and Bangladesh... are priorities for the current year.”¹¹⁴⁸

Building the transmission lines to ship the electricity from the plant had been seen as a problem for long. The likelihood of delays to transmission from Rooppur was identified back in 2020, and an official from the Power Grid Company of Bangladesh warned even then against the plant not being “able to start operation even if the nuclear power project is completed in time” if “the power transmission infrastructure and facilities are not ready.”¹¹⁴⁹ However, in early June 2025, the Power Grid Company of Bangladesh reportedly commissioned the transmission line, technically allowing electricity from Rooppur’s first unit to be exported.¹¹⁵⁰

Thus, the main reason for delays in commissioning the project now falls back to the construction of the reactor itself. There are still a number of technical challenges. According to a professor in the Department of Nuclear Engineering at Dhaka University, some of the challenges are “incomplete safety tests and compliance procedures required for power start-up, uncertainty regarding actual project costs impacting the finalization of the power purchase agreement, lack of necessary gridlines [Editor’s note: statement precedes powerline completion], the preparedness of certified reactor operators, and the absence of an established emergency preparedness and response centre.”¹¹⁵¹

Adding to this are complaints by workers and engineers about working conditions, reportedly raising concerns about safety and security. Between 28 April and 6 May 2025, a number of

1144 - Krishna N. Das and Sudipto Ganguly, “Ousted Bangladesh PM Hasina’s Son Denies Graft in \$12.65 Billion Nuclear Deal”, *Reuters*, 25 December 2024, see <https://www.reuters.com/world/asia-pacific/ousted-bangladesh-pm-hasinas-son-denies-graft-1265-billion-nuclear-deal-2024-12-24/>, accessed 15 July 2025.

1145 - Rosatom, “The Main Construction and Installation Works Are Completed at Rooppur NPP (Bangladesh)”, Press Release, 18 December 2024, see <https://www.rosatom.ru/en/press-centre/news/the-main-construction-and-installation-works-are-completed-at-rooppur-npp-bangladesh/>, accessed 7 January 2025.

1146 - *Daily Sun*, “Rooppur Nuke Plant’s First Unit Construction Completed”, 18 December 2024, see <https://www.daily-sun.com/post/782713>, accessed 15 March 2025.

1147 - BSS, “Rooppur Plant Test Run to Commence Soon, ROSATOM DG Tells CA”, *Bangladesh Sangbad Sangstha*, 26 February 2025, see <https://www.bssnews.net/news/chief-advisers-news/249889>, accessed 16 July 2025.

1148 - WNN, “Grid Connections in Turkey and Bangladesh Among Rosatom’s 2025 Priorities”, 13 March 2025, see <https://world-nuclear-news.org/articles/first-kwh-from-turkey-and-bangladesh-rosatoms-2025-priorities>, accessed 16 March 2025; and *Страна РОСАТОМ*, “Шесть вызовов ближайших шести лет: в «Росатоме» прошел день информирования”, Rosatom, 10 March 2025, see <https://strana-rosatom.ru/2025/03/10/shest-vyzovov-blizhajshih-shesti-let-v-r/>, accessed 18 March 2025.

1149 - Imran Hossain, “Delays in Rooppur Power Transmission Project Likely”, *Dhaka Tribune*, 23 October 2020, see <https://www.dhakatribune.com/bangladesh/nation/2020/10/23/delays-in-rooppur-power-transmission-project-likely>, accessed 20 August 2021.

1150 - Power Grid Bangladesh PLC, Facebook Post, 2 June 2025; and Prothom Alo, “Transmission Line Commissioned, Yet Rooppur Not Ready”, 15 June 2025, see <https://en.prothomalo.com/bangladesh/sncslaklsd>, accessed 27 June 2025.

1151 - Ahmed Humayun Kabir Topu, “Gridline Woes Delay Rooppur Power Plant Launch”, *The Daily Star*, 17 April 2025, see <https://www.thedailystar.net/environment/natural-resources/energy/news/gridline-woes-delay-rooppur-power-plant-launch-3873686>, accessed 13 May 2025.

employees of the Nuclear Power Plant Company Bangladesh Limited (NPCBL) went on strike. According to media reports, this resulted in 18 engineers being dismissed from their positions.¹¹⁵²

Bangladesh's economic challenges, including these large payments that it will have to pay, are evidently taking a toll on investing in renewable energy. The capacity of renewables increased by only 100 MW during 2024; the total capacity at the end of 2024 was 1.1 GW.¹¹⁵³ The increase was entirely due to solar energy expanding by 13 percent, from 746 MW in 2023 to 846 MW.

Egypt



Egypt's first nuclear power plant at El Dabaa involves four VVER-1200 reactors that have been under construction since July 2022 (Unit 1), November 2022 (Unit 2), May 2023 (Unit 3), and January 2024 (Unit 4).¹¹⁵⁴ The project is being financed largely through a US\$25-billion loan from Russia—covering about 85 percent of the estimated costs—and Egypt is to repay this over 22 years with a 3-percent interest rate, starting in October 2029.¹¹⁵⁵

As discussed in previous *WNISR* editions, the long history of Egypt's nuclear ambitions stems back to the mid-1950s, and the El Dabaa site was already selected in the early 1980s.¹¹⁵⁶ The current US\$30 billion-project is implemented by Russia's state-owned company Rosatom and its subsidiaries Atomstroyexport, TVEL, NFCL, and Rusatom Service, as provided by contracts signed in 2015 and put into effect in late 2017.¹¹⁵⁷

The project has been delayed (see *past WNISR editions* for further detail). In December 2017, when notices to proceed were signed, the first unit was to be commissioned in 2026.¹¹⁵⁸ Rosatom maintained in March 2021 that the “launch” of the first unit was “scheduled for 2026” and all four units would be “completed by 2029”.¹¹⁵⁹ By May 2022, it was anticipated that the first

1152 - *The Daily Star*, “18 Engineers Dismissed from Rooppur Nuclear Project Amid Unrest”, 11 May 2025, see <https://www.thedailystar.net/news/bangladesh/news/18-engineers-dismissed-rooppur-nuclear-project-amid-unrest-3891966>, accessed 13 May 2025.

1153 - IRENA, “Renewable Capacity Statistics 2025”, International Renewable Energy Agency, March 2025, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Mar/IRENA_DAT_RE_Capacity_Statistics_2025.pdf, accessed 26 March 2025.

1154 - IAEA, “Power Reactor Information System (PRIS) Database”, n.d., see <http://www.iaea.org/programmes/a2/>.

1155 - Asma Alsharif, “Russia to Lend Egypt \$25 Billion to Build Nuclear Power Plant”, *Reuters*, 1 May 2016, see <https://www.reuters.com/article/us-egypt-russia-nuclear/russia-to-lend-egypt-25-billion-to-build-nuclear-power-plant-idUSKCN0YA1G5>, accessed 24 April 2018.

1156 - Joy Nasr and Ali Ahmad, “Middle East Nuclear Energy Monitor: Country Perspectives 2018”, Energy Policy and Security Program, Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, January 2019, see https://www.aub.edu.lb/ifi/Documents/publications/research_reports/2018-2019/20190103_middle_east_nuclear_energy_monitor_country_perspectives_2018.pdf, accessed 30 July 2023.

1157 - Phil Chaffee, “Rosatom Locks in \$30 Billion Nuclear Deal in Egypt”, *Nuclear Intelligence Weekly*, 15 December 2017.

1158 - Rosatom, “Notices to Proceed Contracts for El Dabaa NPP Construction Signed in the Presence of Presidents of Russian Federation and Egypt”, 11 December 2017, see https://rosatomafrica.com/en/press-centre/news/notices-to-proceed-contracts-for-el-dabaa-npp-construction-signed-in-the-presence-of-presidents-of-r/?sphrase_id=6414, accessed 1 September 2024.

1159 - TASS, “В Росатоме заявили, что пандемия не повлияла на график строительства АЭС ‘Аккую’”, 10 March 2021, see <https://tass.ru/ekonomika/10874139>, accessed 23 May 2025.

two units would start operating in 2028 and 2029 respectively, and full operation of the plant would occur in 2030.¹¹⁶⁰

Per latest available information, these targets remain valid despite Egypt's apparent eagerness to speed up the process. A Rosatom Newsletter paraphrased Madbouly, as "reiterat[ing] Egypt's commitment to providing all possible assistance to accelerate the project delivery in cooperation with Rosatom" in August 2024.¹¹⁶¹ In November 2024, during a meeting between Egypt's Prime Minister Mostafa Madbouly and Rosatom CEO Alexey Likhachev, Madbouly reportedly "underscored Egypt's commitment to completing the first phase of the project as scheduled," while Likhachev "praised Egypt's efforts to expedite the project."¹¹⁶² In February 2025, Likhachev told TASS that Rosatom still expects to complete all four units by 2030.¹¹⁶³

Electricity in Egypt is generated mostly from natural gas (81.3 percent in 2024), followed by oil (7.5 percent), hydro power (6.1 percent), and wind and solar (5.1 percent).¹¹⁶⁴ Egypt's renewable energy capacity has continued to grow, from 3.7 GW in 2015 to 6.7 GW in 2023 and 7.8 GW in 2024.¹¹⁶⁵ Of these 7.8 GW, wind energy constitutes 2.2 GW and solar energy 2.6 GW, which has grown dramatically from 36 MW in 2015. Egypt's official target for renewables is to constitute 42 percent of its electricity generation mix by 2030, but officials have stressed that it would be contingent on international support.¹¹⁶⁶ The role nuclear is to play in this future strategy has not been disclosed yet, but according to some press reports, Egypt is considering to build more reactors, for which it is already setting land aside.¹¹⁶⁷

Türkiye



Türkiye has no operating reactor yet and one nuclear plant with four units under construction.

Unit 1 of Akkuyu nuclear power plant is currently in the final stages of construction and is scheduled to begin trial operation in late 2025, according to Turkish President Recep Tayyip

¹¹⁶⁰ - *EgyptToday*, "Egypt's Nuclear Plants Authority, Rosatom Committed to Dabaa Plant Construction Schedule: Official", 9 May 2022, see <https://www.egypttoday.com/Article/3/115597/Egypt's-Nuclear-Plants-Authority-Rosatom-committed-to-Dabaa-plant-construction>, accessed 17 July 2022.

¹¹⁶¹ - Rosatom, "Atoms Unite", Newsletter #281, September 2024, see <https://rosatomnewsletter.com/2024/09/25/atoms-unite/>, accessed 16 July 2025.

¹¹⁶² - Steven Ganot, "Egypt Accelerates Construction of First Nuclear Power Plant", *The Media Line*, 20 November 2024, see <https://themedialine.org/mideast-daily-news/egypt-accelerates-construction-of-first-nuclear-power-plant/>, accessed 9 June 2025.

¹¹⁶³ - TASS, "Rosatom Plans to Begin Physical Start-up Procedures at Egypt's El Dabaa NPP in 2027", as published by *Pravda Egypt*, 18 February 2025, see <https://egypt.news-pravda.com/en/world/2025/02/18/1689.html>, accessed 27 June 2025.

¹¹⁶⁴ - Calculated from data in Energy Institute, "Statistical Review of World Energy 2025—Data", June 2025, see https://www.energyinst.org/_data/assets/excel_doc/0008/1656215/EI-Stats-Review-ALL-data.xlsx, accessed 27 June 2025.

¹¹⁶⁵ - IRENA, "Renewable Capacity Statistics 2025", March 2025, op. cit.

¹¹⁶⁶ - *Reuters*, "Egypt Reaffirms 42% Renewable Energy Goal for 2030, but Urges International Help", 13 November 2024, see <https://www.reuters.com/business/energy/egypt-reaffirms-42-renewable-energy-goal-2030-urges-international-help-2024-11-12/>, accessed 28 June 2025.

¹¹⁶⁷ - Nadim Kawach, "Egypt Mulls Building New Nuclear Reactor: Report", *ZAWYA/LSEG*, September 2023, see <https://www.zawya.com/en/projects/utilities/egypt-mulls-building-new-nuclear-reactor-report-tezy4fqk>, accessed 31 August 2024; and *NEI Magazine*, "Egypt Plans Second NPP", 30 November 2016, see <https://www.neimagazine.com/news/egypt-plans-second-npp-5684158/>, accessed 16 July 2025.

Erdoğan.¹¹⁶⁸ As previously reported, the project has encountered delays at various stages (see earlier WNISR editions).

Originally, Unit 1 was planned to commence operations in 2023, with construction having started on 3 April 2018.¹¹⁶⁹ The other three units have been under construction since April 2020, March 2021, and July 2022 respectively.¹¹⁷⁰ Despite persistent delays and financing challenges, the authorities, including Türkiye's Minister of Energy, Alparslan Bayraktar, continue to insist that all four units of the plant will be completed by 2028.¹¹⁷¹ Nevertheless, skepticism remains.

As reported in WNISR2024, the schedule for the commissioning of Unit 1 had previously been revised several times between October 2023 and June 2024, then targeting late 2025 as startup date. In response to a parliamentary question submitted by Zonguldak MP Deniz Yavuzylmaz in February 2025, Bayraktar maintained that Unit 1 would be commissioned in 2025, with subsequent units being commissioned at one-year intervals. This timeline suggests that the final unit is expected to be operational by 2028.¹¹⁷² Having said that, Anton Dedusenko, chairman of the Board of Directors of Akkuyu Nuclear JSC gave 2026 as a launch date in an interview in early July 2025.¹¹⁷³

While delays to the original schedule appeared shortly after construction start—long before the impact of the full-scale Russian invasion of Ukraine—Alpaslan Bayraktar attributed the latest delay in the construction of the first reactor at Akkuyu primarily to Siemens Energy's failure to deliver contracted equipment. He further noted that the company had not provided a satisfactory explanation for the disruption.¹¹⁷⁴ Following the minister's remarks, in a written response to German media *Deutsche Welle*, Siemens Energy cited export and customs restrictions arising from sanctions against Russia as the reason for deliveries to Akkuyu being halted for nearly one year.¹¹⁷⁵ Meanwhile, in response to MP Sezgin Tanrikulu's written parliamentary question regarding the delivery, Energy Minister Alparslan Bayraktar stated

1168 - Presidency of Türkiye, "Erdoğan: Akkuyu Nükleer Enerji Santralinin birinci reaktörünün yapımı yakında tamamlanacak (Rusya)", 2 May 2025, see https://www.iletisim.gov.tr/turkce/dis_basinda_turkiye/detay/erdogan-akkuyu-nukleer-enerji-santralinin-birinci-reaktorunun-yapimi-yakinda-tamamlanacak-rusya/, accessed 25 May 2025; and Haber Merkezi, "Erdoğan'dan 'Akkuyu' açıklaması", *BirGün*, 2 May 2025, see <https://www.birgun.net/haber/erdogan-dan-akkuyu-aciklamasi-619989>, accessed 2 May 2025.

1169 - IAEA-PRIS, "Country Statistics—Türkiye—Akkuyu-1", Updated 24 May 2025, see <https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=553>, accessed 25 May 2025.

1170 - WNISR, "Akkuyu-4 in Turkey: Second Construction Start in a Week for the Russian Nuclear Industry—Anyways 4", 24 July 2022 see <https://www.worldnuclearreport.org/Akkuyu-4-in-Turkey-Second-Construction-Start-in-a-Week-for-the-Russian-Nuclear.html>, accessed 3 July 2024.

1171 - Ministry of Energy and Natural Resources, "Hedefimiz 2028'de 4 Reaktörün de Devreye Girmesi", Government of Türkiye, 8 September 2024, see <https://enerji.gov.tr/haber-detay?id=21352>, accessed 25 May 2025.

1172 - Ministry of Energy and Natural Resources, "Zonguldak Milletvekili Sayın Deniz Yavuzylmaz'ın Yazılı Soru Önergesine İlişkin Cevaplar", Answer to Parliamentary Question 7/21747, as released by Turkish Parliament, March 2025, see <https://cdn.tbmm.gov.tr/KKBSPublicFile/D28/Y3/T7/WebOnergeMetni/co2fbbe262b-4672-8108-9f497fbc76.pdf>, accessed 27 May 2025.

1173 - *Türkiye Today*, "Russia Signals Investor Confidence in Türkiye's Flagship Nuclear Project", 2 July 2025, see <https://www.turkiyetoday.com/business/russian-signals-investor-confidence-in-turkiyes-flagship-nuclear-project-3203728>, accessed 7 July 2025.

1174 - Türkiye Nükleer Enerji A.Ş., "Enerji Bakanı Bayraktar Açıkladı: Akkuyu Nükleer'de Alman Siemens Devre Dışı, Çinli Firma Devrede", 12 September 2024, see <https://www.tunas.gov.tr/tr/haber-detay/enerji-bakani-bayraktar-acikladi-akkuyu-nukleerde-alman-siemens-devre-disi-cinli-firma-devrede>, accessed 26 May 2025.

1175 - Elmas Topcu and Pelin Ünker, "Siemens: Akkuyu için ihracata izin yok", *Deutsche Welle*, 14 September 2024, see <https://www.dw.com/tr/siemens-akkuyu-i%C3%A7in-ihracata-izin-yok/a-70210504>, accessed 26 May 2025.

that Siemens Energy had not delivered some of the parts in question and that they had to be sourced from a Chinese company instead.¹¹⁷⁶

Akkuyu Nükleer A.Ş., the builder-owner company in which Rosatom is the majority shareholder, offered more specific insight, claiming that Siemens Energy had been contracted to supply switchyard equipment with a voltage of 400 kilowatts for power transmission. While approximately 40 percent of the deliveries had been completed, the remaining 60 percent were withheld in Germany. Consequently, the installed equipment had to be dismantled and was replaced with new parts from China.¹¹⁷⁷ Energy Minister Bayraktar confirmed that shipment of the Chinese equipment began in August 2024 and was then expected to be delivered in full by December 2024.¹¹⁷⁸ Later, in response to a written parliamentary question on 11 June 2025, he stated that not all of the equipment had been delivered, but it would be delivered and assembled in stages.¹¹⁷⁹ In early 2025, Rosatom CEO Alexey Likhachev announced plans to initiate legal proceedings against Siemens Energy for failing to deliver prepaid equipment.¹¹⁸⁰

Additional factors have also contributed to construction delays, including liquidity constraints that reportedly led to worker strikes over delayed wage payments¹¹⁸¹ and escalated into the alleged dismissal of three thousand subcontractors as of February 2025.¹¹⁸²

The cash problem indeed deepened in 2024, as U.S. banks blocked some of the money transfers—worth at least US\$2 billion—to Türkiye¹¹⁸³ after the Justice Department reportedly discovered that the Akkuyu project was used to circumvent sanctions and funnel funds from the U.S. to “bankroll Russian state initiatives”, per the *Wall Street Journal*.¹¹⁸⁴ Reports suggest that the Russian National Wealth Fund may intervene to solve Akkuyu’s financing problems.¹¹⁸⁵ However, a parliamentary question about the Fund’s involvement submitted by Istanbul MP Sezgin Tanrikulu on 7 March 2025 to Energy Minister Alpaslan Bayraktar was not answered. Tanrikulu also asked about the veracity of media reports that there had been layoffs at the

1176 - Ministry of Energy and Mineral Resources, “Diyarbakır Milletvekili Sayın M. Sezgin Tanrikulu’nun Yazılı Soru Önermesine İlişkin Cevaplar—Esas No 7/25476”, Answer to Parliamentary Question 7/25476, 11 June 2025, see <https://cdn.tbmm.gov.tr/KKBSPublicFile/D28/Y3/T7/WebOnergeMetni/cc045856-e552-495b-8873-99f040d13c1c.pdf>, accessed 12 August 2025.

1177 - Hilken Doğan Boran, “Akkuyu Nükleer Santrali’nin açılması neden gecikti?”, *BBC News Türkçe*, 14 November 2024, see <https://www.bbc.com/turkce/articles/cm2zlo148lxo>, accessed 18 November 2024.

1178 - Ibidem.

1179 - Ministry of Energy and Mineral Resources, “Diyarbakır Milletvekili Sayın M. Sezgin Tanrikulu’nun Yazılı Soru Önermesine İlişkin Cevaplar—Esas No 7/25476”, 11 June 2025, op. cit.

1180 - *Hürriyet Daily News*, “Rosatom to Sue Siemens Over Akkuyu Nuclear Plant”, 6 January 2025, see <https://www.hurriyetdailynews.com/rosatom-to-sue-siemens-over-akkuyu-nuclear-plant-204404>, accessed 26 May 2025.

1181 - *Evrensel Gazetesi*, “Ücretler ödenmedi, Akkuyu’da işçiler iş bıraktı”, March 2025, see <https://www.evrensel.net/haber/547846/ucretler-odenmedi-akkuyuda-isciler-is-birakti>, accessed 7 July 2025.

1182 - Sabrihan Tıknaçoğlu, “Akkuyu’da 3 bin taşeron işçi çıkarıldı”, *Aydınlık*, 6 February 2025, see <https://www.aydinlik.com.tr/haber/akkuyuda-3-bin-tasaron-isci-cikarildi-507329>, accessed 26 May 2025.

1183 - *Nucleonics Week*, “Akkuyu Nuclear Plant Construction in Turkey Is Under Sanction Pressure: Rosatom”, Vol. 65, Issue 28, 10 July 2024.

1184 - Jared Malsin, Costas Paris and Joe Wallace, “Moscow Has \$2 Billion Stuck at JPMorgan. The U.S. Isn’t Sure What to Do With It.”, *The Wall Street Journal*, 2 February 2025, see <https://www.wsj.com/politics/policy/moscow-has-2-billion-stuck-at-jpmorgan-the-u-s-isnt-sure-what-to-do-with-it-bo669584>, accessed 27 May 2025; and *Defence Mirror*, “U.S. Blocks \$2B from Russia to Turkey as Loan for Nuclear Power Plant”, 4 February 2025, see https://www.defensemirror.com/news/38754/U_S__Blocks__2B_from_Russia_to_Turkey_as_Loan_for_Nuclear_Power_Plant, accessed 26 May 2025.

1185 - *Habertürk*, “Akkuyu’da ‘Rusya Varlık Fonu’ devreye giriyor”, 11 February 2025, see <https://www.haberturk.com/ozel-icerikler/guntay-simsek-1019/3764490-akkuyuda-rusya-varlik-fonu-devreye-giriyor>, accessed 27 May 2025.

Akkuyu site due to the U.S. freezing the US\$2 billion loan package.¹¹⁸⁶ In his response, Energy Minister Bayraktar said that personnel planning at the construction site is the responsibility of the project company, but he did not provide any particular information on layoffs.¹¹⁸⁷

Mid-2025, a memo from TSM Energy, one of the main contractors at the power plant, instructing workers to use their existing leave and then take unpaid leave, was leaked on social media.¹¹⁸⁸ The news of layoffs, which first appeared in the media at the beginning of the year, then received more detailed coverage. It was reported that the number of employees at the plant dropped from 35,000 to 12,000, with 10,000 of the 14,000 Russian employees returning home because they had not been paid.¹¹⁸⁹ It is said that the financial resources that cannot be transferred to the project amount to US\$7 billion.¹¹⁹⁰

*10,000 of the 14,000 Russian employees returning home
because they had not been paid*

Rosatom's intention to sell a 49 percent stake in the Akkuyu project has raised questions about financial difficulties. In the early stages of the project, selling a 49 percent stake to a consortium of three parties (Cengiz Holding, Kolin İnşaat Turizm Sanayi ve Ticaret, and Kalyon İnşaat) was on the agenda. However, the sale did not go through at that time. The same companies are now being reconsidered.¹¹⁹¹

In response to the sanctions, Russia reportedly expressed the idea of paying Türkiye with natural gas.¹¹⁹²

Under the terms of the intergovernmental agreement, the delay at the Akkuyu power plant opens the door to price adjustment according to the conditions of the Power Purchase Agreement (PPA), unless force majeure is invoked.

¹¹⁸⁶ - Sezgin Tanrıku, Written Parliamentary Question No. 25476, addressed to Minister of Energy and Natural Resources, Government of Türkiye, 7 March 2025, see <https://cdn.tbmm.gov.tr/KKBSPublicFile/D28/Y3/T7/WebOnergeMetni/d68ed8c6-7263-4219-ad98-63c16493f8f2.pdf>, accessed 12 August 2025.

¹¹⁸⁷ - Ministry of Energy and Mineral Resources, "Diyarbakır Milletvekili Sayın M. Sezgin Tanrıku'nun Yazılı Soru Önermesine İlişkin Cevaplar —Esas No 7/25476", 11 June 2025, op. cit.

¹¹⁸⁸ - Patronların Ensesindeyiz, Post, X (formerly Twitter), 3 July 2025, see <https://x.com/pensendeyiz/status/1940745683713077650>, accessed 3 July 2025.

¹¹⁸⁹ - The problem with payments became more visible in July 2025. Gendarmerie and workers confronted each other during a protest that was held by the workers, who said they had not received their salaries for three months. According to a leaked letter dated 22 July 2025 from TSM Energy, the subcontractor carrying out the construction work, the company did not have the resources to pay its US\$58 million debt to the Social Security Institution; see *Bianet*, "Akkuyu Nuclear Plant Workers Face Harsh Gendarmerie Response During Wage Protest", 23 July 2025, see <https://bianet.org/haber/akkuyu-nuclear-plant-workers-face-harsh-gendarmerie-response-during-wage-protest-309738>, accessed 31 July 2025.

Nucleonics Week reported that 9,000 of the 12,000 remaining Russian workers were fired; see *Nucleonics Week*, "Akkuyu Nuclear Plant Construction in Turkey Affected by Challenges Paying Workers", 23 July 2025.

¹¹⁹⁰ - Mehmet Ali Parto, "Akkuyu'daki maaş sorunu işleri aksattı", *Yeni Şafak*, 15 July 2025, see <https://www.yenisafak.com/ekonomi/akkuyudaki-maas-sorunu-isleri-aksatti-4728793>, accessed 19 July 2025.

¹¹⁹¹ - *Bloomberg HT*, "Rusya, Akkuyu Nükleer Güç Santrali hisselerini satmayı değerlendiriyor", 1 July 2025, see <https://www.bloomberght.com/rusya-akkuyu-nukleer-guc-santrali-hisselerini-satmayi-degerlendiriyor-3751823>; and Rosatom, "Turkish Companies to Acquire Stake in Akkuyu", Newsletter #177, June 2017, see <https://rosatomnewsletter.com/2017/06/26/turkish-companies-to-acquire-stake-in-akkuyu/>; both accessed 7 July 2025.

¹¹⁹² - İhlas Haber Ajansı, "Rusya'dan Akkuyu Nükleer Santrali için yeni finansman teklifi: Doğal gaz ile ödeme", *Dünya Gazetesi*, 11 February 2025, Updated 6 April 2025, see <https://www.dunya.com/ekonomi/rusyadan-akkuyu-nukleer-santrali-icin-yeni-finansman-teklifi-dogal-gaz-ile-odeme-haberi-764132>; and *Bloomberg*, "Russia, Turkey Discuss Gas Swap to Pay for Nuclear Plant", 11 February 2025, see <https://www.bloomberg.com/news/articles/2025-02-11/russia-turkey-discuss-gas-swap-to-pay-for-akkuyu-nuclear-plant>, both accessed 26 May 2025.

According to Article 6, Paragraph 2 of the bilateral agreement:

The Project Company, with the full support of the Russian Party, shall put Unit 1 into commercial operation within seven years from the date of issuance of all documents, permits, licences, consents and approvals necessary for the start of construction of the NPP.¹¹⁹³

As construction officially began on 3 April 2018, more than seven years have passed since.¹¹⁹⁴ The agreement also stipulates that the remaining units should be commissioned at one-year intervals, following the commissioning of Unit 1.

Construction

Despite financial difficulties, Rosatom continues to report some progress on construction activities at the Akkuyu site. Rosatom announced in early 2025 that the first backup diesel generator was commissioned at Unit 1 and startup work of the pumping station was underway.¹¹⁹⁵ Sergei Butckikh, the General Manager of Akkuyu Nuclear JSC, announced that the first shipment of nuclear fuel for Unit 2 has been delivered.¹¹⁹⁶

According to the Minister of Energy, more than 350 Turkish engineers who received training in Russia have begun working at the Akkuyu plant.¹¹⁹⁷

As the project nears completion, strategic and geopolitical considerations have gained prominence. Russia's Minister of Emergency Situations, Lieutenant General Aleksandr Kurenkov proposed conducting a joint exercise in 2026.¹¹⁹⁸ "During the exercise, Russian and Turkish experts will provide training on firefighting and managing emergencies involving the release of radioactive materials," Kurenkov stated. The stated aim of the exercise is to enhance the safety of power plant personnel and nearby communities.¹¹⁹⁹ However, concerns persist over the broader geopolitical implications of the project. Some argue that the Akkuyu nuclear power plant could become a more contentious issue between NATO and Türkiye than the previous S-400 missile defense system controversy.¹²⁰⁰

1193 - Government of Türkiye and Government of Russia, "Agreement Between the Government of the Republic of Turkey and the Government of the Russian Federation on Cooperation in Relation to the Construction and Operation of a Nuclear Power Plant at the Akkuyu Site in the Republic of Turkey", *Resmî Gazete*, signed 12 May 2010, see <https://akkuyu.com/upload/iga-en.pdf>, accessed 29 June 2024.

1194 - Rosatom, "Presidents of Russia and Turkey Vladimir Putin and Recep Tayyip Erdoğan Kicked Off Large-Scale Construction of Akkuyu NPP", Press Release, 4 April 2018, see <http://rosatom.ru/en/press-centre/news/presidents-of-russia-and-turkey-vladimir-putin-and-recep-tayyip-erdo-an-kicked-off-large-scale-const/>, accessed 4 April 2018; and IAEA-PRIS, "Country Statistics—Türkiye—Akkuyu-1", Updated 24 May 2025, op. cit.

1195 - Rosatom, "Start-Up of the First Standby Diesel Generator at Akkuyu NPP Unit 1 Completed", Press Release, 24 February 2025, see https://rosatom.ru/en/press-centre/news/start-up-of-the-first-standby-diesel-generator-at-akkuyu-npp-unit-1-completed-/?sphrase_id=6752275; and Rosatom, "Equipment Start-Up and Adjustment Started at the Pumping Station of Akkuyu NPP Unit 1 (Türkiye)", Press Release, 3 February 2025, see https://rosatom.ru/en/press-centre/news/equipment-start-up-and-adjustment-started-at-the-pumping-station-of-akkuyu-npp-unit-1-t-rkiye/?sphrase_id=6752275; both accessed 11 June 2025.

1196 - Bigpara, "Akkuyu Genel Müdürü Butckikh son durumu anlattı: Nükleerde ilk türbin hazır", 11 March 2025, see https://bigpara.hurriyet.com.tr/haberler/ekonomi-haberleri/akkuyu-genel-muduru-butckikh-son-durumu-anlatti-nukleerde-ilk-turbin-hazir_ID1608800/, accessed 28 May 2025.

1197 - Naila Huseynova, "Over 350 Turkish Engineers Start Activity at Akkuyu Nuclear Power Plant - VIDEO", *Caliber*, 28 May 2025, see <https://caliber.az/en/post/over-350-turkish-engineers-start-activity-at-akkuyu-nuclear-power-plant>, accessed 28 May 2025.

1198 - TRT Haber, "Akkuyu Nükleer Santrali'nde ortak tatbikat planlanıyor", 15 May 2025, see <https://www.trthaber.com/haber/ekonomi/akkuyu-nukleer-santralinde-ortak-tatbikat-planlaniyor-907192.html>, accessed 28 May 2025.

1199 - Ibidem.

1200 - Gönül Tol, "Nato Must Wake Up to Russia's Nuclear Power Deal with Turkey", Middle East Institute, in *The Financial Times*, 21 August 2024, see <https://www.ft.com/content/a6296035-fc94-4e21-ba68-8035678f18e5>, accessed 27 May 2025.

The European Union's Türkiye 2024 Report also drew attention to Türkiye's energy dependence on Russia, emphasizing the need for legislative alignment regarding nuclear safety and stress tests at the Akkuyu nuclear power plant.¹²⁰¹

Corruption Charges on the Akkuyu Nuclear JSC Board of Directors

There have been several changes in the Akkuyu Nuclear JSC Board of Directors approximately five months after the departure of Anastasia Zoteeva and Gennady Sakharov (see [WNISR2024](#)). The new board consists of four people: Anton Dedusenko, Henri Edouard Proglio—former President of French national utility EDF and the only non-Russian member—Ekaterina Lyakhova, and Ruslan Baychurin.¹²⁰² Gennady Sakharov, then-Director of Capital Investments, State Construction Supervision and State Expertise of Rosatom, was arrested on 28 March 2024 on bribery charges and sentenced by a Russian court in May 2025.¹²⁰³ The only official comment on the matter in Türkiye came in October 2024 from the Energy Minister, Alpaslan Bayraktar who, in a written response to a parliamentary question, stated that the accusations against Sakharov were unrelated to the Akkuyu project or his previous role as a board member.¹²⁰⁴

Other Nuclear Newbuild Plans

At COP29 in Azerbaijan, Türkiye signed the—unrealistic (see [past WNISR editions](#))—international pledge to triple operating nuclear energy capacity by 2050.¹²⁰⁵ In addition to Akkuyu, Türkiye officially plans to construct two large-scale nuclear power plants, drawing the attention of several international nuclear energy companies. Sinop, located in northern Türkiye has long been considered a potential site (see [previous WNISR editions](#)), while Kırklareli in the Thrace region has recently been mentioned more frequently by Turkish officials. Russia, South Korea, and China are engaged in negotiations with the Turkish government, and Canada recently joined these countries, expressing interest in supporting Türkiye's nuclear expansion.¹²⁰⁶ In response to a citizen's inquiry filed under the Right to Information Act concerning the proposed nuclear power plant in Thrace, authorities confirmed that consultations were ongoing with China. For Sinop, Rosatom CEO Alexey Likhachev claimed to be one step ahead as President Erdoğan had reportedly extended an offer for Rosatom to build

¹²⁰¹ - European Commission, "Türkiye 2024 Report—Accompanying the document 2024 Communication on EU enlargement policy", Communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of Regions, October 2024, see https://enlargement.ec.europa.eu/document/download/8010c4db-6ef8-4c85-aa06-814408921c89_en?filename=T%C3%BCrkiye%20Report%202024.pdf, accessed 28 May 2025.

¹²⁰² - *Türkiye Ticaret Sicili Gazetesi*, "Ticaret Unvanı: Akkuyu Nükleer Anonim Şirketi", 8 April 2025; and Akkuyu Nükleer, "Bilgi Toplumu Hizmetleri—Şirket Bilgileri (Yönlendirilmiş Mesaj)", Rosatom, 28 May 2025, see <https://akkuyu.com/tr/bilgi-toplumu-hizmetleri>, accessed 28 May 2025.

¹²⁰³ - *Interfax*, "Бывший топ-менеджер «Росатома» Геннадий Сахаров приговорен к 12 годам колонии", 30 May 2025, see <https://www.interfax.ru/russia/1028825>, accessed 11 June 2025.

¹²⁰⁴ - Ministry of Energy and Natural Resources, "İSTANBUL MİLLETVEKİLİ SAYIN CELAL FİRA T'İN YAZILI SORU ÖNERGESİNE İLİŞKİN CEVAPLAR—Esas No. 7/14209", Parliamentary Question 14209, answered 28 October 2024, see <https://cdn.tbmm.gov.tr/KKBSPublicFile/D28/Y2/T7/WebOnergeMetni/ff5d9cb4-46e7-41ed-bcc6-033b887ef7aa.pdf>, accessed 12 August 2025.

¹²⁰⁵ - Ministry of Energy and Natural Resources, "Türkiye Signs the 'Declaration to Triple Nuclear Energy'", Government of Türkiye, 14 November 2024, see <https://enerji.gov.tr/news-detail?id=21401>, accessed 28 May 2025.

¹²⁰⁶ - Nevzat Devranoglu, "Turkey in Nuclear Plant Talks with Candu, Energy Minister Says", *Reuters*, 21 May 2025, see <https://www.reuters.com/business/energy/turkey-nuclear-plant-talks-with-candu-energy-minister-says-2025-05-21/>, accessed 28 May 2025.

a second nuclear power plant there.¹²⁰⁷ As of yet, however, none of the interested countries have officially committed to either of the proposed locations.

Nuclear Waste

Türkiye currently lacks a designated final repository for nuclear waste, and limited information has been disclosed to the public on this issue. Responses obtained through Freedom of Information requests indicate that spent nuclear fuel will be stored onsite at the plant for the duration of its operational life.¹²⁰⁸ In its response the regulator (NDK) indicates that under current plans, “the Project Company (operator) is responsible for the safe management of spent nuclear fuel and radioactive waste arising from the operation of a nuclear power plant and for the decommissioning of the facility.” According to the National Radioactive Waste Plan (URAYP), a geological disposal facility is projected to be commissioned by 2085.¹²⁰⁹

Meanwhile, a Near Surface Disposal Facility for low and intermediate level waste, is scheduled to become operational by 2035. Additionally, the long-term expansion of the solid and solidified waste storage areas at Akkuyu is under consideration to accommodate waste generated over the plant’s anticipated 60-year lifespan.¹²¹⁰

Energy Outlook

As of mid-2025, Türkiye’s total electricity generating capacity reached over 119 GW.¹²¹¹ Hydroelectric power plants lead with 32 GW, followed by natural gas power plants (25 GW), solar energy (23 GW), and wind energy (13 GW).¹²¹² Power plants fueled by both domestic and imported coal together account for 21 GW of capacity. In the preceding 12 months, 5 GW of solar and 1.2 GW of wind capacity were added to the system while other sources remained largely unchanged, with only minor increases in capacity.¹²¹³ Solar and wind energy have been the leading players in Türkiye’s capacity growth in recent years, and this development has been reflected in electricity generation. Solar power’s contribution to electricity generation in Türkiye went from only 3.6 percent in 2020 to 7.5 percent in 2024; thus the solar share more than doubled in just four years. Wind energy’s share rose from 8.1 percent to 10.7 percent, and biomass also increased during the same period from 1.4 percent to 2.6 percent.¹²¹⁴

Peak electricity demand was recorded at 58.7 MWh on 23 July 2024 at 3:45 PM.¹²¹⁵ According to the Turkish Electricity Transmission Corporation (TEİAŞ)’s demand forecast report covering the period between 2025 and 2034, the peak electricity demand is expected to reach

¹²⁰⁷ - *Ekonomim*, “Erdoğan, Sinop’a yapılacak nükleer santrali Rosatom’un inşa etmesini istedi”, 27 October 2024, see <https://www.ekonomim.com/sektorler/enerji/erdogan-sinopa-yapilacak-nukleer-santrali-rosatomun-insa-etmesini-istedi-haberi-776135>, accessed 28 May 2025.

¹²⁰⁸ - Turkish Nuclear Regulatory Authority, Answer to question filed under Right to Information Act, issued 8 July 2024.

¹²⁰⁹ - Ibidem.

¹²¹⁰ - Ibidem.

¹²¹¹ - TEİAŞ, “Power of Energy”, Türkiye Elektrik İletim A.Ş./Turkish Electricity Transmission Corporation, as of June 2025, see <https://www.teias.gov.tr/en-US>, accessed 20 July 2025; and TEİAŞ, “Yük Tevzi Bilgi Sistemi Günlük İşletme Neticeleri”, 1 July 2025.

¹²¹² - TEİAŞ, “Yük Tevzi Bilgi Sistemi Günlük İşletme Neticeleri”, July 2025.

¹²¹³ - Ibidem, and TEİAŞ, “Yük Tevzi Bilgi Sistemi Günlük İşletme Neticeleri”, July 2024.

¹²¹⁴ - TEİAŞ, “Yıllık Türkiye Puant Raporu—2020”, 2020; and TEİAŞ, “Yıllık Türkiye Puant Raporu—2024”, 2024.

¹²¹⁵ - Ibidem.

81 GW by 2034 based on the reference scenario. The same scenario sees Türkiye's electricity consumption going from 348 TWh in 2024 to 478 TWh in 2034.¹²¹⁶

Türkiye's total greenhouse gas emissions as CO₂ equivalent were 552 million tons at the end of 2023.¹²¹⁷ Türkiye's Nationally Determined Contribution (NDC) target for 2030 is to keep total emissions below 695 million tons of CO₂ equivalent.¹²¹⁸ Although this target implies an increase from the 2012 base year, Türkiye's aim is to increase the capacity of renewable energy sources in order to limit emissions compared to a "business as usual" scenario. According to the National Energy Plan of Türkiye, the country's energy goals for 2030 are to reach 33 GW of solar capacity, 18 GW of wind capacity, 35 GW of hydroelectric capacity, and 4.8 GW of nuclear capacity (corresponding to the Akkuyu plant).¹²¹⁹ The Energy Transition–Renewable Energy 2035 roadmap, which was announced at the end of 2024, set out a very ambitious target of 120 GW of combined installed wind and solar power capacity by 2035.¹²²⁰

POTENTIAL NEWCOMER NUCLEAR COUNTRIES IN AFRICA

African countries have some of the highest population growth rates in the world, and this is coupled with substantive economic growth and an increasing middle class that have resulted in dramatically higher electricity demand and associated acute power supply disruptions.¹²²¹ Interventions that show promise of alleviating the electricity shortfalls enjoy interest and support from the political leadership and the public at large.

As a result, initiatives to build nuclear power plants have been common in many African countries over the past decades. Importantly, outside South Africa and Egypt—who already operate or are in the course of building a nuclear plant—only four African countries having considered nuclear power (Algeria, Libya, Morocco, and Nigeria) have an operational capacity on the grid exceeding 10,000 MW. These are therefore the only countries in which building a typical 1,000 MW nuclear power generating unit would not exceed 10 percent of the total national power generating capacity, an order of magnitude considered a maximum, including for the IAEA. See *Africa Focus* in *WNISR2024* for details and references.

WNISR2024 also detailed efforts over many years by the Russian state and its nuclear utility Rosatom to very actively seek nuclear cooperation agreements, typically with a statement of

¹²¹⁶ - Ministry of Energy and Natural Resources, "Elektrik", Government of Türkiye, Updated 20 July 2025, see <https://enerji.gov.tr/bilgi-merkezi-enerji-elektrik>, accessed 20 July 2025; and TEİAŞ, "10 Yıllık Talep Tahminleri Raporu (2025-2034)", December 2024, see <https://webim.teias.gov.tr/file/78d82946-c07e-438c-beb8-971d6d40c1d2?download>, accessed 20 July 2025.

¹²¹⁷ - Turkish Statistical Institute, "Greenhouse Gas Emissions Statistics, 1990-2023 (Corrected)", Press Release No. 53974, 26 March 2025, see <https://data.tuik.gov.tr/Bulten/Index?p=Greenhouse-Gas-Emissions-Statistics-1990-2023-53974&dil=2>, accessed 20 July 2025.

¹²¹⁸ - Government of Türkiye, "Republic of Türkiye Updated First Nationally Determined Contribution", April 2023, see https://unfccc.int/sites/default/files/NDC/2023-04/T%C3%9CRK%C4%B0YE_UPDATED%201st%20NDC_EN.pdf, accessed 20 July 2025.

¹²¹⁹ - Ibidem.

¹²²⁰ - Ministry of Energy and Natural Resources, "Yenilenebilir Enerjide 2035 Yol Haritası", Government of Türkiye, 21 October 2024, see https://enerji.gov.tr/Media/Dizin/BHIM/tr/Duyurular/Yenilenebilir%20Enerjide%202035%20Yol%20Haritas%C4%B1%20Lansman%20Sunumu_202410221014.pdf, accessed 20 July 2025.

¹²²¹ - International Energy Forum, "How Can We Tackle Energy Poverty in Africa?", 7 October 2024, see <https://www.ief.org/news/how-can-we-tackle-energy-poverty-in-africa>, accessed 9 June 2025.

intent to eventually build a nuclear plant in any interested nation, regardless of that country's financial capacity.

While, until recently, Russia had been largely unchallenged in pursuing aggressive nuclear marketing in Africa, there were already signs during the period covered by WNISR2024 that China was increasing its presence in Africa. A London-based China expert recently stated: “China is strategically positioning itself to exert significant influence over Africa’s nuclear energy sector in the coming decades.”¹²²² However, unlike Russia, Chinese efforts appear focused on aid in energy projects in general rather than specifically nuclear ones—its ability to supply solar panels and build solar farms fast and on a massive scale in particular ensured a significant competitive advantage.¹²²³

The United States also responded to interest in nuclear technology, often in particular marketing Small Modular Reactors (SMRs). These efforts focused on economically stronger countries such as Ghana and Kenya, with which the U.S. concluded nuclear agreements in the past year.¹²²⁴ It remains to be seen if the American initiatives will persist under the Trump administration, which has already instituted major cuts to aid and developmental initiatives in Africa.¹²²⁵

Over the period covered by the current report, China has again substantially increased its activity in the African energy sector. It is now directly building large solar farms in countries such as Zambia¹²²⁶ and Botswana.¹²²⁷

When it comes to nuclear projects, China is now seemingly preferred to Russia in several countries where Russia was once considered the clear front-runner for partnering on a nuclear build. The three African countries that appear to have made some planning progress towards a nuclear power program have all had stronger engagement with China in the past year, as laid out in the sections that follow.

Opposition to nuclear developments in Africa has typically taken the form of local initiatives, but in June 2025, nine African organizations from Burkina Faso, Ghana, Kenya, Nigeria, South Africa, Tanzania, and Uganda met and cooperated with European organizations in the production of a report titled “The Alarming Rise of False Climate Solutions in Africa: The Nuclear Energy Misadventure”.¹²²⁸ This joint analysis of the issues surrounding attempts to

¹²²² - Lse Ideas, “China’s Strategic Pursuit of Nuclear Energy Dominance in Africa”, *The China-Global South Project*, 10 April 2025, see <https://chinaglobalsouth.com/analysis/chinas-strategic-pursuit-of-nuclear-energy-dominance-in-africa/>, accessed 9 June 2025.

¹²²³ - Njenga Hakeenah, “South Africa’s Largest Private Solar Project to Power Chinese Chrome Smelting Factory”, *The China-Global South Project*, 18 February 2025, see <https://chinaglobalsouth.com/2025/02/18/south-africas-largest-private-solar-project-to-power-chinese-chrome-smelting-factory/>, accessed 2 June 2025.

¹²²⁴ - Office of Nuclear Energy, “Commercial SMR Agreement Reached at U.S-Africa Nuclear Energy Summit”, U.S. Department of Energy, 29 August 2024, see <https://www.energy.gov/ne/articles/commercial-smr-agreement-reached-us-africa-nuclear-energy-summit>, accessed 15 April 2025.

¹²²⁵ - Jakkie Cilliers, “The Toll of USAID Cuts on Africa”, ISS African Futures & Innovation Programme, 25 February 2025, see <https://futures.issafrica.org/blog/2025/The-toll-of-USAID-cuts-on-Africa>, accessed 9 June 2025.

¹²²⁶ - PowerChina, “Powerchina Launches Zambia’s Largest Single PV Project”, Power Construction Corporation of China, 27 May 2025, see https://en.powerchina.cn/2025-05/27/c_828949.htm, accessed 9 June 2025.

¹²²⁷ - Njenga Hakeenah, “Chinese Consortium Joins Botswana’s Renewable Energy Coterie”, *The China-Global South Project*, 22 August 2024, see <https://chinaglobalsouth.com/2024/08/22/chinese-consortium-joins-botswanas-renewable-energy-production-coterie/>, accessed 9 June 2025.

¹²²⁸ - SAFCEI, “New Report Catalogues Africa’s Nuclear Energy Misadventure”, Southern African Faith Communities’ Environment Institute, 12 June 2025, see <https://safcei.org/new-report-catalogues-africas-nuclear-energy-misadventure/>, accessed 27 July 2025.

grow the nuclear sector in Africa could mark increased cooperation and effectiveness of anti-nuclear civil movements on the continent.

Ghana

Ghana has long explored a move to nuclear energy and has, as a result, already established associated governance structures, institutions, and processes. It has a Nuclear Regulatory Authority,¹²²⁹ the Ghana Atomic Energy Commission with its Nuclear Power Institute,¹²³⁰ and a company, Nuclear Power Ghana, set up in 2018 to develop and operate the country's proposed first nuclear plant¹²³¹. It also runs a small research reactor.

It was announced in August 2022 that Ghana has officially decided to include nuclear energy in the planning for the future national electricity mix.¹²³² In September 2023, Nsuban, a coastal site, was designated as preferred location for the country's proposed first nuclear plant, along with an inland backup site at Obotan.¹²³³ In May 2024, it was reported that "16 countries and companies" had sought interest in contributing to a 1 GW nuclear plant, and that the list had been narrowed down to bidders from five countries: China, France, Russia, South Korea, and the U.S., with the Ghanaian authorities planning to make a decision on the successful bidder by December 2024, for the addition of 1 GW of nuclear power by 2034.¹²³⁴

The nature and outcome of this bidding process is unclear. None of the major nuclear builders have communicated on the issue. At the IAEA's General Conference in September 2024, Ghana stated it had "signed two Corporation Framework Agreements for a Small Modular Reactor (SMR) and a conventional large reactor. Successful negotiations with the two vendors will lead to the country potentially executing two projects concurrently."¹²³⁵

Some reports from March 2025 suggest that China had been identified as the preferred builder of the large plant, which would now have a capacity of 1.2 GW. At the same time a U.S.-Japanese SMR initiative led by NuScale Power and Regnum Technology Group would build twelve SMR modules of 77 MW each, totaling 924 MW.¹²³⁶

¹²²⁹ - Nuclear Regulatory Authority of Ghana, "Ghana's Nuclear Power Programme", 2024, see <https://nra.gov.gh/nuclear-power.php>, accessed 5 July 2024.

¹²³⁰ - Nuclear Power Institute, "About the Institute", Ghana Atomic Energy Commission, Undated, see <https://npi.gaec.gov.gh/about-the-institute/>, accessed 14 June 2025.

¹²³¹ - NPG, "About Us", Nuclear Power Ghana, 2024, see <https://nuclearpowergh.com/about-us/>, accessed 5 July 2024.

¹²³² - GNA, "President Akufo-Addo Approves Nuclear Technology in Ghana's Energy Mix", *Ghana News Agency*, 31 August 2022, see <https://gna.org.gh/2022/08/president-akufo-addo-approves-nuclear-technology-in-ghanas-energy-mix/>, accessed 4 August 2024.

¹²³³ - GNA, "Ghana Selects Nsuban, Obotan As Potential Sites for First Nuclear Plant", *Ghana News Agency*, 22 September 2023, see <https://www.ghanabusinessnews.com/2023/09/22/ghana-selects-nsuban-obotan-as-potential-sites-for-first-nuclear-plant/>, accessed 8 June 2025.

¹²³⁴ - Maxwell Akalaare Adombila, "French, Russia, Chinese Firms Vie to Build Ghana's First Nuclear Power Plant", *Reuters*, 21 May 2024, see <https://www.reuters.com/business/energy/french-russia-chinese-firms-vie-build-ghanas-first-nuclear-power-plant-2024-05-21/>, accessed 5 July 2024.

¹²³⁵ - Ophelia Mensah Hayford, "Statement of the Republic of Ghana", Minister for Environment, Science, Technology and Innovation, Government of Ghana, delivered at the 68th Regular Session of the IAEA, 16–20 September 2024, see <https://www.iaea.org/sites/default/files/24/09/ghana-gc68.pdf>, accessed 29 April 2025.

¹²³⁶ - GhanaWeb, "Ghana Selects US, China as Vendors for First Nuclear Plants", *GhanaWeb*, 29 March 2025, see <https://www.ghanaweb.com/GhanaHomePage/business/Ghana-selects-US-China-as-vendors-for-first-nuclear-plants-1977784>, accessed 8 June 2025.

Despite reports on such decisions, it is impossible to find official documentation, with the website of the designated operator of nuclear plants, Nuclear Power Ghana, silent on the issue.¹²³⁷ The same reports however state that no contracts have been signed ratifying such agreements—in-line with Ghana’s statement to the IAEA General Conference—neither have transactional details such as costs and funding been disclosed. Adding to the uncertainty, there seem to be conflicting views regarding the preferred mode of nuclear power, with some government officials actively promoting a floating nuclear plant.¹²³⁸

In February 2025, Ghana hosted an IAEA Site and External Events Design Review Service (SEED) mission to review the nuclear site selection process.¹²³⁹ This illustrates that the process of identifying the potential plant location is still in progress, and that any construction start is still some way off.

Kenya

While talk about establishing a nuclear plant in Kenya has been going on for decades, and the country had instituted supporting steps such as setting up an official Nuclear Power Energy Agency (NuPEA), there had been few concrete moves to steer such a project towards realization. Towards the end of 2024 there were still plans to initiate by 2027 the construction of a 1 GW plant adjacent to the Indian Ocean at Uyombo in Kilifi County.¹²⁴⁰ This in turn galvanized opposition from local communities, non-governmental organizations and parliamentary opposition.¹²⁴¹

In what would have been a far-reaching move, in January 2025 the Kenyan government announced its intention to dissolve NuPEA.¹²⁴² The motion did not specifically target NuPEA, as many other governmental organizations were equally affected. It also did not aim to shut down NuPEA’s functions, but rather to relocate them elsewhere in government.¹²⁴³ This is however a clear indication of uncertainty and instability in the organization responsible for managing all potential nuclear programs, and, although NuPEA continues to function for now, it is difficult to see any nuclear developments proceeding in this state of flux. Notably, in its budget the

1237 - NPG, “Nuclear Power Ghana—Homepage”, Nuclear Power Ghana, 2025, see <https://nuclearpowergh.com/>, accessed 8 June 2025.

1238 - Yunus Kemp, “Ghana: Why Floating Nuclear Energy Plants Could Be a Workable Fit”, *ESI-Africa*, 29 May 2025, see <https://www.esi-africa.com/industry-sectors/generation/ghana-why-floating-nuclear-energy-plants-could-be-a-workable-fit/>, accessed 8 June 2025.

1239 - IAEA, “IAEA Team Concludes Site and External Events Design Review for Ghana’s First Nuclear Power Plant”, Press Release 16/2025, 21 February 2025, see <https://www.iaea.org/newscenter/pressreleases/iaea-team-concludes-site-and-external-events-design-review-for-ghanas-first-nuclear-power-plant>, accessed 8 June 2025.

1240 - Darrell Proctor, “Kenya Moves Forward with Plans for Country’s First Nuclear Power Plant”, *POWER Magazine*, 25 November 2024, see <http://www.powermag.com/kenya-moves-forward-with-plans-for-countrys-first-nuclear-power-plant/>, accessed 7 June 2025.

1241 - Right Livelihood Foundation, “Kenya Halts Nuclear Projects After Campaign Led by Laureate Phyllis Omido”, Press Release, 24 January 2025, see <https://rightlivelihood.org/news/kenya-halts-nuclear-projects-after-campaign-led-by-laureate-phyllis-omid/>, accessed 7 June 2025.

1242 - Executive Office of the President of Kenya, “Despatch from Cabinet—Issue No.1 of 2025”, Press Release, 21 January 2025, see <https://www.president.go.ke/wp-content/uploads/Despatch-from-Cabinet-Issue-No.-1-of-2025-21.01.2025.pdf>, accessed 14 June 2025.

1243 - Ibidem; and Felix Kipkemoi, “Nupea CEO: Our Plan to Develop Nuclear Power Remains on Course”, *The Star*, 6 February 2025, see <https://www.the-star.co.ke/news/2025-02-06-nupea-ceo-our-plan-to-develop-nuclear-power-remains-on-course>, accessed 9 June 2025.

Kenyan government only allocated 743.8 million Kenyan shillings (about US\$5.7 million) to nuclear energy development for the 2025/2026 financial year.¹²⁴⁴

Should a nuclear newbuild project be initiated, China here too has been trying to position itself as the favored construction partner, and an intergovernmental Memorandum of Understanding strengthening its partnership with Kenya was signed in March 2025.¹²⁴⁵ The United States had also been actively pursuing nuclear development projects in Kenya in the second half of 2024, concluding a general nuclear cooperation agreement in August 2024.¹²⁴⁶ It remains to be seen whether and to what extent such initiatives will be pursued under the new U.S. administration.

Unlike Ghana and Nigeria, Kenya has made some progress in the past year in initiating renewable energy projects to help alleviate power scarcity, although these developments are still not happening on the scale required to achieve medium term energy security.¹²⁴⁷

Nigeria

For years, the Nigerian administration and various national institutions have strongly supported the idea of the implementation of a national nuclear power program. Nigeria had in prior years signed agreements on nuclear power development with South Korea, France, Russia, and India, and the Nigerian Nuclear Regulatory Authority (NNRA) signed cooperation agreements with nuclear regulators in the U.S., Pakistan, South Korea, and Russia.¹²⁴⁸ Preferred locations for nuclear builds have reportedly been identified at Geregu, for which some preliminary feasibility studies have reportedly been carried out,¹²⁴⁹ and Akwa Ibom, but no firm site decision and approvals appear to have been made.¹²⁵⁰ A currently suggested timeline for building a local nuclear can be viewed in a presentation made in late 2024 by an official of the Nigerian Atomic Energy Commission, which proposes the construction of a nuclear plant to commence in 2028/2029 with commissioning in 2034.¹²⁵¹

¹²⁴⁴ - Parliament of Kenya, “Education Sector Gets Lion’s Share of KSH 4.239 Trillion Budget as Treasury CS Unveils 2025/2026 Spending Plan in Parliament”, 13 June 2025, see <http://parliament.go.ke/node/24052>, accessed 14 June 2025.

¹²⁴⁵ - *bne IntelliNews*, “Kenya Signs Nuclear Energy Pact with Chinese Firm”, 21 March 2025, see <https://www.intellinews.com/kenya-signs-nuclear-energy-pact-with-chinese-firm-372850/>, accessed 9 June 2025; and State Department for Energy, “Kenya Signs MOU on Nuclear Power Collaboration with China”, Ministry of Energy and Petroleum of Kenya, 20 March 2025, see <https://www.energy.go.ke/kenya-signs-mou-nuclear-power-collaboration-china>, accessed 14 June 2025.

¹²⁴⁶ - *ESI Africa*, “Kenya-US to Sign Nuclear Energy Agreement”, 29 August 2024, see <https://www.esi-africa.com/industry-sectors/generation/kenya-us-to-sign-nuclear-energy-agreement/>, accessed 14 June 2025.

¹²⁴⁷ - Patrick Jowett, “Kenya Launches Tender for 80 MW of Solar”, *pV magazine International*, 5 March 2025, see <https://www.pv-magazine.com/2025/03/05/kenya-launches-tender-for-80-mw-of-solar/>, accessed 9 June 2025.

¹²⁴⁸ - WNN, “Nigeria Moving Ahead on Nuclear Power Plant Plan”, 18 March 2022, see <https://www.world-nuclear-news.org/Articles/Nigeria-moving-ahead-on-C2Aonuclear-power-plant-plan>, accessed 18 March 2022.

¹²⁴⁹ - NAEC, “Technical Meeting on Feasibility Studies and Site Specific Data Collection at Geregu/Dodo-Gbagi Nuclear Power Plant Site.”, Nigeria Atomic Energy Commission, 13 February 2025, see <https://nigatom.gov.ng/tm-on-feasibility-studies/>, accessed 14 June 2025.

¹²⁵⁰ - Nuclear Business Platform, “Nigeria’s Path to Nuclear Energy: Advancing Infrastructure, Partnerships, and Power Goals”, 4 December 2024, see <https://www.nuclearbusiness-platform.com/media/insights/nigerias-path-to-nuclear-energy-advancing-infrastructure-partnerships-and-power-goals>, accessed 9 June 2025.

¹²⁵¹ - Awwal Bisallah, “Progress in Nigeria’s Nuclear Energy Programme”, Deputy Director and Head, International Cooperation and Liaison Department, Nigeria Atomic Energy Commission, as presented at 23rd International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) Dialogue Forum on Nuclear Energy Innovations to Support Net-Zero Transition, IAEA, 30 November 2024, see <https://nucleus.iaea.org/sites/INPRO/df23/day2-MS/Nigeria.pdf>, accessed 14 June 2025.

As reported in **WNISR2024**, Chinese nuclear developers are now active in Nigeria, having opened a regional office in Lagos.¹²⁵² During a state visit to China in September 2024, Nigerian President Bola Tinubu signed a series of bilateral cooperation agreements, including cooperation in nuclear power developments.¹²⁵³

In recent years projections for nuclear builds suggested a setup akin to the Akkuyu and El Dabaa projects, i.e. four units of 1200 MW each. Such a configuration is however not supported by the current Power Minister, who instead favored nuclear power generation using SMRs.¹²⁵⁴

Despite the pronounced ambitions to soon develop nuclear plants and activities suggesting work on this is well under way, it is telling that the 2024 Nigeria Integrated Resource Plan, the country's official roadmap for electricity generation, has not included any nuclear power in its projections leading all the way to 2045.¹²⁵⁵

There is therefore no indication that Nigeria has in the last year moved any closer to initiating a nuclear power program.

Uganda

WNISR2024 reported on Uganda's vague and unrealistic ambitions to develop 24 GW of nuclear power. This target was reaffirmed in 2025, which is being viewed as a major contributor to an aimed-for total generation capacity of about 52.5 GW by 2040,¹²⁵⁶ which in turn corresponds to over 25 times the country's mid-2024 grid generating capacity of 2 GW.¹²⁵⁷ In line with the proposed first step of building a 1-GW unit of an eventually envisaged 8.4-GW nuclear plant at Buyende, the Ugandan government in May 2025 concluded a contract with Korean Hydro and Nuclear Power (KHNP), where this entity, with Dohwa Engineering and KEPCO E&C, would "undertake pre-feasibility or site evaluation studies" over 26 months, only after which a full feasibility study and resettlement plan would commence.¹²⁵⁸ This schedule alone casts major

¹²⁵² - NAEC, "NAEC and CNNC Seek Collaboration on Nuclear Science and Technology", Nigeria Atomic Energy Commission, October 2023, see <https://nigatom.gov.ng/naec-and-cnnc-seek-collaboration/>, accessed 18 August 2024; and CNNC, "Africa", Updated 29 September 2024, see https://en.cnncc.com.cn/2024-09/29/c_1035462.htm, accessed 14 June 2025.

¹²⁵³ - Presidency of Nigeria, "President Tinubu Meets Chinese President Xi Jinping; Nigeria and China Elevate Ties to Comprehensive Strategic Partnership", Press Release, The Statehouse, 3 September 2024, see <https://statehouse.gov.ng/news/president-bola-tinubu-meets-chinese-president-xi-jinping-nigeria-and-china-elevate-ties-to-comprehensive-strategic-partnership/>, accessed 14 June 2025.

¹²⁵⁴ - Goddy Ikeh, "Nigeria's Power Minister Rejects Plans to Construct Nuclear Power Plants", *African Press Agency*, 8 May 2025, see <https://apanews.net/nigerias-power-minister-rejects-plans-to-construct-nuclear-power-plants/>; and Waliat Musa, "Concerns, Doubts Trail Nigeria's Nuclear Energy Ambition", *The Guardian*, 14 May 2025, see <https://guardian.ng/energy/concerns-doubts-trail-nigerias-nuclear-energy-ambition/>; both accessed 8 June 2025.

¹²⁵⁵ - Federal Ministry of Power, "Nigeria Integrated Resource Plan (NIRP 2024)", Government of Nigeria, May 2025, see <http://power.gov.ng/download/nigeria-integrated-resource-plan-nirp-2024/>, accessed 14 June 2025.

¹²⁵⁶ - Julius Barigaba, "Uganda Sets 2031 Target for Nuclear Energy", *The EastAfrican*, 3 May 2025, see <https://www.theeastafrikan.co.ke/tea/business-tech/uganda-sets-2031-target-for-nuclear-energy-5062240>, accessed 4 June 2025.

¹²⁵⁷ - ERA, "Trend of Uganda's Installed Capacity", Electricity Regulatory Authority, 21 July 2025, see <https://www.era.go.ug/installed-capacity/>, accessed 21 July 2025.

¹²⁵⁸ - Julius Barigaba, "Uganda Sets 2031 Target for Nuclear Energy", *The EastAfrican*, 3 May 2025, see <https://www.theeastafrikan.co.ke/tea/business-tech/uganda-sets-2031-target-for-nuclear-energy-5062240>, accessed 4 June 2025; and GovInfoHub, "Uganda Moves Closer to Nuclear Energy as Buyende Plant Site Gets Contractor", Uganda Printing and Publishing Corporation, 4 June 2025, see <https://govinfohub.go.ug/index.php/2025/06/04/uganda-moves-closer-to-nuclear-energy-as-buyende-plant-site-gets-contractor/>, accessed 15 June 2025.

doubt on the declared aim expressed by the responsible Ugandan Minister to have the first 1 GW unit at Buyende operational by 2031.¹²⁵⁹

CASE STUDIES ITALY AND POLAND

Italy



Italy was one of the very early adopters of nuclear power and started building its first reactor, the 153-MW Gas Graphite Reactor at Latina, in 1958. It was commissioned in 1963 and was closed in November 1986. The last of four and largest unit to be commissioned in the country—the 860-MW BWR at Caorso—started building in 1970, was connected to the grid in 1978, and closed in October 1986. The 260-MW PWR Enrico Fermi (or Trino) was the last nuclear reactor to generate power in the country. It was first connected to the grid in 1964 and closed in March 1987.

The nation was deeply shocked about the Chornobyl disaster in April 1986 that also led to significant levels of contamination in Italy with parts of the harvest being destroyed. A national referendum in November 1987 led to the termination of Italy's nuclear program.

When the Chornobyl disaster began, besides the four operating units, three additional reactors were under construction: the two 982-MW BWRs Montalto Di Castro-1 and -2 and the 35-MW prototype Heavy-Water Light Water-Cooled Cirene reactor. Their construction was abandoned following the 1987 referendum.

A second national referendum was held in June 2011, only three months after the Fukushima disaster started unfolding. Then-President Berlusconi had planned to reintroduce nuclear power and had passed legislation to allow for nuclear newbuild, but 94 percent of Italian voters rejected the law.¹²⁶⁰

Decommissioning

Since the late 1990s, decommissioning at all four facilities has been underway and is in various stages with the final goal of brownfield release (i.e., completed decommissioning but wastes or other materials still onsite). The work is being conducted by Italian company Società Gestione Impianti Nucleari SpA (Sogin), which in 2024, 37 years after the last nuclear power generation, signed a collaboration agreement with the European Commission's Joint Research Center "to implement and develop a common nuclear dismantling and radioactive waste management strategy."¹²⁶¹

¹²⁵⁹ - Ibidem; and Philip Wafula, "Buyende Nuclear Power Plant to Generate Initial 1,000MW by 2031 – Energy Minister", *Monitor*, 28 May 2025, see <https://www.monitor.co.ug/uganda/news/national/buyende-nuclear-power-plant-to-generate-initial-1-000mw-by-2031--5060254>, accessed 21 July 2025.

¹²⁶⁰ - Ministry of the Interior, "Referendum del 12 e 13 giugno 2011", Government of Italy, via Wayback Machine, archived 28 September 2011, see <https://web.archive.org/web/20110928052803/http://referendum.interno.it/RFO00.htm>, accessed 11 August 2025.

¹²⁶¹ - Sogin, "Sogin and JRC Sign a Nuclear Decommissioning Agreement", Società Gestione Impianti Nucleari SpA, 18 January 2024, see <https://www.sogin.it/en/media/news/Sogin-and-JRC-sign-a-nuclear-decommissioning-agreement.html>, accessed 19 August 2024.

Decommissioning of the smallest reactor operated in Italy—the 150-MW BWR Garigliano—is underway, but when reactor dismantling is to be completed is unclear, as the Italian project website claims a target year of 2031,¹²⁶² while the English language site claims the year 2025.¹²⁶³ At the Enrico Fermi plant, decommissioning work has been ongoing since 1999. There has been no official update on progress since WNISR2021, but according to a news report from February 2024, reactor internals dismantling has now begun, and the completion date has been postponed to 2036.¹²⁶⁴

At Italy's largest reactor, the 860-MW BWR Caorso, decommissioning began in 1999, but the dismantling of the reactor building's external components only began in November 2024 with internal dismantling expected to begin in 2026 and to be completed by 2030.¹²⁶⁵ The release of the site as brownfield is expected for 2031.¹²⁶⁶ See [section on Italy](#) in [Decommissioning Status Report](#) and [previous WNISR editions](#) for more details on decommissioning.

Italy is also in the process of finding a final waste repository, with radioactive waste currently being stored at ten interim storage facilities spread across the country. A map of potential locations for the final repository was released in 2022.¹²⁶⁷

New Program-Restart Initiatives

Italy's National Energy and Climate Plan (NECP) as published in July 2024 contains the term “nuclear” 110 times, which is surprising for a country that abandoned nuclear power almost 40 years ago. The report sees,

great potential to develop new nuclear technologies for Italy to help revitalise nuclear energy, not only at international level but potentially at national level.

It states that,

the recovery in Italian territory of the production of energy from nuclear sources could play an important role [in the reduction of greenhouse gas emissions].

Furthermore, it informs that the government has set up a National Platform for Sustainable Nuclear (PNNS) and notes that

¹²⁶² - Sogin, “Smantellamento del reattore”, Centrale del Garigliano, Undated, see <https://www.sogin.it/it/chiusuradelciclonucleare/sitinucleariitaliani/centraledigarigliano/progettidedecommissioning/smantellamento-del-reattore.html>, accessed 6 May 2025 and 22 July 2025.

¹²⁶³ - Sogin, “Garigliano Nuclear Power Plant—Decommissioning Projects—Reactor dismantling”, Undated, see <https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/gariglianonuclearpowerplant/decommissioningprojects/reactor-dismantling.html>, accessed 23 June 2023 and 22 July 2025.

¹²⁶⁴ - Vanni Caratto, “Decommissioning nucleare, a Trino si è arrivati allo ‘smontaggio’ del reattore”, *Radiotelevisione Italiana*, 23 February 2024, see <https://www.rainews.it/tgr/piemonte/video/2024/02/viaggio-nella-centrale-di-trino-ca4c9555-f619-42a2-b9b5-a305146516b.html>, accessed 16 May 2024.

¹²⁶⁵ - Sogin, “Smantellamento edificio reattore”, Undated (in Italian), see <https://www.sogin.it/it/chiusuradelciclonucleare/sitinucleariitaliani/centraledicaorso/progettidedecommissioning/Pagine/Smantellamento-edificio-reattore.aspx#>, accessed 16 May 2024.

¹²⁶⁶ - Sogin, “Caorso Nuclear Power Plant”, Undated, see <https://sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/caorsonuclearpowerplant/Pagine/default.aspx>, accessed 16 May 2024.

¹²⁶⁷ - Maria Rosaria Di Nucci and Andrea Prontera, “Nuclear Waste Governance in Italy: Between Participation Rhetoric and Regionalism”, in Maarten Arentsen and Rinie Van Est, “The Future of Radioactive Waste Governance”, Springer Fachmedien Wiesbaden, 2023, pp. 51–83, see https://link.springer.com/10.1007/978-3-658-40496-3_3, accessed 23 June 2023.

in 2050, in the “With nuclear” scenario, nuclear production covers around 11 % of the electricity demand. In addition to meeting increased demand, nuclear reduces the need for both CCS [Carbon Capture and Storage] natural gas generation from 11.5 to 4 TWh and bioenergy production with CCS from 12.5 to 6 TWh.¹²⁶⁸

This scenario projects 8 GW of nuclear capacity operating by 2050, an ambitious goal, but it estimates feasibility at double that amount, i.e., 16 GW of nuclear newbuild. While Italian companies have contributed to the construction of nuclear power plants in various countries,¹²⁶⁹ the last time they started building a nuclear reactor at home that eventually generated power was nearly 55 years ago. Thus, Italy is a true—potential—newcomer country.

In July 2024, Électricité de France (EDF) signed a non-binding MoU with four Italian companies, Edison, Ansaldo Energia, Ansaldo Nucleare, and Federacciai, “aimed at promoting cooperation in the use of nuclear energy to boost the competitiveness and decarbonisation of the Italian steel industry.” The agreement further prudently states that the signatories would “undertake to consider co-investment opportunities in new nuclear energy and, in particular, in the construction of Small Modular Reactors in Italy over the upcoming decade.”¹²⁷⁰

A number of Italian startups are also involved in nuclear development. One example is Terra Innovatum, a company founded in 2021 that promotes a helium-cooled, graphite/beryllium-moderated design called SOLO, “from 1 MW to 1 GW”, and presents it as “The World’s First Micro Modular Nuclear Reactor commercially deployable anywhere globally within the next three years.”¹²⁷¹ In an April 2025 investor presentation, the company claimed to have “completed” the design in October 2024, but the design has not yet gone beyond pre-pre-licensing steps in the U.S., where Terra Innovatum in January 2025 filed a Regulatory Engagement Plan for a non-power reactor license application.¹²⁷² In the 13-page document, the company states its intention to apply for “a Construction Permit (CP) of the FOAK [First Of A Kind] Research Test Reactor (RTR) facility to be deployed on a site yet-to-be-determined in the US territory.”¹²⁷³ The company has “2–10 employees”, according to its LinkedIn page.¹²⁷⁴

¹²⁶⁸ - Ministry of the Environment and Energy Security, “National Plan Integrated for Energy and Climate”, Government of Italy, June 2024, see https://commission.europa.eu/document/download/5ef1819e-1c42-446f-91do-abb9cf7719e8_en?filename=IT_FINAL%20UPDATED%20NECP%202021-2030%20%28English%29_o.pdf, accessed 11 July 2024.

¹²⁶⁹ - Most notably ENEL was previously involved in the construction of the notorious Soviet-designed Slovakian Mochovce Units 3 and 4, that originally started building in 1985, to be completed by a Czech-led consortium, with Unit 4 still not operating. Two Italian managers are still under police investigation and are “facing charges of the crime of breach of duty in the management of another’s property committed in the form of complicity, preparatory proceedings are underway and procedural actions are still being carried out,” according to Roman Hajek, spokesperson for the Presidium of the Police Force in Slovakia; see SITA, “Investigation Not Over at Slovenske Elektrarne, Italian Managers Still Not Brought to Justice”, *Slovenska Tlacova Agentura*, 13 August 2025.

¹²⁷⁰ - EDF, “EDF, Edison, Federacciai, Ansaldo Energia and Ansaldo Nucleare Signed a Memorandum of Understanding for the Use of Nuclear Energy to Boost the Competitiveness and Decarbonisation of the Italian Steel Industry”, Press Release, 23 July 2024, see <https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-edison-federacciai-ansaldo-energia-and-ansaldo-nucleare-signed-a-memorandum-of-understanding-for-the-use-of-nuclear-energy-to-boost-the-competitiveness-and-decarbonisation-of-the-italian>, accessed 13 August 2024.

¹²⁷¹ - Terra Innovatum, Homepage, Undated, see <https://www.terrainnovatum.com/>, accessed 20 August 2025.

¹²⁷² - GSR III Acquisition Corp and Terra Innovatum, “Investor Presentation April 2025”, April 2025, see https://www.x-solo.com/_files/ugd/be748d_85bc146c663a4c3285fa73aao5d58453.pdf, accessed 19 May 2025.

¹²⁷³ - Terra Innovatum, “Regulatory Engagement Plan for Submittal and Approval of an Application to Construct SOLO Micro Modular Nuclear Reactor”, 17 January 2025, see <https://www.nrc.gov/docs/ML2501/ML25017A401.pdf>, accessed 20 August 2025.

¹²⁷⁴ - Terra Innovatum, Profile, LinkedIn, see <https://www.linkedin.com/company/terra-innovatum-solo>, accessed 12 August 2025.

Political, Legal, Industrial Steps and Comments

In December 2024, the 100% Renewables Network published a 12-page Nuclear Cost Report that concluded that “Nuclear would make electricity more expensive. This is much more expensive than renewable sources. And the ‘small’ ‘Small Modular Reactor’ reactors are even more expensive.”¹²⁷⁵

On 28 February 2025, the Italian government nevertheless approved a draft delegation law on “sustainable nuclear energy”. The draft law demands “a clear break with respect to the nuclear plants of the past” and advocates for the “use of the best available technologies, including modular and advanced technologies.”¹²⁷⁶

On 14 May 2025, the three companies Enel, Ansaldo Energia, and Leonardo established Nuclitalia, which “will be in charge of studying advanced technologies and analyzing market opportunities in the new nuclear sector” and “assessing the most innovative and mature designs of new sustainable nuclear power, with an initial focus on water-cooled Small Modular Reactors (SMRs).” Enel holds 51 percent of the capital, Ansaldo Energia 39 percent, and Leonardo 10 percent. All three companies are “under the common control of Italy’s Ministry of Economy and Finance.”¹²⁷⁷

The establishment of the Eagles Consortium was announced on 16 June 2025. Italy’s Ansaldo Nucleare and ENEA got together with Romania’s RATEN and Belgium’s SCK CEN “to design and commercialize Lead-Cooled IV Generation Small Modular Reactor” and is committed to start up “its first demonstrator by 2035”. The reactor would have “around 350MWe power” and use uranium-plutonium fuel.¹²⁷⁸

Specialized trade platform *Montel* so far sees that “Italy is taking small steps toward reviving its long-abandoned nuclear sector, with political support growing but lingering public resistance, high costs, and policy uncertainty still clouding its return.”¹²⁷⁹

In May 2025, the daily *il Fatto Quotidiano* published a blog piece that stated:

The only way to manage diversity in the majority is a frenzied centralization of decisions in the hands of the prime minister. An example of this is the way Italy is dealing with the relaunch of nuclear power; journalists and complacent “experts” repeat Pichetto Fratin and Georgia Meloni’s statements without any comparison on the merit and consequences

¹²⁷⁵ - Kyoto Club, “La coalizione 100% Rinnovabili Network presenta il report sui costi del nucleare”, 10 December 2024, see <https://www.kyotoclub.org/it/media-e-documenti/comunicati/2024/12/10/la-coalizione-100-rinnovabili-network-presenta-il-report-sui-costi-del-nucleare/>, accessed 13 August 2025.

¹²⁷⁶ - Council of Ministers, “Comunicato stampa del Consiglio dei Ministri n. 116”, Press Release, Government of Italy, 28 February 2025, see <https://www.governo.it/it/articolo/comunicato-stampa-del-consiglio-dei-ministri-n-116/27778>, accessed 23 April 2025.

¹²⁷⁷ - Enel, “Nuclitalia Has Been Created: Enel, Ansaldo Energia and Leonardo Join Forces on Research on Nuclear Power”, Press Release, 14 May 2025, see <https://www.enel.com/media/explore/search-press-releases/press/2025/05/nuclitalia-has-been-created-enel-ansaldo-energia-and-leonardo-join-forces-on-research-on-nuclear-power->, accessed 20 May 2025.

¹²⁷⁸ - Ansaldo Energia, “Leading Nuclear European Organizations Unite to Develop EAGLES-300, Next-Generation Lead-Cooled Small Modular Reactor (SMR)”, Press Release, 16 June 2025, see <https://www.ansaldoenergia.com/about-us/media-center/power-generation-news-insights/detail-news/leading-nuclear-european-organizations-unite-to-develop-eagles-300-next-generation-lead-cooled-small-modular-reactor-smr>, accessed 23 June 2025.

¹²⁷⁹ - Beatrice Bedeschi, “Italy Warms to Nuclear, but Revival Still Fragile”, *Montel*, 27 May 2025.

that the atomic fission processes will impose on the country's energy, economic, social and environmental balances, exposing future generations to risk.¹²⁸⁰

A June 2025 assessment by the Bank of Italy concludes:

The analysis shows that, given the structure of the market and the electricity bill, reintroducing nuclear power would not have a significant impact on price levels. (...) In terms of energy dependence, the reduction in hydrocarbon imports would be offset by increased imports of technology and fuel for nuclear production, which are currently concentrated in countries that are not particularly close to Italy in geopolitical terms. (...) Another important element that emerges from the analysis is the uncertainty surrounding the technologies chosen, most of which are not yet available for commercialization. This uncertainty calls for a cautious approach that also prepares and promotes alternative strategies.¹²⁸¹

Il Fatto Quotidiano commented on the Bank of Italy's analysis by saying it “dismantles the pro-nuclear rhetoric”.¹²⁸²

Electricity Mix

Electricity consumption has been relatively stable over the past 25 years, peaking in 2008 at 352 TWh and dropping to 315 TWh in 2024. Italy has constantly increased electricity imports since 2008 when net imports were just 3 TWh to 51 TWh in 2024.

In 2007, fossil fuels provided 84.4 percent of the domestic electricity generation and renewables 15.6 percent. In 2024, fossil fuels were down to 50.7 percent, of which 44 percent was natural gas, and renewables had more than tripled to 49.3 percent, of which hydro contributed 19.3 percent, solar 13.5 percent, wind 8.4 percent, and bioenergy 6 percent.¹²⁸³

Poland

WNISR2024 featured a focus section dedicated to Polish nuclear ambitions. It covered various past implementation attempts and detailed how plans evolved. From the 2018-draft Energy Policy of Poland until 2040 to the latest Polish Nuclear Power Program released for public consultation in 2025, the extended target of deploying 6–9 GW of nuclear capacity has been the official policy of successive administrations in recent years.

As depicted in WNISR2024, ongoing and tracked activities can be divided into three areas:

- ➔ Construction of three large reactors at the Lubiatowo-Kopalino site in the Choczewo municipality in Pomerania, a project that was awarded to U.S.-based Westinghouse (as

¹²⁸⁰ - Mario Agostinelli and Alfiero Grandi, “Nucleare, Meloni e Pichetto Fratin centralizzano le decisioni. Risultato: ritardi e scelte sbagliate”, Blog, *Il Fatto Quotidiano*, 22 May 2025, see <https://www.ilfattoquotidiano.it/2025/05/22/nucleare-meloni-pichetto-fratin-ritardi/7998306/>, accessed 22 May 2025.

¹²⁸¹ - Luciano Lavecchia and Alessandra Pasquini, “L’atomo fuggente: analisi di un possibile ritorno al nucleare in Italia”, Banca d’Italia, Questioni di Economia e Finanza, No. 947, June 2025, see https://www.bancaditalia.it/pubblicazioni/qef/2025-0947/QEF_947_25.pdf, accessed 22 July 2025.

¹²⁸² - Nicola Borzi, “Nucleare, Banca d’Italia stronca i sogni di Meloni”, *Il Fatto Quotidiano*, 28 June 2025.

¹²⁸³ - All numbers from EMBER, “Electricity Data Explorer”, 2025, see <https://ember-energy.org/data/electricity-data-explorer>, accessed 19 August 2025.

design provider of the AP-1000) following a tender which also included France's Électricité de France (EDF) and South Korea's Korea Hydro & Nuclear Power (KHNP).

- ➔ Construction of two APR-1400 reactors, a vague project, to be implemented by KHNP at a site yet to be determined.
- ➔ Various private sector driven initiatives based on Small Modular Reactors (SMRs), e.g. the BWRX-300 by ORLEN Synthos Green Energy (OSGE) with GE-Hitachi and projects by NuScale and Last Energy.

The Pomeranian Project (Lubiatowo-Kopalino)

Westinghouse was formally appointed in November 2022 as the technology vendor of three large reactors for the Pomeranian project at a price of around US\$20 billion.¹²⁸⁴ Westinghouse and the Polish state-owned project company, Polskie Elektrownie Jądrowe (PEJ),¹²⁸⁵ signed a cooperation agreement in December 2022.¹²⁸⁶ The companies further advanced the agreement in February 2023 by signing a contract covering front-end engineering, early procurement work, and program development.¹²⁸⁷ In July 2023, the Ministry of Climate granted a “decision-in-principle” on the project allowing for further administrative applications to proceed.¹²⁸⁸ In September 2023, PEJ and the newly formed consortium Westinghouse-Bechtel¹²⁸⁹ signed an 18-month Engineering Services Contract (ESC) that was to provide, by the end of the period, the design documentation for the first nuclear plant in Poland.¹²⁹⁰ This ESC expired in March 2025 but was replaced by an Engineering Development Agreement (EDA) between the three partners signed in late April 2025 to allow continuation of the project.¹²⁹¹

¹²⁸⁴ - Alan Charlish, Anna Włodarczyk-Semczuk, Anna Koper and Marek Strzelecki, “Poland’s First Nuclear Power Plant to Cost Around \$20 Bln - PM”, *Reuters*, 2 November 2022, see <https://www.reuters.com/business/energy/polands-first-nuclear-power-station-cost-around-20-bln-says-pm-2022-11-02/>; and Prime Minister’s Office, “Uchwała w sprawie budowy wielkoskalowych elektrowni jądrowych w Rzeczypospolitej Polskiej”, Press Release, Government of Poland, 2 November 2022, see <https://www.gov.pl/web/premier/uchwala-w-sprawie-budowy-wielkoskalowych-elektrowni-jadrowych-w-rzeczypospolitej-polskiej>; both accessed 1 August 2023.

¹²⁸⁵ - PEJ, “Key information”, Polskie Elektrownie Jądrowe, Undated, see <https://pej.pl/en/the-project/key-information/>, accessed 10 July 2025.

¹²⁸⁶ - PEJ, “Polskie Elektrownie Jądrowe and Westinghouse Electric Company Have Signed an Agreement Defining Principles of Cooperation in the Preparation of the Construction Process of the First Nuclear Power Plant in Poland”, 15 December 2022, see <https://ppej.pl/en/news/polskie-elektrownie-jadrowe-and-westinghouse-electric-company-have-signed-an-agreement-defining-principles-of-cooperation-in-the-preparation-of-the>, accessed 10 June 2024.

¹²⁸⁷ - Westinghouse, “Westinghouse and Polskie Elektrownie Jądrowe Advance Poland’s Nuclear Energy Program with Contract Signing”, Press Release, 22 February 2023, see <https://info.westinghousenuclear.com/news/wec-pej-poland-contract-signing>, accessed 1 August 2023.

¹²⁸⁸ - PEJ, “The Polskie Elektrownie Jądrowe Company with a Decision-In-Principle for the First Nuclear Power Plant in Poland”, Press Release, 12 July 2023.

¹²⁸⁹ - Westinghouse, “Westinghouse and Bechtel Sign Consortium Agreement for First Nuclear Power Plant in Poland”, Press Release, 21 September 2023, see <https://info.westinghousenuclear.com/news/westinghouse-and-bechtel-sign-consortium-agreement-for-first-nuclear-power-plant-in-poland>, accessed 18 July 2025.

¹²⁹⁰ - Westinghouse, “Historic Contract Paves the Way for Site Work on Poland’s First Nuclear Power Plant”, Press Release, 27 September 2023, see <https://info.westinghousenuclear.com/news/historic-contract-paves-the-way-for-site-work-on-polands-first-nuclear-power-plant>, accessed 19 January 2024.

¹²⁹¹ - PEJ, “We Have Agreed on the Terms and Conditions of the Engineering Development Agreement (EDA)”, Press Release, 1 April 2025, see <https://pej.pl/en/press-center/news/we-have-agreed-on-the-terms-and-conditions-of-the-engineering-development-agreement-eda/>, accessed 10 June 2025; and Westinghouse, “Poland’s First Nuclear Plant Moves Forward with Westinghouse-Bechtel, PEJ Agreement”, Press Release, 30 April 2025, see <https://info.westinghousenuclear.com/news/polands-first-nuclear-plant-moves-forward-with-westinghouse-bechtel-pej-agreement>, accessed 1 May 2025.

A few months prior to the EDA's signing, new delays in the project were confirmed. While the start of construction work was scheduled for 2026 and electricity generation for 2033,¹²⁹² in December 2024 a three-year delay was announced.¹²⁹³ According to the Secretary of State for Strategic Energy Infrastructure, Wojciech Wrochna, pouring of first concrete was then scheduled for 2028 and connection to the grid of the first unit in 2036, with the second and third unit to follow in 2037 and 2038.¹²⁹⁴

Just after the ESC was signed, general elections in Poland resulted in a leadership change that brought a center-right government under Donald Tusk, who had already been Polish Prime Minister from 2007 to 2014, into office in December 2023.¹²⁹⁵ While clearly in favor of nuclear power, prior to the election Tusk reportedly agreed that the Polish nuclear power construction plan was “not based on a robust economic analysis and lack[ed] a business plan.”¹²⁹⁶ The new administration prompted an investigation into whether the target of first nuclear operations by 2033 was realistic. Incoming Climate and Environment Minister Paulina Hennig-Kloska said in February 2024 that the government doubted the ambitious target was achievable given the substantial delays and uncertainties.¹²⁹⁷ Industry Minister Marzena Czarnecka stated in a radio interview in May 2024 that the earliest completion date of the Pomeranian project would be in 2039 or 2040.¹²⁹⁸ After concerns were raised that the delay could lead to “an energy disaster”, Czarnecka clarified her statement saying that the target date of 2039 or 2040 referred to the whole plant's completion and that the first reactor was to come online by 2035 with construction start in 2028.¹²⁹⁹ As stated above, six months later, in December 2024, Wrochna reported another slightly different schedule with pouring of first concrete in 2028 and connection to the grid of the three units in the years 2036, 2037, and 2038.

In April 2024, PEJ's then-authorized representative Jan Chadam said that the project's final cost was still not confirmed and gave an indicative figure of PLN150 billion (~US\$₂₀₂₄ 38 billion),¹³⁰⁰

¹²⁹² - Sonal Patel, “Westinghouse, Bechtel Form Consortium to Design and Build Poland's First Nuclear Plant”, *POWER Magazine*, 25 May 2023, see <https://www.powermag.com/westinghouse-bechtel-form-consortium-to-design-and-build-polands-first-nuclear-plant/>, accessed 6 June 2023.

¹²⁹³ - Kamen Kraev, “Poland / New Schedule Sees Three-Year Delay For First Nuclear Power Plant”, *NucNet*, 12 December 2024, see <https://www.nucnet.org/news/new-schedule-sees-three-year-delay-for-first-nuclear-power-plant-12-4-2024>, accessed 16 December 2024.

¹²⁹⁴ - Ibidem; and Ministry of Industry, “Wiceminister Przemysłu i Pełnomocnik Rządu ds. Strategicznej Infrastruktury Energetycznej Wojciech Wrochna o aktualizacji PPEJ na spotkaniu prasowym”, Government of Poland, 12 December 2024, see <https://www.gov.pl/web/przemysl/wiceminister-przemyslu-i-pelnomocnik-rzadu-ds-strategicznej-infrastruktury-energetycznej-wojciech-wrochna-o-aktualizacji-ppej-na-spotkaniu-prasowym>, accessed 18 July 2025.

¹²⁹⁵ - Andrew Higgins, “Who Is Donald Tusk, the Man Who Retook Power From Poland's Right-Wing Leaders?”, *The New York Times*, 12 December 2023, see <https://www.nytimes.com/2023/12/12/world/europe/donald-tusk-poland-prime-minister.html>, accessed 31 May 2024.

¹²⁹⁶ - Grzegorz Adamczyk, “Polish Opposition Wants to Potentially Withdraw from Polish-US Nuclear Power Deal if it Comes to Power”, *Remix News*, 4 October 2023, see <https://rmx.news/poland/polish-opposition-wants-to-potentially-withdraw-from-polish-us-nuclear-power-deal-if-it-comes-to-power/>, accessed 31 May 2024.

¹²⁹⁷ - Marek Strzelecki, “Poland Analyzes if Nuclear Plant Will Be Ready by 2033 Amid Delays”, *Reuters*, 13 February 2024, see <https://www.reuters.com/business/energy/poland-analyzes-if-nuclear-plant-will-be-ready-by-2033-amid-delays-2024-02-13/>, accessed 14 May 2024.

¹²⁹⁸ - Grzegorz Adamczyk, “Polish Industry Minister Announces Massive Delay in Nuclear Power Plant Project”, *Remix News*, 9 May 2024, see <https://rmx.news/article/polish-industry-minister-announces-massive-delay-in-nuclear-power-plant-project/>, accessed 30 May 2024.

¹²⁹⁹ - Ibidem.

¹³⁰⁰ - Polska Agencja Prasowa, “Poland's First Nuclear Plant to Cost Approx. PLN 150 bln”, 18 April 2024, see <https://biznes.pap.pl/en/news/all/info/3578950,poland-s-first-nuclear-plant-to-cost-approx--pln-150-bln>, accessed 30 May 2024.

but by the end of 2024 new estimates of “total investment costs” ranged around PLN192 billion (US\$₂₀₂₄48.2 billion),¹³⁰¹ more than double the estimates of November 2022¹³⁰².

It should be noted that in recent projects Westinghouse refrained from taking on construction as the liable builder-company. In early June 2024, the *Wall Street Journal* reported: “Westinghouse said it learned from its U.S. experience during the 2010s and no longer takes on reactor construction...In Ukraine, Westinghouse said Energoatom will be responsible for construction of the new reactors...”¹³⁰³ In Bulgaria, South Korean company Hyundai is the main contractor, and Westinghouse is providing technology and engineering. In Poland, Westinghouse has partnered up with U.S. construction giant Bechtel and the Polish state-owned PEJ.

Regarding the financing package, President Andrzej Duda signed a bill committing PLN60.2 billion (US\$16 billion) from the state budget for 2025–2030 to cover 30 percent of the project’s estimated costs.¹³⁰⁴ Additionally, the proposed state support mechanism includes state guarantees covering 100 percent of the debt taken by PEJ on the project and a two-way Contract for Difference (CfD) guaranteeing revenue stability over the entire 60-year projected lifetime of the plant. The bill was signed in March 2025.¹³⁰⁵ The proposal led to the opening of an in-depth investigation by the European Commission in relation to:¹³⁰⁶

- ➔ The **appropriateness** and **proportionality** of the aid package. Given there are three different aid measures (equity, guarantees, two-way CfD) that together limit the risk for the beneficiary, it is important to ensure that overall no more aid than what is strictly necessary is ultimately granted. In particular, the Commission will examine further (i) whether the 60-year duration of the CfD is justified taking into account the other two measures, and (ii) whether there could have been other companies interested in leading the project which might have resulted in a smaller aid amount.
- ➔ The **impact of the aid package on competition in the electricity market** and whether this is kept to the minimum. The Commission will investigate whether the design of the two-way CfD sufficiently incentivises the power plant to operate and participate efficiently in the electricity markets, within its technical capacity. This is important to minimise market distortions, facilitate the integration of renewables, and allow the electricity system to move towards decarbonisation. In particular, the power plant should plan its maintenance and refuelling in an optimal way and adapt its power production to market prices. In addition, the Commission cannot exclude that the aid will not be passed-on to electricity consumers through direct contracts.

¹³⁰¹ - European Commission, “Commission Opens in-Depth State Aid Investigation into Polish Support for Nuclear Power Plant”, Press Release, 18 December 2024, see https://ec.europa.eu/commission/presscorner/detail/en/ip_24_6437, accessed 10 July 2025.

¹³⁰² - Reuters, “Poland’s First Nuclear Power Plant to Cost Around \$20 Bln - PM”, 2 November 2022, op. cit.

¹³⁰³ - Kim Mackrael, James Marson, Nikita Nikolaenko and Jennifer Hiller, “The American Company Trying to Keep Ukraine’s Nuclear Reactors Online”, *The Wall Street Journal*, 7 June 2024, see <https://www.wsj.com/world/the-american-company-trying-to-keep-ukraines-nuclear-reactors-online-e636917a>, accessed 8 June 2024.

¹³⁰⁴ - Government of Poland, “Ustawa z dnia 20 lutego 2025 r. o zmianie ustawy o przygotowaniu i realizacji inwestycji w zakresie obiektów energetyki jądrowej oraz inwestycji towarzyszących oraz ustawy o wpłatach z zysku przez jednoosobowe spółki Skarbu Państwa”, *Dziennik Ustaw*, promulgated 27 March 2025, see <https://www.dziennikustaw.gov.pl/D2025000039301.pdf>, accessed 19 July 2025.

¹³⁰⁵ - European Commission, “Commission Opens In-Depth State Aid Investigation Into Polish Support for Nuclear Power Plant”, Press Release, 18 December 2024, see https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_24_6437/IP_24_6437_EN.pdf, accessed 12 May 2025.

¹³⁰⁶ - Ibidem.

In March 2025, the European Commission published an invitation for interested parties to submit comments to the state aid investigation.¹³⁰⁷

Further financial aid would be provided by the U.S. International Development Finance Corporation (DFC), which signed a letter of intent in November 2024 to also provide PLN4 billion (US\$1 billion) for the plant.¹³⁰⁸ By June 2025, PEJ announced it had “obtained letters of support for more than 70% of the assumed amount of debt financing” from “11 export credit agencies from Europe, North America and Asia.”¹³⁰⁹

PEJ experienced two major changes in the top management within two years. In February 2024, the whole management board was dismissed, and Leszek Juchniewicz was appointed as the new CEO.¹³¹⁰ Press coverage suggested that the move was due the board’s ties to the previous nationalist government. However, only a little more than a year after, in March 2025, Juchniewicz was also dismissed, with immediate effect, without grounds publicly provided.¹³¹¹

A Second, Korean Project Remains Vague

In October 2022, a few days after Westinghouse was awarded the Lubiatowo-Kopalino project (see [above](#)), two preliminary agreements for the development of a nuclear power station based on Korean technology in Pątnów, central Łódzkie province were signed. Polska Grupa Energetyczna (PGE) and local electricity producer ZE PAK signed a letter of intent with KHNP to create a plan for the construction of the Pątnów plant, using Korea’s APR-1400 reactor technology, with a total capacity of 2.8 GW. Meanwhile Jacek Sasin, Poland’s then-State Assets Minister, and Chang-Yang Lee, South Korea’s then-Minister of Trade, Industry and Energy signed an agreement pledging cooperation in support of the project.¹³¹²

ZE PAK and PGE announced in March 2023 that they would establish a joint venture to “represent the Polish side at all stages of the [Pątnów] project”, which was planned with at least two APR-1400 reactors to be delivered by KHNP and scheduled to be on the grid by 2035.¹³¹³ In April 2023, the 50-50 joint venture, named PGE PAK Energia Jądrowa, was established.¹³¹⁴ In

¹³⁰⁷ - European Commission, “Invitation to Submit Comments Pursuant to Article 108(2) of the Treaty on the Functioning of the European Union”, 4 March 2025, see https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:C_202501389, accessed 10 July 2025.

¹³⁰⁸ - PEJ, “PEJ Receives Interest in Financing for the First Polish Nuclear Power Plant”, Press Release, 13 November 2024, see <https://pej.pl/en/press-center/news/pej-receives-interest-in-financing-for-the-first-polish-nuclear-power-plant/>, accessed 29 April 2025.

¹³⁰⁹ - PEJ, “PEJ Secures Further Funding and Plans to Enter the Commercial Financial Market”, Press Release, 12 June 2025, see https://pej.pl/en/press-center/news/___trashed-2/, accessed 18 June 2025.

¹³¹⁰ - Marcin Czekanski, “Poland Fires Nuclear Developer Managers, Appoints CEO”, *Montel*, 23 February 2024, see <https://montelnews.com/news/9d4a93d8-14e7-49fo-9bf2-d68f7baa5cdd/poland-fires-nuclear-developer-managers-names-ceo>, accessed 11 July 2025.

¹³¹¹ - PEJ, “Change in the Management Board of Polskie Elektrownie Jądrowe”, Press Release, 10 March 2025, see <https://pej.pl/en/press-center/news/change-in-the-management-board-of-polskie-elektrownie-jadrowe-2/>, accessed 19 July 2025.

¹³¹² - ZE PAK, “ZE PAK, PGE and KHNP Signed a Letter of Intent”, Press Release, 20 March 2024, see <https://www.zepak.com.pl/en/about-us/press-office/news/14036-ze-pak-pge-and-khnp-signed-a-letter-of-intent.html>, accessed 19 July 2025.

¹³¹³ - ZE PAK, “PGE and ZE PAK Will Establish a Company to Implement a Nuclear Power Plant Construction Project”, Press Release, 8 March 2023, see <https://www.zepak.com.pl/en/about-us/press-office/news/14521-pge-and-ze-pak-will-establish-a-company-to-implement-a-nuclear-power-plant-construction-project.html>, accessed 6 June 2023.

¹³¹⁴ - ZE PAK, “Establishment of PGE PAK Energia Jądrowa – Construction of a Nuclear Power Plant in Konin/Pątnów in the Greater Poland Region”, 13 April 2023, see <https://www.zepak.com.pl/en/about-us/press-office/news/14646-establishment-of-pge-pak-energia-jadrowa-construction-of-a-nuclear-power-plant-in-koninpatnow-in-the-greater-poland-region.html>; and WNN, “Approval Sought for Second Large Polish Nuclear Power Plant”, 17 August 2023, see <https://world-nuclear-news.org/Articles/Approval-sought-for-second-large-Polish-nuclear-po>; both accessed 11 June 2024.

November 2023, the Ministry of Climate and Environment granted a “decision-in-principle” for two APR-1400 reactors. This approval marks a first step in the Polish licensing process for nuclear facilities.¹³¹⁵

In January 2024, KHNP president Joo-ho Whang visited Warsaw for the grand opening of a three-person office. He announced that an agreement for a feasibility study for the project was to be signed by the end of March 2024, and that the financing scheme and EIA would be concluded by 2025, allowing for an “ambitious but achievable” beginning of commercial operation of the first reactor by 2035.¹³¹⁶ However, in late May 2024—after the change in Polish government—PGE president Dariusz Marzec said that the company was “very far away” from making an investment decision, given that the ongoing pre-feasibility studies would require several years to conclude, casting uncertainty on the project’s specifics as defined so far.¹³¹⁷

While the Pomeranian project was followed by two engineering service agreements and concrete steps towards financing, this was not the case for the Pątnów project. With the change in government in late 2023, the momentum of the Pątnów project slowed down as well. In addition, Westinghouse disputed the export of APR-1000/APR-1400 technology by KHNP claiming license infringements, further escalating the conflict in the context of KHNP’s bid in the Czech tender (see [Czech Republic](#)).¹³¹⁸ However, in early 2025, South Korea and the United States signed a Memorandum of Understanding (MoU) notably “to cooperate in expanding civil nuclear power in third countries while strengthening their respective administration of export controls on civil nuclear technology.”¹³¹⁹ Only one week later, on 16 January 2025, Westinghouse announced a Global Settlement Agreement with KEPCO and KHNP ending the longstanding dispute over claims of unauthorized transfer of technology and technical information.¹³²⁰ While the details of the agreement remain confidential, KHNP President Joo-ho Whang said that the agreement will serve as an opportunity to build closer cooperation between KHNP and Westinghouse.¹³²¹ But even with the resolution of the Westinghouse KHNP

¹³¹⁵ - Ministry of State Assets, “Minister Jacek Sasin: Przygotowaliśmy dobry program energetyki jądrowej, który powinny kontynuować kolejne rządy”, Government of Poland, 27 November 2023, see <https://www.gov.pl/web/aktywa-panstwowe/minister-jacek-sasin-przygotowalismy-dobry-program-energetyki-jadrowej-ktory-powinny-kontynuowac-kolejne-rzady>, accessed 12 June 2024; and WNN, “Second Large Polish Nuclear Plant Gets Approval”, 27 November 2023, see <https://www.world-nuclear-news.org/Articles/Second-large-Polish-nuclear-plant-gets-approval>, accessed 14 December 2023.

¹³¹⁶ - PAP, “Koreański dostawca reaktorów urządza się w Polsce. Otworzył biuro w Warszawie”, 18 January 2024, see <https://businessinsider.com.pl/biznes/koreanski-dostawca-reaktorow-uradza-sie-w-polsce-otworzyl-biuro-w-warszawie/2wgosql>, accessed 30 May 2024.

¹³¹⁷ - Robert Kędzierski, “Prezes PGE o elektrowni jądrowej: Decyzja o budowie z Koreańczykami jeszcze długo nie zapadnie”, *Money.pl*, 28 May 2024, see <https://www.money.pl/gospodarka/prezes-pge-o-elektrowni-jadrowej-decyzja-o-budowie-z-koreanczykami-jeszcze-dlugo-nie-zapadnie-7032465122233024a.html>, accessed 31 May 2024.

¹³¹⁸ - *Nucleonics Week*, “Westinghouse Disputes KHNP Authority to Sell Reactor Technology in Czech Republic”, Vol. 65, Issue 30, 24 July 2024.

¹³¹⁹ - United States Government and Government of South Korea, “Joint Statement of the United States of America and the Republic of Korea on the Expansion of Peaceful Nuclear Energy”, as released by the U.S. Department of Energy, 8 January 2025, see <https://www.energy.gov/articles/joint-statement-united-states-america-and-republic-korea-expansion-peaceful-nuclear-energy>, accessed 12 July 2025.

¹³²⁰ - Westinghouse, “Westinghouse Announces Global Settlement Agreement with KEPCO and KHNP”, 16 January 2025, see <https://info.westinghousenuclear.com/news/westinghouse-announces-global-settlement-agreement-with-kepc-and-khnp>, accessed 12 May 2025.

¹³²¹ - WNN, “Westinghouse Reaches Agreement On IP With Korean Companies”, 17 January 2025, see <https://www.world-nuclear-news.org/articles/westinghouse-reaches-agreement-on-ip-with-korean-companies>, accessed 12 May 2025; and KHNP, “한국수력원자력, 미국 웨스팅하우스와 글로벌 협력 강화”, Press Release, 17 January 2025, see <https://www.khnp.co.kr/main/selectBbsNttView.do?key=2289&bbsNo=71&nttNo=62307&searchCtgr=&searchCnd=all&searchKrdw=&integrDeptCode=&pageIndex=2>, accessed 25 February 2025.

legal dispute, it remains to be seen if the resources to follow through with two large reactor projects in the country can be made available.

None of the steps taken so far are binding engagements. In January 2025, a preliminary agreement was signed between both Polish companies providing terms for the potential takeover by PGE of ZE PAK's shares and equity interests in PGE PAK Energia Jądrow. Exclusive negotiation rights ran until 30 June 2025.¹³²² In its Group Strategy until 2035, released earlier that month, PGE announced “until 2035, expenditure only on preparation of projects for administrative and investment decisions,” clarifying that “subsequent decisions depend on the results of location research and market demand.”¹³²³ The accompanying Press Release details “in nuclear energy area expenditures of approx. few hundred millions PLN solely for conducting necessary research and analyses in 3 potential locations – Bełchatów, Turów and possibly Konin.”¹³²⁴

The Polish Nuclear Power Program released for public consultation by the Ministry of Industry in June 2025 expects site selection in 2027, where construction would start in 2032. It is now to host three units, which would be commissioned between 2041 and 2043. However, Poland seems to have hit reset on a possible cooperation with KHNP, as the provisional schedule for the second Polish nuclear plant project estimates that a “strategic partner (technology)” will be chosen in 2027. Curiously, a decision-in-principle is already expected in 2026.¹³²⁵

Perspectives on SMR Deployment

When looking at plans for Small Modular Reactor (SMR) deployment in Poland—a newcomer country—one should keep in mind that the Polish nuclear regulatory environment was tailored to regulate only a few nuclear facilities. One requirement for the acceptance of the large reactor project at Lubiatowo-Kopalino, therefore, was a proven and already licensed design. The licensing of three AP-1000 reactors already required an expansion of staff at the Polish nuclear regulatory authority, PAA, and resulted in delays in routine tasks for existing facilities.¹³²⁶ So, the licensing capacities for novel SMR designs involving a larger number of additional sites should be considered with caution. Nevertheless, Poland is eyeing the possibility of investing into the deployment of SMRs. Various cooperation agreements have been signed.

BWRX-300: In April 2023, the U.S. Export-Import Bank and the U.S. International Development Finance Corporation signed letters of interest to provide loans of up to US\$3 billion and US\$1 billion, respectively, to the ORLEN Synthos Green Energy (OSGE)-

¹³²² - PGE, “Consolidated Financial Statements of the PGE Polska Grupa Energetyczna S.A. Capital Group for the year 2024”, 2025, see https://www.gkpge.pl/en/content/download/d8aee6d031cf5f08e5902b918a861d4a/file/ssf_gkpge_2024_en.pdf?inLanguage=eng-GB&version=2&contentId=169204; and PGE, “Signing of Term Sheet with ZE PAK S.A. on Potential Acquisition of Shares in PAK CCGT Sp. z o.o. and in PGE PAK Energia Jądrowa S.A.”, Press Release 3/2025, 23 January 2025, see [https://www.gkpge.pl/en/for-investors/current-reports/signing-of-term-sheet-with-ze-pak-s.a.-on-potential-acquisition-of-shares-in-pak-ccgt-sp.-z-o.o.-and-in-pge-pak-energia-jadrowa-s.a.](https://www.gkpge.pl/en/for-investors/current-reports/signing-of-term-sheet-with-ze-pak-s.a.-on-potential-acquisition-of-shares-in-pak-ccgt-sp.-z-o.o.-and-in-pge-pak-energia-jadrowa-s.a;); both accessed 19 July 2025.

¹³²³ - PGE, “PGE Group Strategy until 2035”, June 2025, see https://www.gkpge.pl/content/download/f4053a369cea34cofo4723c3687dda5/file/PGE_SA_20250612_Strategia_PGE_2035_EN.pdf, accessed 19 July 2025.

¹³²⁴ - PGE, “Adoption of the New PGE Group’s Strategy for 2035”, Press Release 22/2025, 12 June 2025, see <https://www.gkpge.pl/en/for-investors/current-reports/adoption-of-the-new-pge-group-s-strategy-for-2035>, accessed 19 July 2025.

¹³²⁵ - Ministry of Industry, “Programu polskiej energetyki jądrowej”, Government of Poland, 12 June 2025, see <https://www.gov.pl/attachment/ccb8eee8-43e5-4d3b-ad71-f5a111822f8a>, accessed 19 July 2025.

¹³²⁶ - IAEA, “Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation (ARTEMIS) Mission to Poland”, October 2017.

led project—jointly established by ORLEN and Synthos Green Energy—that as of April 2023 envisioned the construction of up to 20 GE Hitachi (GEH) BWRX-300 reactors in Poland, with the startup of the first one over-ambitiously scheduled for 2029.¹³²⁷ In 2023, the BWRX-300 design passed an (optional) pre-licensing review in which the President of the Polish National Atomic Energy Agency issued a “general opinion on selected technical assumptions of the BWRX-300 reactor technology,” deeming them “compliant with the national nuclear safety requirements,” though pointing to one which “must be verified again before the start of the relevant administrative process related to obtaining licenses of the President of the PAA.”¹³²⁸ In April 2025, the Canadian Nuclear Safety Commission (CNSC) issued a construction license for the BWRX-300 at the Darlington site in Ontario¹³²⁹ (an informal prerequisite for a license in Poland). In November 2024, OSGE reached an agreement with Laurentis to cooperate on the preparation of the Preliminary Safety Analysis Report, which is now planned for mid-2026.¹³³⁰

In September 2023, OSGE was also selected to receive funds from the U.S. Department of State for “Coal-to-SMR” feasibility studies under “Project Phoenix.”¹³³¹ On 7 December 2023, six projects—at Włocławek, Stawy Monowskie, Stalowa Wola, Ostrołęka, Nowa Huta, and Dąbrowa Górnicza—envisioning up to 24 individual reactors on the grid by 2030 (clearly unrealistic and overambitious), received approval-in-principle from Poland’s Ministry of Climate and Environment, only a few days before the new government came into power.¹³³²

As of June 2024, three sites of the OSGE project, namely Stawy Monowskie, Włocławek, and Ostrołęka, totaling up to 4.6 GW or 15 reactors, had entered environmental proceedings with the General Directorate for Environmental Protection (GDEP) to establish the required scope of Environmental Impact Assessment (EIA) Reports, while applications had yet to be filed

¹³²⁷ - Monika Scisłowska, “US Ready to Lend Poland \$4 Billion for Nuclear Energy Plan”, *The Associated Press*, 17 April 2023, see <https://apnews.com/article/nuclear-energy-us-poland-221e7fcb13bba60bd872929a9c822aa>; and EXIM, “Export-Import Bank of the United States Issues a \$3B Letter of Interest for U.S. Nuclear Exports to Poland”, Press Release, Export-Import Bank of the United States, 17 April 2023, see <https://www.exim.gov/news/export-import-bank-united-states-issues-3b-letter-interest-for-nuclear-exports-poland>; also OSGE, “US Government Financial Institutions Indicate Willingness to Support ORLEN Synthos Green Energy with its GE Hitachi BWRX-300 Small Modular Reactor Deployment Program in Poland”, ORLEN Synthos Green Energy, Press Release, 17 April 2023, see <https://osge.com/en/us-government-financial-institutions-indicate-willingness-to-support-osge/>; all accessed 11 June 2024.

¹³²⁸ - National Atomic Energy Agency, “General Opinion of the President of the PAA on BWRX-300”, 23 May 2023, see <https://www.gov.pl/web/paa-en/general-opinion-of-the-president-of-the-paa-on-bwr-300>, accessed 29 May 2023.

¹³²⁹ - CNSC, “Commission Authorizes Ontario Power Generation Inc. to Construct 1 BWRX-300 Reactor at the Darlington New Nuclear Project site”, Canadian Nuclear Safety Commission, Updated 4 April 2025, see <https://www.canada.ca/en/nuclear-safety-commission/news/2025/04/commission-authorizes-ontario-power-generation-inc-to-construct-1-bwr-300-reactor-at-the-darlington-new-nuclear-project-site.html>, accessed 11 July 2025.

¹³³⁰ - OSGE, “OSGE Podpisuje Umowę Z Laurentis Na Przygotowanie Wstępnego Raportu Bezpieczeństwa Dla BWRX-300”, 14 November 2024, see <https://osge.com/osge-podpisuje-umowe-z-laurentis-na-przygotowanie-wstepnego-raportu-bezpieczenstwa-dla-bwr-300/>, accessed 11 July 2025; and Laurentis Energy Partners, “Laurentis Signs Agreement With OSGE to Support Preliminary Work for SMR Development in Poland”, 14 November 2024, see <https://laurentisenergy.com/releases/laurentis-signs-agreement-with-osge-to-support-preliminary-work-for-smr-development-in-poland/>, accessed 15 May 2025.

¹³³¹ - U.S. Department of State, “Special Presidential Envoy for Climate Kerry Announces Project Phoenix Participants and the Nuclear Expediting the Energy Transition (NEXT) Program”, Press Release, 7 September 2023, see <https://www.state.gov/special-presidential-envoy-for-climate-kerry-announces-project-phoenix-participants-and-the-nuclear-expediting-the-energy-transition-next-program/>; and OSGE, “OSGE Selected to the Project Phoenix by the U.S. Department of State”, 9 November 2023, see <https://osge.com/en/osge-selected-to-the-project-phoenix-by-the-u-s-department-of-state/>; both accessed 12 June 2024.

¹³³² - Alan Charlish, “Poland Approves Construction of SMR Nuclear Units at Six Sites”, *Reuters*, 7 December 2023, see <https://www.reuters.com/sustainability/climate-energy/poland-approves-construction-smr-nuclear-units-six-sites-2023-12-07/>, accessed 30 May 2024; and OSGE, “OSGE Obtained Six Decisions-in-Principle”, 7 December 2023, see <https://osge.com/en/osge-obtained-six-decisions-in-principle/>, accessed 11 June 2024.

for the remaining three sites.¹³³³ In February 2024, GDEP issued a decision on the required scope of environmental reporting on the Stawy Monowskie project and announced that it was starting to carry out environmental and siting studies necessary for the preparation of the EIA Report.¹³³⁴ According to the company, it could take about two years for the EIA report to be completed.¹³³⁵ In February 2025, GDEP issued similar decisions on the Ostrołęka and Włocławek project ideas, and OSGE can now begin environmental and siting research at those locations as well.¹³³⁶

Last Energy: In June 2022, Polish state-owned company Enea S.A. and U.S. SMR developer Last Energy agreed to cooperate on the deployment of SMRs.¹³³⁷ In March 2023, after contracting power purchase agreements (totaling over US\$4.3 billion in electricity sales and US\$1 billion in infrastructure investments) with industrial partners of Poland's Katowice Special Economic Zone and in the U.K., Last Energy felt optimistic enough to announce the deployment of ten 20 MWe "Micro Modular Nuclear Power Plants" with the target of commissioning a first plant by 2025—later corrected on the website to 2027—to provide customers with electricity and heat.¹³³⁸ The reactor design is not licensed anywhere yet, and a construction license application had not been filed as of mid-2025, which indicates that the delayed target date will not hold either.

NuScale: In September 2021, SMR developer NuScale signed an MoU with Polish mining company KGHM and engineering firm Piela Business Engineering (PBE).¹³³⁹ In July 2023, the project was granted first approval by the Ministry of Climate and Environment, theoretically allowing the project to move to the next administrative steps, including siting decisions and building permits.¹³⁴⁰ However, so far, the administrative procedures appear to be limited to so called "regulatory opinions", a legal instrument in Poland to obtain a preliminary, non-

¹³³³ - OSGE, "Three Environmental Proceedings in Progress", 1 September 2023, see <https://osge.com/en/three-environmental-proceedings-in-progress/>, accessed 11 June 2024; and Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, "Grenzüberschreitende Umweltverträglichkeitsprüfungen (UVP) zum Bau von Small Modular Reactors (SMR) in Polen- BMUV - Meldung", Government of Germany, March 2024, see <https://www.bmuv.de/ME10946>, accessed 31 May 2024.

¹³³⁴ - GDEP, "Zawiadomienie Generalnego Dyrektora Ochrony Środowiska z 1 lutego 2024 r., znak: DOOŚ-WDŚZOO.420.23.2023. AKA.24", General Directorate for Environmental Protection, 1 February 2024, see <https://www.gov.pl/web/gdos/zawiadomienie-generalnego-dyrektora-ochrony-srodowiska-z-1-lutego-2024-r-znak-doo-s-wdszoo420232023aka24>, accessed 11 June 2024.

¹³³⁵ - OSGE, "OSGE with the Scope of the Environmental Report for the First SMR Project", 2 February 2024, see <https://osge.com/en/osge-with-the-scope-of-the-environmental-report-for-the-first-smr-project/>, accessed 12 June 2024.

¹³³⁶ - OSGE, "OSGE z zakresem raportów środowiskowych dla Włocławka i Ostrołęki", 6 February 2025, see <https://osge.com/osge-z-zakresem-raportow-srodowiskowych-dla-wloclawka-i-ostroleki/>, accessed 19 July 2025.

¹³³⁷ - Last Energy, "Last Energy, Enea Group to Develop Small Modular Nuclear Reactors, As Polish Government Prioritizes Energy Security and Net-Zero Goals", Press Release, as published on *GlobeNewswire*, 23 June 2022, see <https://www.globenewswire.com/news-release/2022/06/23/2468500/0/en/Last-Energy-Enea-Group-to-Develop-Small-Modular-Nuclear-Reactors-As-Polish-Government-Prioritizes-Energy-Security-and-Net-Zero-Goals.html>, accessed 11 June 2024.

¹³³⁸ - Last Energy, "Last Energy Agrees to Develop 10 of its 20 Mwe Micro Nuclear Power Plants in KSSE", Undated, see <https://www.lastenergy.com/case-studies/ksse>, accessed 12 June 2024 and 19 July 2025.

¹³³⁹ - NuScale, "NuScale Power Signs Memorandum of Understanding with KGHM and PBE to Explore SMR Deployment in Poland", Press Release, 23 September 2021, see <https://www.nuscalepower.com/press-releases/2021/nuscale-signs-mou-with-kgbm-and-pbe>, accessed 24 July 2024.

¹³⁴⁰ - KGHM, "KGHM Has Received the Basic Decision Regarding the Construction of a Small Modular Reactor (SMR) Power Plant", Press Release, 13 July 2023, see <https://media.kghm.com/en/news-and-press-releases/kgbm-has-received-the-basic-decision-regarding-the-construction-of-a-small-modular-reactor-smr-power-plant>, accessed 24 July 2024.

binding, general assessment of a project design outside of the regulatory authority's formal licensing process.¹³⁴¹

In March 2025, the Vice President of KGHM's management board confirmed that SMRs were still considered an option “over the long term”; he did not mention NuScale, but he remarked that “the SMR project at KGHM has the status of a research and development initiative”, and provided the following reminder:¹³⁴²

The future of all SMR projects in Poland will depend, among other factors, on the economic viability of such investments, progress in the commercialization of this technology abroad, and relevant legislation.

Conclusions on Nuclear Project Developments

Of the various Polish initiatives, two stand out and continue to move forward. The construction project of three AP-1000s at the Lubiatowo-Kopalino site and the OSGE BWRX-300 project. While the announced schedules for both projects (especially the BWRX-300) seem overly optimistic, both reactor designs meet the informal prerequisite of being licensed by an experienced regulator elsewhere. While the AP-1000 has been built in China and the U.S., the BWRX-300 has received a construction license in Canada. Both projects showed slow but consistent steps in the licensing procedure. This was not the case for the other projects. There was little to no movement from mid-2024 to mid-2025 in the NuScale and Last Energy projects, and nothing has been reported on an earlier Rolls-Royce SMR initiative (see [Poland Focus: Perspectives for SMR Deployment in WNISR2024](#)).

Non-Nuclear Energy Developments

Meanwhile, renewable energies are being rapidly deployed in Poland. In 2024, wind contributed 14.6 percent to total electricity generation, while solar contributed 9 percent—four times its share in 2021. The combined share of wind and solar doubled from 11.3 percent to 23.5 percent in just three years from 2021 to 2024. At the same time, the share of fossil fuels—still dominating the Polish power system—has been reduced from almost 83 percent to 70 percent, coal accounting still for 53.5 percent of total production, down from 71.3 percent in 2021.¹³⁴³ In other words, while discussions about the nuclear program dominate the news, renewables have started to rapidly decarbonize the Polish power system.

¹³⁴¹ - National Atomic Energy Agency of Poland, “Second Opinion of the President of the PAA on the Application of KGHM Polska Miedź S.A.”, 26 April 2024, see <https://www.gov.pl/web/paa-en/second-opinion-of-the-president-of-the-paa-on-the-application-of-kghm-polska-miedz-sa>, accessed 12 June 2024.

¹³⁴² - KGHM, “Investor Chat of KGHM Polska Miedź S.A.”, Q&A with Piotr Krzyżewski, Vice President, Management Board, KGHM, 28 March 2025, see https://kghm.com/sites/default/files/KGHM%20Investor%20chat_28%20March%202025.pdf, accessed 19 July 2025.

¹³⁴³ - EMBER, “Electricity Data Explorer”, July 2025, see https://ember-energy.org/data/electricity-data-explorer/?metric=pct_share&entity=Poland&fuel=total; and EMBER, “Yearly Electricity Data”, July 2025, see https://storage.googleapis.com/emb-prod-bkt-publicdata/public-downloads/yearly_full_release_long_format.csv, accessed 3 August 2025.

OTHER EXAMPLES

There is an increasing number of countries that claim planning the introduction of nuclear power programs. Many of these claims are either lacking credibility or imply time frames that are at this point irrelevant for an annual report on the industry (see also [Potential Nuclear Newcomer Countries in Africa](#)). Early potential newcomers include Ecuador, Estonia, Indonesia, Jordan, Kazakhstan, Saudi Arabia, and Uzbekistan that are briefly analyzed hereunder.

Ecuador

According to the IAEA, “Ecuador is well on the road to including nuclear power in its energy mix.”¹³⁴⁴ However, there does not appear to be any official energy plan including nuclear power so far. In October 2024, Ecuador’s President vaguely stated that there was a “dialogue with France” on nuclear power.¹³⁴⁵

Later that month, it was reported that a Vice-Minister of Electricity had unveiled an “ambitious roadmap” to deploy a 300-MW reactor by 2029. A 1-GW reactor would follow in the longer term.¹³⁴⁶ No official communication is available.

In May 2025, the government signed an MoU with the IAEA for assistance in the implementation of a nuclear program according to the Milestones approach.¹³⁴⁷

The country remains far from fulfilling the basic conditions for a nuclear power program. Ecuador has an installed electricity generating capacity of less than 10 GW and it is unclear whether the grid could deal with a nuclear reactor of any size. It has no regulatory framework and no institutions like a nuclear regulator or a nuclear waste management agency.

Estonia

In November 2020, the Estonian government decided to set up an interministerial Nuclear Energy Working Group (NEWG) that would also convene members from other national organizations. The NEWG’s final report explains that “The ultimate goal of the NEWG is to form coordinated views with the public on the possibilities of introducing nuclear energy in Estonia and to submit its conclusions and proposals to the Government of the Republic.” The Group concluded that “the introduction of nuclear energy in Estonia is feasible” and that “small modular reactors (SMRs) with a power capacity of less than 400 MVA (400 MW) would be suitable for Estonia.” It also pointed to a number of significant challenges:

¹³⁴⁴ - Katy Laffan, “Ecuador: Support to Nuclear Power Plans, the Galapagos and More”, IAEA Office of Public Information and Communication, 14 May 2025, see <https://www.iaea.org/newscenter/news/ecuador-support-to-nuclear-power-plans-the-galapagos-and-more>, accessed 31 August 2025.

¹³⁴⁵ - Presidency of Ecuador, “De La Dependencia De Las Lluvias a Una Matriz Energética Diversa Y Renovable: El Plan Del Gobierno De Noboa”, 27 October 2024, see <https://www.comunicacion.gob.ec/de-la-dependencia-de-las-lluvias-a-una-matriz-energetica-diversa-y-renovable-el-plan-del-gobierno-de-noboa/>, accessed 17 May 2025.

¹³⁴⁶ - *The Cuenca Dispatch*, “Energy Ministry Unveils Plan for First Nuclear Power Plant Amid Energy Crisis”, 24 February 2025, see <https://thecuencadispatch.com/energy-ministry-unveils-plan-for-first-nuclear-power-plant-amid-energy-crisis/>, accessed 17 May 2025.

¹³⁴⁷ - Katy Laffan, “Director General in Ecuador to Support Nuclear Power Plans, the Galapagos and More”, IAEA, 14 May 2025, see <https://www.iaea.org/newscenter/news/director-general-in-ecuador-to-support-nuclear-power-plans-the-galapagos-and-more>, accessed 16 May 2025.

- “The country needs to make an informed decision on the introduction of nuclear energy, based on a broad political consensus. The Riigikogu [Estonian Parliament] can decide whether to support the launch of a nuclear energy programme, which includes the creation of a regulatory and legal framework, the launch of planning processes and the selection of a suitable technology and developer.”
- “...the launch of a nuclear energy programme will require the regulation of more complex activities and the implementation of new measures.”
- “The construction of a nuclear power plant will require developing a wide range of skills, including acquiring knowledge and experience through international cooperation. Emergency planning and security aspects also need to be considered.”¹³⁴⁸

In a significant development, in June 2024, the Riigikogu passed a resolution, based on the NEWG’s conclusions, on supporting the adoption of nuclear energy in Estonia which would allow for “the drafting of the Nuclear Energy and Safety Act and, if necessary, amending and supplementing the existing legislation, as well as the establishment of an institution regulating the safe use of nuclear energy and the development of sectoral competences.”¹³⁴⁹ Surprisingly, the resolution was passed with only 41 members voting in favor, while 25 voted against and two abstained, although 55 members had submitted the resolution.

Estonia’s Prime Minister appears well aware of the long lead times of nuclear projects. In April 2025, he stated in response to parliamentary questions that “the construction of nuclear energy is a long process, even if it’s very fast-tracked – it’s an approximate estimate... it takes about 10 to 15 years” pointing to the opportunities of renewables “in the meantime”.¹³⁵⁰

Indonesia

The Indonesian government has been contemplating the launch of a national nuclear program for many years with little concrete commitments so far. In its statement to the IAEA General Assembly in September 2024, the Indonesian statement said:¹³⁵¹

We are developing a comprehensive Nuclear Power Plants (NPPs) roadmap, using the INPRO [International Project on Innovative Nuclear Reactors and Fuel Cycles] method under the IAEA’s expertise. (...) We plan to reduce our reliance on fossil fuels and integrate nuclear energy into our energy mix, to generate reliable power and cut greenhouse gas emissions for a more sustainable future.

¹³⁴⁸ - NEWG, “Final Report – Possibilities for the Implementation of Nuclear Energy in Estonia”, Nuclear Energy Working Group, 2023, see <https://kliimaministeerium.ee/sites/default/files/documents/2024-02/Final%20Report%20-%20Possibilities%20of%20the%20Implementation%20of%20Nuclear%20Energy%20in%20Estonia.pdf>, accessed 1 September 2025.

¹³⁴⁹ - Riigikogu Press Service, “The Riigikogu Passed a Resolution on Supporting the Adoption of Nuclear Energy in Estonia”, Parliament of Estonia, 12 June 2024, see <https://www.riigikogu.ee/en/press-releases/plenary-assembly/the-riigikogu-passed-a-resolution-on-supporting-the-adoption-of-nuclear-energy-in-estonia/>, accessed 1 September 2025.

¹³⁵⁰ - Riigikogu, “Riigikogus käsitleti energeetikaga seotud küsimusi”, Parliament of Estonia, 14 April 2025, see <https://www.riigikogu.ee/istungi-ulevaated/riigikogus-kasitleti-energeetikaga-seotud-kusimusi/>, accessed 1 September 2025.

¹³⁵¹ - Damos D. Agusman, “National Statement of Indonesia”, Ambassador Extraordinary and Plenipotentiary, Permanent Representative, delivered at 68th Regular Session of the General Conference of the International Atomic Energy Agency, 16 September 2024, as released by the IAEA, see <https://www.iaea.org/sites/default/files/24/09/indonesia-gc68.pdf>, accessed 29 April 2025.

A senior official at the Indonesian Presidential Office told *Reuters* in May 2025 that the country is planning national power generating capacity of over 100 GW by 2040, including 75 GW of renewables, 18 GW of natural gas, and 10 GW of nuclear. According to the official, Rosatom, China National Nuclear Corporation (CNNC), Rolls-Royce, EDF, and NuScale “have shown interest in Indonesia’s nuclear power ambitions.”¹³⁵²

It seems like a long way yet to the implementation of a nuclear construction project in Indonesia.

Jordan

Jordan officialized its interest in nuclear power by establishing the Jordan Atomic Energy Commission (JAEC) through law in 2008.¹³⁵³ Since then, JAEC has announced plans to import diverse nuclear reactors. The most advanced of these plans was a 2015 agreement with Russia to build two 1000-MW nuclear reactors.¹³⁵⁴ But this was ultimately canceled in 2018.¹³⁵⁵ Since then JAEC has expressed interest in a wide variety of Small Modular Reactor (SMR) designs developed by companies based in different countries. Indeed, by 2024, the JAEC webpage was announcing that the country had signed “more than 15 nuclear cooperation agreements”.¹³⁵⁶ In February 2025, JAEC signed a “memorandum of mutual understanding on cooperation in the field of peaceful use of nuclear energy” with Kazakhstan’s Energy Ministry.¹³⁵⁷ The envisaged cooperation likely mainly relates to uranium mining and exploration in Jordan, as an MoU with Kazatomprom to that extent was signed at the time,¹³⁵⁸ and Kazakhstan has no reactor design to offer.

Jordan has so far not selected a design, vendor, site, or completed a financing package, let alone started building any nuclear power plant, small or large.

Despite these many agreements, Jordan has so far not selected a design, vendor, site, or completed a financing package, let alone started building any nuclear power plant, small or large. This was underscored in July 2024, when a statement by Khaled Al-Khasawneh, Commissioner of Nuclear Reactors at the JAEC, could only mention “plans to incorporate

¹³⁵² - Stefano Sulaiman, “Indonesia plans 10 GW nuclear power in major renewable energy push, presidential aide says”, *Reuters*, 1 May 2025, see <https://www.reuters.com/sustainability/cop/indonesia-plans-10-gw-nuclear-power-major-renewable-energy-push-presidential-2025-05-01/>, accessed 17 May 2025.

¹³⁵³ - JAEC, “About Us”, Jordan Atomic Energy Commission, 2021, see <http://www.jaec.gov.jo/Pages/viewpage?pageID=1>, accessed 1 May 2021.

¹³⁵⁴ - Sam McNeil, “Jordan, Russia Sign \$10 Billion Deal on Nuclear Power Plant”, *The Associated Press*, 24 March 2015, see <https://apnews.com/general-news-f841a5e91e1f4086a22501b7ebe1dd71>, accessed 28 June 2025.

¹³⁵⁵ - Mohammad Ghazal, “Funding Issues Behind Scrapping Nuclear Deal with Russia”, *The Jordan Times*, 12 June 2018, see <http://www.jordantimes.com/news/local/funding-issues-behind-scrapping-nuclear-deal-russia-%E2%80%94jaec>, accessed 5 July 2018.

¹³⁵⁶ - JAEC, “International Cooperation”, Jordan Atomic Energy Commission, 26 July 2024, see <https://www.jaec.gov.jo/Pages/viewpage?pageID=41>, accessed 25 July 2024; and JAEC, “Information Center—International Cooperation”, as of 16 July 2025, see https://www.jaec.gov.jo/En/Pages/International_Cooperation, accessed 16 July 2025.

¹³⁵⁷ - Adlet Seilkhanov, “Kazakhstan, Jordan Sign a Number of Agreements”, *Kazinform International News Agency*, 19 February 2025, see <https://qazinform.com/news/kazakhstan-jordan-sign-a-number-of-agreements-503aa8>, accessed 28 June 2025.

¹³⁵⁸ - Kazatomprom, “Kazatomprom and JUMCO Develop Cooperation in the Uranium Industry”, Press Release, 19 February 2025, see https://www.kazatomprom.kz/en/media/view/kazatomprom_and_jumco_develop_cooperation_in_the_uranium_industry, accessed 15 July 2025.

small modular reactors...into the national energy mix” and how “technical assessments and economic feasibility studies for several SMR designs” were “in progress, along with detailed feasibility studies on using nuclear power for water desalination and pumping in Jordan.”¹³⁵⁹

In contrast to its nuclear plans, Jordan has been expanding renewable energy: capacity has been growing quite rapidly, from 200 MW in 2015 to 2.7 GW in 2024, which consisted mostly of solar energy (2.1 GW), followed by wind power (0.6 GW), renewable energy representing 38 percent of total electricity capacity.¹³⁶⁰ The government is targeting having solar power and other renewable energy sources contributing 50 percent of the total electricity generation by 2033.¹³⁶¹ According to the Ministry of Energy and Mineral Resources, the 2030-target for renewable energy sources will already be met “between 2027 and 2028”, serving as “incentive to raise future ambitions even further.”¹³⁶²

Kazakhstan



Kazakhstan is one of five countries in the world to have abandoned commercial nuclear power—while currently contemplating to restart a program—the others being Germany, Italy, Lithuania, and Taiwan. Kazakhstan serves as a lens through which the full spectrum of nuclear energy applications—ranging from commercial power production and uranium mining to nuclear weapons testing—with all their ambiguities, can be examined. The country possesses significant uranium resources and has been the world’s leading uranium producer for more than a decade.¹³⁶³ This is set against the backdrop of Kazakhstan abandoning its commercial nuclear program in 1998, which had been based on a Soviet-era BN-350 fast breeder reactor.¹³⁶⁴

The construction of a new power plant was brought to the table in the 1990s after Kazakhstan’s independence, but the plan became more significant in 2024, when a referendum on the future of Kazakhstan’s civil nuclear program was held. Kazakhstan is heavily dependent on fossil fuels

¹³⁵⁹ - Petra, “Jordan Eyes 41K Tons of Yellowcake for Nuclear Energy”, *Jordan News Agency*, 16 July 2024, see https://petra.gov.jo/Include/InnerPage.jsp?ID=61690&lang=en&name=en_news, accessed 13 August 2024.

¹³⁶⁰ - IRENA, “Renewable Capacity Statistics 2025”, March 2025, op. cit.

¹³⁶¹ - ZAWYA, “Jordan Targets 50% Renewable Energy in 2033”, 20 June 2025, see <https://www.zawya.com/en/projects/utilities/jordan-targets-50-renewable-energy-in-2033-sobozs7g>, accessed 28 June 2025.

¹³⁶² - Ministry of Energy and Mineral Resources, “Jordan Launches Workshop to Update National Energy Strategy for 2025–2035”, Government of Jordan, 7 May 2025, see <https://www.memr.gov.jo/En/NewsDetails/202505073>, accessed 16 July 2025.

¹³⁶³ - WNA, “World Uranium Mining Production”, World Nuclear Association, Updated 16 May 2025, see <https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production>, accessed 17 June 2025; and OECD/NEA and IAEA, “Uranium 2022: Resources, Production and Demand”, No. 7634, Nuclear Energy Agency, Organisation for Economic Co-operation and Development, and International Atomic Energy Agency, approved by Nuclear Development Committee, 20 February 2023, see https://www.oecd-nea.org/jcms/pl_79960/uranium-2022-resources-production-and-demand?details=true, accessed 21 August 2023.

¹³⁶⁴ - Caroline Peachey, “Local Residents Pay for Decommissioning of Kazakhstan’s BN-350 Reactor”, *NEI Magazine*, 27 February 2020, see <https://www.neimagazine.com/news/newslocal-residents-pay-for-decommissioning-of-kazakhstans-bn-350-reactor-7796914>, accessed 2 July 2021; and S. Krechetov, “Nuclear Power in Kazakhstan and Current Status of the BN-350 fast reactor”, Atomic Energy Agency, presented at the 31th Annual Meeting of the International Working Group on Fast Reactors, IAEA, 12 May 1998, see https://inis.iaea.org/collection/NCLCollectionStore/_Public/31/044/31044862.pdf?r=1&r=1, accessed 5 June 2019.

that in 2024 sourced 85 percent of its electricity generation.¹³⁶⁵ In recent years the country has faced an increase in electricity consumption with production struggling to keep up.¹³⁶⁶

In April 2019, during a visit by Kazakhstan's then-acting President Kassym-Jomart Tokayev to Moscow, Vladimir Putin raised the possibility of constructing a new nuclear power plant in Kazakhstan with the support of Russian State Atomic Energy Corporation Rosatom. Government sources reportedly commented that while no decision had been made, a potential site had been identified.¹³⁶⁷ However, later that same year, shortly after his election as president, Tokayev reportedly denied any immediate plans for building a new nuclear plant in Kazakhstan, while stating that if such a project were to proceed, a referendum would be held.¹³⁶⁸

In February 2022, the government presented its “Green with NPP” scenario, which would focus on “green energy sources, gas and nuclear generation” to commission 17.5 GW of new capacity by 2035.¹³⁶⁹ At the time, it was reported that the government had been considering six suppliers for SMRs or large reactors as part of its ongoing feasibility studies: Korea Hydro & Nuclear Power (KHNP), NuScale, GE Hitachi, China National Nuclear Corporation (CNNC), Rosatom, and Électricité de France (EDF). But in June 2022, NuScale and GE Hitachi were excluded from the process as their proposed technologies had not been implemented anywhere yet.¹³⁷⁰

In September 2023, Kazakhstan's President Kassym-Jomart Tokayev suggested holding a national referendum in 2024 on the question of building nuclear power reactors. But according to media reports, in May 2024, a spokesperson of the Energy Ministry stated that the referendum had been delayed “over fears that the Kazakh population could vote against the plant's construction.”¹³⁷¹ Ahead of the referendum, the government had indeed strongly advocated in favor of the nuclear program, leaving little to no room for alternatives: “As world practice shows, construction of a nuclear power plant seems to be the only true solution to replace retiring capacities and ensure energy independence of Kazakhstan. At the present stage, there is no alternative to nuclear power plants.”¹³⁷²

¹³⁶⁵ - EMBER, “Kazakhstan—Electricity Data Explorer”, Updated 10 April 2025, see <https://ember-energy.org/countries-and-regions/kazakhstan>, accessed 8 July 2025.

¹³⁶⁶ - Adlet Seilkhanov, “Kazakhstan Sees Record Electricity Consumption and Production Gap in Years”, *Kazinform International News Agency*, 2 May 2025, see <https://qazinform.com/news/kazakhstan-sees-record-electricity-consumption-and-production-gap-in-years-925of8>, accessed 1 July 2025.

¹³⁶⁷ - Bruce Pannier, “Putin Offers Russian Help To Build Kazakh Nuclear Plant”, *RadioFreeEurope/RadioLiberty*, 6 April 2019, see <https://www.rferl.org/a/kazakhstan-putin-offers-russian-nuclear-plant-help/29865177.html>, accessed 1 May 2021.

¹³⁶⁸ - Ботагоз Айтжанова, “Токаев об АЭС: Если понадобится, проведем референдум”, *Tengri News*, 10 June 2019, see https://tengrinews.kz/kazakhstan_news/tokaev-ob-aes-esli-ponadobitsya-provedem-referendum-371061/, accessed 2 July 2025.

¹³⁶⁹ - Prime Minister's Office, “Ministry of Energy Developed New Concept of Energy Security”, Government of Kazakhstan, 15 February 2022, see <https://primeminister.kz/en/news/energetika-ministrilgi-energetikalyk-kauipsizdiktin-zhana-tuzhyrymdamasyn-azirledi-151237>, accessed 14 July 2025.

¹³⁷⁰ - *Interfax*, “Kazakhstan Signs Memorandum with Korea Hydro & Nuclear Power”, 28 June 2022, see <https://interfax.com/newsroom/top-stories/80722/>, accessed 11 July 2025; and WNN, “Kazakh, Korean Companies to Cooperate in Nuclear Power Projects”, 29 June 2022, see <https://www.world-nuclear-news.org/Articles/Kazakh,-Korean-companies-to-cooperate-in-nuclear-p>, accessed 29 August 2022.

¹³⁷¹ - *Nuclear Intelligence Weekly*, “Kazakhstan pushes back planned referendum on large-reactor nuclear plant”, 15 May 2024.

¹³⁷² - Prime Minister's Office, “Satkaliyev: Currently, No Alternative to NPP Available”, Government of Kazakhstan, 27 August 2024, see <https://primeminister.kz/en/news/satkaliyev-currently-no-alternative-to-npp-available-28990>; and Prime Minister's Office, “Government Adopts Decision on Holding Referendum on NPP Construction”, Government of Kazakhstan, 27 August 2024, see <https://primeminister.kz/en/news/government-adopts-decision-on-holding-referendum-on-npp-construction-28993>; both accessed 14 July 2025.

In September 2024, the platform AES Kerek Emes (“No Need for a nuclear power plant”) held a panel discussion addressing the question, “Does Kazakhstan need nuclear power?” The critiques raised by participants during the panel discussion covered a range of concerns, including ecological risks, challenges of nuclear waste management, delays in project timelines, and significant financial risks associated with such large-scale initiatives. The financial concerns were particularly heightened due to fears of possible corruption. Additionally, Kazakhstani ecologists voiced strong opposition to the use of nuclear power, citing its potential negative impact on the environment.¹³⁷³

Right before the referendum, at least 12 activists organizing peaceful protests against the nuclear power projects were detained by the police.¹³⁷⁴ Most were released on their own recognizance, while five remained in detention pending their trial for “attempting to organize mass riots”, scheduled for July 2025.¹³⁷⁵

Nevertheless, the referendum was held on 7 October 2024. Over 71 percent of the votes backed the exploitation of nuclear energy and construction of nuclear power plants in Kazakhstan.¹³⁷⁶ Following the referendum, President Tokayev announced the plan to not only accelerate construction of a first plant, but also to create a ‘nuclear cluster’ and fully develop the industry.¹³⁷⁷ Further, upon establishing the national Nuclear Energy Agency by presidential decree¹³⁷⁸ in March 2025, he stated:

The question is not to ensure only the current energy needs of the country. It is strategically important for us to create a new energy industry that will provide a solid basis for dynamic economic development for decades to come. That is why I consider it necessary to build not one, but three nuclear power plants and, ultimately, form a full-fledged nuclear cluster. Given

¹³⁷³ - Радио Азаттык, “Встреча платформы «АЭС керек емес» в Алматы прошла в присутствии людей из управления внутренней политики”, *Radio Free Europe/Radio Liberty*, 19 September 2024, see <https://rus.azattyq.org/a/33126328.html>, accessed 7 July 2025; and Радио Азаттык, “Первая в Казахстане АЭС будет построена в Алматинской области, которая граничит с Чуйской и Иссык-Кульской областями Кыргызстана”, *Radio Free Europe/Radio Liberty*, 25 February 2025, see <https://rus.azattyq.org/a/pervaya-v-kazahstane-aes-budet-postroena-v-almatinskoy-oblasti-kotoraya-granichit-s-chuyskoy-i-issyk-kulskoy-oblastyami-kyrgyzstana/33327480.html>, accessed 13 May 2025.

¹³⁷⁴ - Радио Азаттык, “В Алматы завели уголовные дела против более десятка активистов перед референдумом по АЭС”, *Radio Free Europe/Radio Liberty*, 1 October 2024, see <https://rus.azattyq.org/a/33141509.html>, accessed 30 June 2025; and Власть, “Дела пяти задержанных перед референдумом по АЭС активистов переданы в суд”, *vlast.kz*, 16 June 2025, see <https://vlast.kz/novosti/65348-dela-pati-zaderzannyh-pered-referendumom-po-aes-aktivistov-peredany-v-sud.html>, accessed 8 July 2025; also Amnesty International, “Kazakhstan 2024”, 17 July 2025, see <https://www.amnesty.org/en/location/europe-and-central-asia/eastern-europe-and-central-asia/kazakhstan/report-kazakhstan/>, accessed 17 July 2025.

¹³⁷⁵ - Ibidem; and Власть, “«Какой госпереворот могут сделать пенсионеры?»”, 6 February 2025, see <https://vlast.kz/politika/63754-kakoj-gosperevorot-mogut-sdelat-pensionery.html>; also Власть, “Суд вновь продлил арест пяти активистам, задержанным перед референдумом по строительству АЭС”, 24 February 2025, see <https://vlast.kz/kz/novosti/63988-sud-vnov-prodlil-arest-pati-aktivistam-zaderzannym-pered-referendumom-po-stroitelstvu-aes.html>; both accessed 8 July 2025.

¹³⁷⁶ - Алина Шашкина, “Референдум по АЭС: озвучены итоговые результаты голосования”, *Tengri News*, 8 October 2024, see https://tengrinews.kz/kazakhstan_news/referendum-aes-ozvuchenyi-itogovyie-rezultaty-golosovaniya-550317/, accessed 5 May 2025; and Central Election Commission, “The Central Referendum Commission of the Republic of Kazakhstan Has Announced the Results of the Republican Referendum”, Press Release, Government of Kazakhstan, 8 October 2024, see <https://www.election.gov.kz/eng/news/releases/index.php?ID=9596>, accessed 15 July 2025.

¹³⁷⁷ - Тамара Вааль, “Ядерный кластер будет создан в Казахстане - Токаев”, *Власть*, 28 January 2025, see <https://vlast.kz/novosti/63633-adernyj-klaster-budet-sozdan-v-kazahstane-tokaev.html>, accessed 12 May 2025.

¹³⁷⁸ - President of Kazakhstan, “Правовые акты—О мерах по дальнейшему совершенствованию системы государственного управления Республики Казахстан”, 18 March 2025, see <https://akorda.kz/ru/o-merah-po-dalneyshemu-sovershenstvovaniyu-sistemy-gosudarstvennogo-upravleniya-respubliki-kazakhstan-1822324>, accessed 14 July 2025.

the exceptional importance of this task, I decided to create a Nuclear Energy Agency under the President.¹³⁷⁹

In February 2025, by decree, the site of the first nuclear power plant was officially narrowed down to the Zhambyl district of the Almaty region.¹³⁸⁰ More specifically, Ülken, a small settlement at the southern end of Lake Balkhash, has been mentioned as the preferred location for the plant.¹³⁸¹ Although the village was not officially named in the government decree, civil activist Alnur Ilyashev filed a lawsuit challenging the government's decision to define this location for the plant. Ilyashev raised concerns about the proposed site's proximity to the Sary-Shagan military ballistic missile defense test site, which is just 22 kilometers from the borders of the Ülken rural district. He argues that this poses significant risks, citing International Atomic Energy Agency (IAEA) safety standards, which recommend a much greater distance between such facilities and sensitive areas.¹³⁸²

In March 2025, the government planned to select a vendor or consortium by 1 July 2025¹³⁸³ and “conclude an intergovernmental agreement and relevant contracts” by November 2025.¹³⁸⁴

Until 14 June 2025, the list of possible companies to build the power plant included Russia's Rosatom, China's CNNC, France's EDF, and Korea's KHNP. The envisaged designs all corresponded to large units.¹³⁸⁵ But finally, the Atomic Energy Agency of Kazakhstan announced Rosatom as the technical supplier of the first new Kazakhstani nuclear power plant.¹³⁸⁶ Possibly to dispel the doubts of the critics, Almasadam Satkaliyev, chairman of the Atomic Energy Agency, assured that “the station will be completely Kazakhstani. The owner, operator, and manufacturer of uranium raw materials will be the Republic of Kazakhstan.”¹³⁸⁷ On 20 June 2025, both parties agreed on an “Indicative Road Map...envisaging the stages of project preparation and implementation, including surveying, conclusion of an EPC [Engineering,

¹³⁷⁹ - President of Kazakhstan, “Выступление Главы государства Касым-Жомарта Токаева на четвертом заседании Национального курултая”, 12 May 2025, see <https://www.akorda.kz/ru/vystuplenie-glavy-gosudarstva-kasym-zhomarta-tokaeva-na-chetvertom-zasedanii-nacionalnogo-kurultaya-142359>, accessed 12 May 2025.

¹³⁸⁰ - *Tengri News*, “В Казахстане утвердили место строительства первой АЭС”, 25 February 2025, see https://tengrinews.kz/kazakhstan_news/v-kazahstane-utverdili-mesto-stroitelstva-pervoy-aes-563510/, accessed 13 May 2025.

¹³⁸¹ - Светлана Антонова, “Равнодушных практически нет”. Большие надежды маленького Улкана”, *Tengri News*, 27 September 2024, see <https://tengrinews.kz/article/ravnodushnyih-prakticheski-net-bolshie-nadejdy-malenkogo-2582/>, accessed 2 July 2025; and Prime Minister of Kazakhstan, “Nuclear Power Plants Among Safest and Most Reliable Energy Sources Worldwide – Expert”, 27 August 2024, see <https://primeminister.kz/en/news/nuclear-power-plants-among-safest-and-most-reliable-energy-sources-worldwide-expert-28991>, accessed 14 July 2025.

¹³⁸² - *KazTAG*, “Строительство АЭС в Казахстане – суд приступил к рассмотрению иска к правительству”, *Kazakh Telegraph Agency*, 13 June 2025, see <https://kaztag.kz/ru/news/stroitelstvo-aes-v-kazahstane-sud-pristupil-k-rassmotreniyu-iska-k-pravitelstvu->, accessed 7 July 2025; and Данияр Ишанов, “АЭС у арендуемого Россией полигона: суд по иску активиста Альнура Ильяшева завершается в Астане”, *BES.media*, 4 July 2025, see <https://bes.media/news/aes-u-sari-shagana-sud-po-isku-alnura-ilyasheva-vishel-na-finishnyu-priamuyu-v-astane>, accessed 9 July 2025.

¹³⁸³ - That has apparently not happened.

¹³⁸⁴ - Prime Minister of Kazakhstan, “Ministry of Energy of Kazakhstan: 2024 Results and Strategic Plans for 2025”, 3 March 2025, see <https://primeminister.kz/en/news/reviews/ministry-of-energy-of-kazakhstan-2024-results-and-strategic-plans-for-2025-29771>, accessed 14 July 2025.

¹³⁸⁵ - Prime Minister of Kazakhstan, “Nuclear Power Plants Among Safest and Most Reliable Energy Sources Worldwide – Expert”, 27 August 2024, op. cit.

¹³⁸⁶ - Atomic Energy Agency of Kazakhstan, “Выбран лидер международного консорциума для строительства первой АЭС в Казахстане”, Government of Kazakhstan, 14 June 2025, see <https://betaegov.kz/memleket/entities/atom-energiyasy/press/news/details/1017485>, accessed 14 July 2025.

¹³⁸⁷ - Азаттық Азия, “«Росатом» возглавит строительство первой АЭС в Казахстане. Как Астана делала выбор”, *Радио Азаттық*, 14 June 2025, see <https://rus.azattyq.org/a/rosatom-vozglavit-stroitelstvo-pervoy-aes-v-kazahstane-vtoruyu-aes-kitay-predpolozhitelno-kak-astana-delala-vybor/33443071.html>, accessed 30 June 2025.

Procurement and Construction] contract and development of project documentation,” while Atomstroyexport and Kazakhstan Nuclear Power Plants concluded a framework agreement.¹³⁸⁸ Although no price for the project has been communicated so far, the intergovernmental agreement is reportedly planned to be signed by the end of 2025.¹³⁸⁹

On the same day as proclaiming Rosatom as the winning bidder, Chairman Satkaliyev of the Atomic Energy Agency issued a separate statement setting the stage for a later agreement with CNNC:

We plan to sign a separate general agreement with China on cooperation in the nuclear industry. And we want to see Chinese technologies in Kazakhstan for the construction of another nuclear power plant...Objectively, there are not many countries in the world that can master the entire nuclear cycle on their own. And China is undoubtedly one of the countries that has all the necessary technologies and the entire industrial base, and our next main priority is cooperation with China...We have a very high level of agreement. We are interested in adopting Chinese experience, we understand their ability to carry out construction quickly and efficiently, and we have already begun working in this direction¹³⁹⁰

According to the government, work is already underway to “select locations for two additional plants,”¹³⁹¹ among them is the town of Kurchatov in Eastern Kazakhstan.¹³⁹²

In recent years, Kazakhstan has increasingly engaged in strategic partnerships concerning uranium mining, e.g., with France,¹³⁹³ and uranium supply deals with countries seeking an alternative to Russian uranium following the Russian invasion of Ukraine.¹³⁹⁴

Saudi Arabia

Saudi Arabia established The King Abdullah City for Atomic and Renewable Energy (KA-CARE) in 2010.¹³⁹⁵ Progress in the past decade and a half has been slow at best, and mostly involved

¹³⁸⁸ - Rosatom, “Rosatom and Agency for Atomic Energy of the Republic of Kazakhstan Approved Roadmap for NPP Construction in Kazakhstan”, Press Release, 20 June 2025, see <https://rosatom.ru/en/press-centre/news/rosatom-and-agency-for-atomic-energy-of-the-republic-of-kazakhstan-approved-roadmap-for-npp-construction/>, accessed 23 June 2025.

¹³⁸⁹ - Азаттық Азия, “Казахстан планирует до конца года подписать соглашение с Россией о строительстве АЭС”, *Радио Азаттык*, 14 June 2025, see <https://rus.azattyq.org/a/33456350.html>, accessed 7 July 2025.

¹³⁹⁰ - Atomic Energy Agency of Kazakhstan, “Китайская CNNC станет лидером консорциума по строительству еще одной АЭС в Казахстане”, Government of Kazakhstan, 14 June 2025, see <https://beta.gov.kz/memleket/entities/atom-energiyasys/press/news/details/1017542>, accessed 17 July 2025.

¹³⁹¹ - Prime Minister of Kazakhstan, “Six Years of Progress: Kazakhstan on Sustainable Development Pathway”, 17 March 2025, see <https://primeminister.kz/en/news/six-years-of-progress-kazakhstan-on-sustainable-development-pathway-29812>, accessed 14 July 2025.

¹³⁹² - Надежда Лыкова, “Подходящие площадки для строительства второй казахстанской АЭС назвали в Минэнерго”, *Tengri News*, 26 February 2025, see https://tengrinews.kz/kazakhstan_news/podhodyaschie-ploschadki-stroitelstva-vtoroy-kazahstanskoy-563659/, accessed 14 May 2025.

¹³⁹³ - WNN, “Presidents Look to Strengthen Kazakh-French Partnership”, 6 November 2024, see <https://world-nuclear-news.org/articles/presidents-look-to-strengthen-kazakh-french-partnership>, accessed 14 May 2025.

¹³⁹⁴ - Kazatomprom, “Kazatomprom Signs a New Supply Agreement with ČEZ, a. s.”, 15 April 2025, see https://www.kazatomprom.kz/en/media/view/signs_a_new_supply_agreement_with_%C4%8CEZ; and Kazatomprom, “Kazatomprom and Axpo Power AG Sign First-Ever Contract for the Supply of Uranium to Nuclear Power Plants in Switzerland”, 17 February 2025, see https://www.kazatomprom.kz/en/media/view/kazatomprom_and_axpo_power_ag_sign_first-ever_contract_for_the_supply_of_uranium_to_nuclear_power_plants_in_switzerland; both accessed 15 July 2025.

¹³⁹⁵ - Abdullah bin Abdul Aziz Al Saud, “Royal Decree Establishing King Abdullah City for Atomic and Renewable Energy”, Decree No A/35, 2010, see <https://www.climate-laws.org/geographies/saudi-arabia/policies/royal-decree-establishing-king-abdullah-city-for-atomic-and-renewable-energy-2010>, accessed 11 June 2021.

officials reiterating plans to build nuclear plants. As the Saudi Minister of Energy declared at the General Conference of the IAEA in September 2024, “the Kingdom is moving towards utilizing nuclear energy and its radiation applications for peaceful purposes... including the construction of the first nuclear power plant in the Kingdom.”¹³⁹⁶

The slow rate of progress is also seen in choosing the potential builders of Saudi Arabia’s first nuclear plant. In mid-2022, KA-CARE invited bids from South Korea, China, France, and Russia to construct two nuclear reactors.¹³⁹⁷ Since then the deadlines have been extended several times. One unnamed source told the *Middle East Economic Digest* (MEED) in early 2025 that the bid deadline is “more like a moving target, running in parallel with the progress in the bilateral government-to-government talks.”¹³⁹⁸

In 2023, *Nuclear Intelligence Weekly* reported that Saudi Arabia had received bids from Korea Electric Power Company (KEPCO), China National Nuclear Corporation (CNNC), Russia’s state-owned Rosatom, and France’s EDF.¹³⁹⁹ However, in May 2025, KEPCO reportedly said that it has been in talks with Saudi Arabia and the company is “pushing to submit bids to six different energy projects in the region, including a nuclear power plant construction project and a combined heat and power plant project in Saudi Arabia, this year.”¹⁴⁰⁰ This suggests that it has not yet put in a bid.

No U.S. company has put in a bid. The Congressional Research Service says as of September 2024 that

Congress has directed that no funds appropriated for the Department of State, foreign operations, and related programs ‘should’ be used by the Export-Import bank to support nuclear exports to Saudi Arabia until the kingdom has a 123 agreement ‘in effect’; ‘has committed to renounce uranium enrichment and reprocessing on its territory under that agreement’; and has ‘signed and implemented’ an Additional Protocol with the IAEA.¹⁴⁰¹

However, in April 2025, U.S. Secretary of Energy Chris Wright reportedly declared that his government “has revived talks with Saudi officials over a deal that would give Saudi Arabia access to U.S. nuclear technology and potentially allow it to enrich uranium” that is meant to “enable the kingdom to develop a commercial nuclear power industry.”¹⁴⁰² The following month, upon the conclusion of preliminary agreements on energy and critical minerals cooperation, the U.S. Department of Energy specified: “The two sides also outlined areas for cooperation on civil nuclear energy, including safety, security, and nonproliferation programs;

¹³⁹⁶ - Abdulaziz bin Salman bin Abdulaziz, “National Statement of the Kingdom of Saudi Arabia”, Minister of Energy, Government of Saudi Arabia, delivered at the 68th General Conference of the International Atomic Energy Agency, 16 September 2024, see https://www.iaea.org/sites/default/files/24/09/saudi_arabia-gc68.pdf, accessed 29 April 2025.

¹³⁹⁷ - Dan Yurman, “Saudi Arabia Kicks Off RFP for Twin 1400 MWe PWRs”, *Neutron Bytes*, 2 June 2022, see <https://neutronbytes.com/2022/06/02/saudi-arabia-kicks-off-rfp-for-twin-1400-mwe-pwrs/>, accessed 25 July 2024.

¹³⁹⁸ - Jennifer Aguinaldo, “Saudi Arabia Holds High-Level Nuclear Talks”, *Middle East Economic Digest*, 23 April 2025, see <https://www.meed.com/saudi-arabia-holds-high-level-nuclear-talks>, accessed 28 June 2025.

¹³⁹⁹ - Phil Chaffee and Jessica Sondgeroth, “Vendors Line Up for Saudi Nuclear Plant”, *Nuclear Intelligence Weekly*, 31 March 2023.

¹⁴⁰⁰ - *Yonhap News Agency*, “KEPCO in Talks with Vietnam, Saudi Arabia, Turkey for Potential Power Plant Deals”, 29 May 2025, see <https://koreajoongangdaily.joins.com/news/2025-05-29/business/industry/Kepco-in-talks-with-Vietnam-Saudi-Arabia-Turkey-for-potential-power-plant-deals/2318315>, accessed 28 June 2028.

¹⁴⁰¹ - Christopher M. Blanchard and Paul K. Kerr, “Prospects for U.S.-Saudi Nuclear Energy Cooperation”, Congressional Research Service, Updated 23 September 2024, see <https://sgp.fas.org/crs/mideast/IF10799.pdf>, accessed 16 July 2025.

¹⁴⁰² - Vivian Nereim, “U.S. Revives Talks With Saudi Arabia on Transfer of Nuclear Technology”, *The New York Times*, 13 April 2025, see <https://www.nytimes.com/2025/04/13/world/middleeast/saudi-arabia-nuclear-talks-trump.html>, accessed 14 April 2025.

vocational training and workforce development; U.S. Generation III+ advanced large reactor technologies and small modular reactors; uranium exploration, mining, and milling; and safe and secure nuclear waste disposal.”¹⁴⁰³ Even if these talks move forward, it is unlikely to result in a reactor export in the short term.

In the meanwhile, total renewable energy capacity in Saudi Arabia has grown from 24 MW (solar only) in 2015 and 3 GW in 2023 to 4.7 GW in 2024, a 200-fold increase over a decade.¹⁴⁰⁴ Renewable energy still constitutes only 5 percent of the total electricity capacity. The bulk of renewable capacity remains solar with over 90 percent. Wind energy capacity has been stagnant at 403 MW since 2022. Production of electricity from solar and wind power plants in 2024 amounted to only 8.2 TWh and 1.6 TWh respectively, only 2.2 percent of the total amount electricity generated, the rest being covered by natural gas (over 63 percent) and oil (34.5 percent).¹⁴⁰⁵

Uzbekistan

Although Uzbekistan’s uranium reserves are smaller than those of neighboring Kazakhstan, the country has significantly increased its uranium mining activities in recent years.¹⁴⁰⁶ Similar to Kazakhstan, electricity production in Uzbekistan is heavily dependent on fossil fuels. However, unlike Kazakhstan, where coal is the main energy source, Uzbekistan’s main source of power generation is natural gas, accounting for over 80 percent of the electricity mix in 2023.¹⁴⁰⁷ As in Kazakhstan, the demand for energy in Uzbekistan is projected to double by 2030.¹⁴⁰⁸

In 2017, Uzbekistan entered into a framework agreement on nuclear cooperation with Russia. This was followed in September 2018 by a more specific agreement for Rosatom to construct two VVER-1200 reactors.¹⁴⁰⁹

In an April 2019 interview with *Nuclear Engineering International* (NEI), Jurabek Mirzamakhmudov, Director General of Uzatom—the state-controlled Atomic Energy Agency of Uzbekistan—announced plans to conduct site analysis at three potential locations. Mirzamakhmudov stated that the project would be partially financed through a soft loan from

¹⁴⁰³ - U.S. Department of Energy, “United States and Saudi Arabia Strengthen Alliance with Energy & Critical Mineral Deals”, United States Government, 13 May 2025, see <https://www.energy.gov/articles/united-states-and-saudi-arabia-strengthen-alliance-energy-critical-mineral-deals>, accessed 16 July 2025.

¹⁴⁰⁴ - IRENA, “Renewable Capacity Statistics 2025”, March 2025, op. cit.

¹⁴⁰⁵ - Energy Institute, “Statistical Review of World Energy 2025”, 74th Edition, June 2025, see https://www.energyinst.org/_data/assets/excel_doc/0008/1656215/EI-Stats-Review-ALL-data.xlsx, accessed 27 June 2025.

¹⁴⁰⁶ - WNA, “World Uranium Mining Production” Updated 16 May 2025, see <https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production>, accessed 17 July 2025; and NEA and IAEA, “Uranium 2024: Resources, Production and Demand”, NEA No. 7683, Nuclear Energy Agency and International Atomic Energy Agency, 23 April 2025, see https://www.oecd-nea.org/jcms/pl_103179/uranium-2024-resources-production-and-demand?details=true, accessed 17 June 2025.

¹⁴⁰⁷ - EMBER, “Uzbekistan—Electricity Data Explorer”, Updated 10 April 2025, see <https://ember-energy.org/data/electricity-data-explorer/?entity=Uzbekistan>, accessed 22 July 2025.

¹⁴⁰⁸ - *Gazeta*, “Uzbekistan’s Electricity Demand to Grow Steadily by 7.5% Annually Until 2030 — Energy Minister”, 30 September 2024, see <https://www.gazeta.uz/en/2024/09/30/jurabek-mirzamakhmudov>, accessed 9 July 2025; and World Bank Group, “Uzbekistan to Enhance Energy Production through Hydropower with World Bank Support”, Press Release, 25 June 2025, see <https://www.worldbank.org/en/news/press-release/2025/06/25/uzbekistan-to-enhance-energy-production-through-hydropower-with-world-bank-support>, accessed 17 July 2025.

¹⁴⁰⁹ - *NEI Magazine*, “Uzbekistan’s Energy Plans”, 29 July 2020, see <https://www.neimagazine.com/advanced-reactorsfusion/uzbekistans-energy-plans-8051183/>, accessed 13 September 2024.

Russia. While the reactors are intended primarily to supply power for domestic use, some of the electricity could also be exported to neighboring countries, such as Afghanistan.¹⁴¹⁰ It was later reported that the goal was to select and license a site by September 2020;¹⁴¹¹ however, this timeline was not met.

The first export contract for an SMR anywhere in the world

In May 2022, Mirzamakhmudov announced that a site had been selected in the Farish district of the Jizzakh region, near Lake Tuzkan, to host two Rosatom supplied VVER-1200 reactors. He noted in an interview that while the financing package was still under negotiation, sanctions imposed on Russia due to the war in Ukraine would not affect the project.¹⁴¹²

Nevertheless in May 2024, Uzbekistan apparently moved away from the idea to build two large nuclear reactors and signed an agreement with Russia's Rosatom to build six 55-MW Small Modular Reactors (SMRs) in the eastern Jizzakh region, which marks the first export contract for an SMR anywhere in the world.¹⁴¹³ The design to be implemented is the RITM-200N, an adaptation for land-based applications of the RITM-200 design that is used on the Russian icebreaker fleet.¹⁴¹⁴ If built, this will be the reactor's first installation outside Russia.

In April 2025, per Rosatom "on-site work began to set up a construction yard that will accommodate production facilities (particularly prefabrication workshops), administrative buildings, and warehouses" to support the construction of the RITM-200 cluster in the Jizzakh region.¹⁴¹⁵ Additionally, Rosatom began with the production of the reactor pressure vessel of the first reactor block of the RITM-200 cluster.¹⁴¹⁶ In April 2025, the head of Rosatom was quoted by Russian news agency TASS as saying that licensing and first concrete would be "implemented in a year or maybe earlier."¹⁴¹⁷

In April 2025 Shanghai Electric was named as potential manufacturer for the turbines of the reactor following a meeting between Uzatom, Rosatom, and Shanghai Electric at the office of China National Nuclear Corporation (CNNC).¹⁴¹⁸

¹⁴¹⁰ - NEI Magazine, "Uzbekistan's Nuclear Aspirations", Interview with Jurabek Mirzamakhmudov, Director General of Uzatom, 9 April 2019, see <https://www.neimagazine.com/features/featureuzbekistans-nuclear-aspirations-7145738/>, accessed 1 May 2021.

¹⁴¹¹ - WNN, "Russia and Uzbekistan Agree to Start Survey of New Plant Site", 17 May 2019, see <https://www.world-nuclear-news.org/Articles/Russia-and-Uzbekistan-agree-to-start-survey-of-new>, accessed 1 May 2021.

¹⁴¹² - Nuclear Intelligence Weekly, "Uzbekistan – Site Selected for First Nuclear Plant", 1 July 2022.

¹⁴¹³ - Nuclear Intelligence Weekly, "Newbuild: Uzbekistan Shifts Plans From Large Reactors to SMRs", 31 May 2024; and Rosatom, "The Russian Federation and Uzbekistan Sign an Agreement on the Construction of a Small Nuclear Power Plant", Press Release, 27 May 2024, see <https://www.rosatom.ru/en/press-centre/news/the-russian-federation-and-uzbekistan-sign-an-agreement-on-the-construction-of-a-small-nuclear-powe/>, accessed 31 May 2024; and Interfax, "Росатом' выбран для возведения малой АЭС в Узбекистане", 15 October 2024, see <https://www.interfax.ru/business/986768>, accessed 8 July 2025.

¹⁴¹⁴ - Iaroslav O. Bykh and Inna V. Yurina, "Regulatory Control Features and Principles for a Land-Based RITM-200N SNPP Project", Rosatom, as presented at 21st INPRO Dialogue Forum on the Deployment of Small Modular Reactor Projects and Technologies to Support the Sustainable Development Goals (SMRs for SDGs), IAEA.

¹⁴¹⁵ - Rosatom, "Uzbekistan: Nuclear Future Takes Shape", Newsletter #290, June 2025, see <https://rosatomnewsletter.com/2025/06/23/uzbekistan-nuclear-future-takes-shape/>, accessed 15 July 2025.

¹⁴¹⁶ - Ibidem; and Rosatom, "Rosatom Starts Production of Reactor Equipment for the First Unit of Low-Power NPP in Uzbekistan", Press Release, 13 May 2025, see <https://rosatom.ru/en/press-centre/news/rosatom-starts-production-of-reactor-equipment-for-the-first-unit-of-low-power-npp-in-uzbekistan/>, accessed 23 June 2025.

¹⁴¹⁷ - TASS, "First Concrete Can Be Poured at Nuclear Plant Site in Uzbekistan in a Year — Rosatom", see <https://tass.com/economy/1950507>, accessed 17 July 2025.

¹⁴¹⁸ - Interfax, "Uzatom, Rosatom, CNNC Might Sign Trilateral Agreement on Nuclear Plant Project in Uzbekistan", 23 April 2025, see <https://interfax.com/newsroom/top-stories/111130/>, accessed 15 July 2025.

In June 2025, Deputy Prime Minister of the Russian Federation, Alexander Novak, reportedly stated that “Today, specific economic parameters are being discussed. Two units of 1000 MW each and two units of 55 MW each.”¹⁴¹⁹ The next day, Rosatom announced that an agreement with Uzatom had been officialized “to study the possibilities of implementing a project to construct a large nuclear power plant in the Republic of Uzbekistan” which “specifies the main terms and conditions for the potential implementation of the construction of two VVER-1000 power units with possible upgrade to four units.”¹⁴²⁰ Rosatom had reportedly already signaled in April 2025, that “it is not a question of if, but when the leadership of Uzbekistan returns to the topic of a large nuclear power plant, we will have proposals ready.”

This statement contradicts both the initial plan to build two VVER-1200 reactors and the official plan to build six RITM-200N reactors.

Thus, according to some sources the plan to build six RITM-200N reactors was “upgraded” to include two VVER-1000 reactors and two RITM-200N reactors. It has not yet been disclosed whether the VVER-1000 and RITM-200N reactors will be built at the same location or at separate sites.¹⁴²¹

¹⁴¹⁹ - *Interfax*, “Russia, Uzbekistan Discussing Economic Parameters of NPP Construction - Deputy PM Novak”, 19 June 2025, see <https://interfax.com/newsroom/top-stories/112135/>, accessed 17 July 2025.

¹⁴²⁰ - Rosatom, “Uzatom and Rosatom Increasing Cooperation in Enhancing Nuclear Power Capacity in the Republic of Uzbekistan”, 20 June 2025, see <https://rosatom.ru/en/press-centre/news/uzatom-and-rosatom-increasing-cooperation-in-enhancing-nuclear-power-capacity-in-the-republic-of-uzb/>, accessed 23 June 2025.

¹⁴²¹ - *Eurasia Daily*, “Проект «Росатома» в Узбекистане увеличился на большую АЭС”, 12 June 2025, see <https://eadaily.com/ru/news/2025/06/12/proekt-rosatoma-v-uzbekistane-uvelichilsya-na-bolshuyu-aes>, accessed 8 July 2025.

RUSSIA NUCLEAR INTERDEPENDENCIES

Russia is a major global supplier of nuclear fuel services, including uranium mining, conversion, enrichment, and fuel assembly fabrication for Soviet-designed VVER pressurized water reactors, of which there are 19 in the E.U. and 15 in Ukraine. In particular, since Russia's full-scale invasion of Ukraine in February 2022, E.U. members and others in the region have discussed and taken measures to deprive Russia of the considerable revenue streams provided by such businesses and reduce the inherent risk of the region's dependence on Russia. But compared to Russian supplies of oil, natural gas, and coal, the nuclear sector has received less attention. While the U.S. banned the import of uranium products from Russia in May 2024 (allowing for conditional waivers until 2028), the E.U. has not established any sanctions in the nuclear sector—a strong indicator of dependency on Russia.

However, as highlighted in this chapter, the dependency is multi-faceted; Russia is also dependent on the West for European companies' cutting-edge technology used in its reactors, and business interests of these same companies have certainly contributed to prevent or delay sanctions.

This chapter provides an updated overview of these interdependencies, with a special focus on the supply of VVER fuel elements in the E.U., which in the past have exclusively been provided by Russia. Meanwhile, all E.U. and Ukraine operators of VVER reactors have signed contracts with alternative fuel suppliers from Western countries, where the Russian government-controlled company, Rosatom, is still partially involved. Further, the E.U. announced a Roadmap Towards Ending Russian Energy Imports that is to be translated into legislative proposals, which will possibly include measures in the nuclear sector. Western companies have also announced significant expansions of their uranium enrichment capacities to accelerate the end of Russian dominance in this area.

RUSSIA'S ROLE IN THE GLOBAL NUCLEAR FUEL SUPPLY CHAIN

According to the World Nuclear Association (WNA), as of 2022, Russia held about 20 percent of the world's estimated primary uranium conversion capacities¹⁴²² and 44 percent of enrichment capacities globally.¹⁴²³ Russia therefore clearly dominates uranium enrichment services globally. Its share of the worldwide capacities will change over the coming years due to added capacities in other countries, but a clear picture on the global scale is yet to emerge—beyond the E.U. only partial information is available on individual countries' uranium conversion and enrichment capacities. In 2022, Russia also contributed 5 percent to the world's natural

¹⁴²² - WNA, "Conversion and Deconversion", World Nuclear Association, Updated 20 November 2024, see <https://world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/conversion-and-deconversion>, accessed 15 May 2025.

¹⁴²³ - WNA, "Uranium Enrichment", Updated 21 March 2025, see <https://world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment>, accessed 16 May 2025.

uranium production, while Kazakhstan provided 43 percent and Uzbekistan an estimated 6.7 percent (both countries have close ties to Russia).¹⁴²⁴

In 2024, the U.S. imported 335 tons of enriched uranium from Russia (valued at US\$624 million), down from 702 tons (US\$1.2 billion) in 2023—the highest volume since 2013—and 588 tons (US\$830 million) in 2022. Thus the U.S. reduced the quantity of these imports last year by more than 52 percent compared to 2023 when Russia was its largest supplier.¹⁴²⁵ In May 2024, the U.S. introduced a ban on the import of Russian uranium products into the U.S. starting in August 2024, but it allows for a waiver process through 1 January 2028.¹⁴²⁶ Russia responded with a “tit-for-tat” ban on enriched uranium exports to the U.S. in November 2024. However, a Kremlin spokesperson reportedly stated that “in cases where it serves our interests, Russia’s Federal Service for Technical and Export Control may decide to exclude certain items from this list of bans.”¹⁴²⁷ In other words, the Russian ban is supposed to work exactly as the U.S. one: if in the national interest, a waiver may be granted. Whether the reduced U.S. imports of enriched uranium in 2024 reflect an effect of these mutual sanctions or not remains unclear.

On the other hand, an analysis of Chinese trade data shows increased deliveries of enriched uranium from Russia to China and a significant increase in deliveries from China to the U.S. in 2023 and 2024.¹⁴²⁸ In particular, China’s imports from Russia reached a maximum of 748 t in 2024,¹⁴²⁹ after 467 t in 2023, 685 t in 2022, 0 t in 2021, 48 t in 2020, and 504 t in 2019. In the same time frame, U.S. imports from China were 7 t in 2019, no reported imports between 2020 and 2022, but 294 t in 2023 and 124 t in 2024, so that China ranked as the sixth largest enriched uranium supplier (of ten) to the U.S. in 2023 and 2024.¹⁴³⁰ Whether these deliveries are to be considered as a “displacement” of the reduced deliveries from Russia to the U.S. cannot be established from this data.

Figure 54 shows the origin of natural uranium, conversion services, and enrichment services supplied to the E.U. based on data provided by the Euratom Supply Agency (ESA). After a spike in all three categories in 2023, Rosatom’s share decreased in 2024, but it still provided 16–24 percent of the respective services in 2024 compared to a 23.5–38 percent share in 2023.

¹⁴²⁴ - WNA, “World Uranium Mining Production”, Updated 16 May 2024, see <https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production>, accessed 22 June 2025.

¹⁴²⁵ - Research by products “HS code 284420-Enriched uranium and plutonium and their compounds”; see World Integrated Trade Solution, “United States Enriched Uranium and Plutonium and Their Compou Imports by Country”, World Bank, as of 3 July 2025, see <https://wits.worldbank.org/trade/comtrade/en/country/USA/year/2024/tradeflow/Imports/partner/ALL/product/284420>, accessed 3 July 2025.

¹⁴²⁶ - U.S. Department of State, “Prohibiting Imports of Uranium Products from the Russian Federation”, Press Release, United States Government, 14 May 2024, see <https://2021-2025.state.gov/prohibiting-imports-of-uranium-products-from-the-russian-federation/>, accessed 26 June 2025.

¹⁴²⁷ - Government of Russia, “Правительство ввело временные ограничения на экспорт обогащённого урана в США—Постановление от 14 ноября 2024 года №1544”, Resolution No. 1544 of 14 November 2024, 2024; and TASS, “Russia May Lift Ban on Uranium Exports to US If It Aligns with National Interests, Kremlin”, 18 November 2024, see <https://tass.com/economy/1873935>, accessed 26 June 2025.

¹⁴²⁸ - Darya Dolzikova, “Russia’s Role in Global Nuclear Supply Chains”, Senior Researcher, Proliferation and Nuclear Policy, Royal United Services Institute, presented at “Bellona Forum: Russia’s Nuclear Industry in Times of War”, Bellona, posted on Youtube, 13 May 2025, see <https://www.youtube.com/watch?v=Xg2rqmqjAgk>, accessed 15 May 2025.

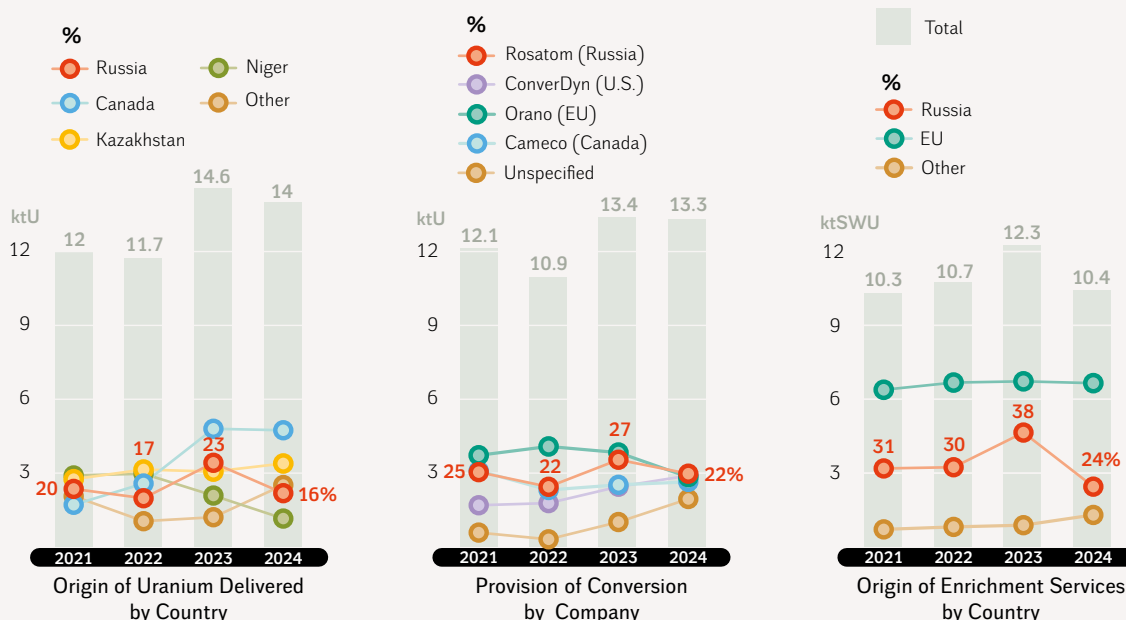
¹⁴²⁹ - Research by products “HS code 284420-Enriched uranium and plutonium and their compounds”; see World Integrated Trade Solution, “China Enriched Uranium and Plutonium and their Compou Imports by Country”, World Bank, as of 4 July 2025, see <https://wits.worldbank.org/trade/comtrade/en/country/CHN/year/2024/tradeflow/Imports/partner/ALL/product/284420>, accessed 4 July 2025.

¹⁴³⁰ - World Integrated Trade Solution, “United States Enriched Uranium and Plutonium and Their Compou Imports by Country”, World Bank, as of 3 July 2025, op. cit.

Figure 54 · Providers of Nuclear Fuel Services to the E.U.

Natural Uranium, Conversion and Enrichment Services to the E.U., by Provider Country 2021–2024

in Thousand Tons of Uranium (ktU) and Thousand Tons of Separative Work Units (ktSWU)



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Source: ESA, 2022–2025

Note: Total uranium delivered to E.U. utilities in 2021 also includes 196 t (1.6 percent) of re-enriched uranium, not represented.

According to ESA statements in early 2023, without Russia the nameplate capacity of uranium conversion and enrichment plants in the E.U. would be “sufficient for the E.U. to be self-dependent,” but the “Global West” would be missing enrichment capacity of 3,500–8,000 tSWU (thousand Separative Work Units).¹⁴³¹ According to their respective 2024 annual reports, Urenco (U.K.-Netherlands-Germany) and Orano (France) have announced plans to expand their global capacities by 1,800 tSWU¹⁴³² and 2,500 tSWU,¹⁴³³ respectively, i.e., 4,300 tSWU in total, accounting for a little more than the minimum capacity gap of 3,500 tSWU claimed earlier by ESA. The “Global West”, therefore, would significantly reduce its dependency on Russia for enrichment capacity.

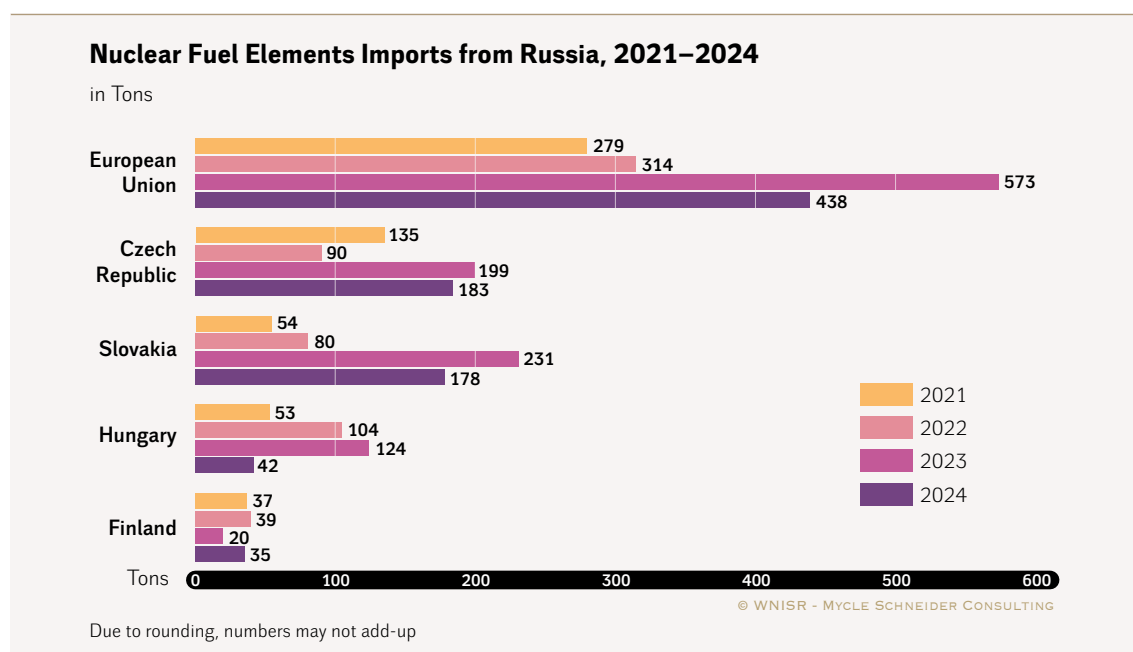
The E.U.’s fuel assembly imports from Russia for the 19 Soviet-designed VVERs (Vodo-Vodianoï Energuetitcheski Reaktor) have declined to 438 tons in 2024 from a peak of 573 tons in 2023, though they still exceed the 314 tons in 2022 (see Figure 54). The high volumes in 2023 and 2024 most likely reflect stockpiling, given political uncertainties and anticipated sanctions due to Russia’s war in Ukraine, until alternative fuel supplies become available.

¹⁴³¹ - Euratom Supply Agency, Slides from PPT Presentation at Hearing in German Federal Parliament, 6 February 2023.

¹⁴³² - Urenco, “Annual Report & Accounts 2024”, 2025, p. 7, see <https://www.urenco.com/cdn/uploads/supporting-files/Urenco-AR-2024.pdf>, accessed 26 June 2025.

¹⁴³³ - Orano, “Annual Activity Report 2024”, 2025, p. 322, see https://cdn.orano.group/orano/docs/default-source/orano-doc/finance/publications-financieres-et-reglementees/2024/orano_annual-activity-report_2024_online.pdf, accessed 26 June 2025.

Figure 55 - E.U. Imports of Russian Nuclear Fuel Elements

Source: Eurostat Database, 2025¹⁴³⁴Note: EU Total does not count imports to Bulgaria (data not available). For more detail, see investigation by Bellona.¹⁴³⁵

While the E.U.'s sanctions against Russia in response to its invasion of Ukraine—the 17th package of which was approved on 20 May 2025—have excluded the nuclear sector thus far, on 6 May 2025 the E.U. announced a Roadmap Towards Ending Russian Energy Imports, including nuclear supplies. The proposed measures include the following:

- ➔ trade measures to make the purchase of Russian enriched uranium less attractive
- ➔ a ban on new contracts with Russian suppliers through the Euratom Supply Agency
- ➔ development of a step-by-step phaseout plan for Russian nuclear imports in cooperation with Member States by the end of 2025

However, Hungary and Slovakia immediately rejected the plan, with the Slovakian prime minister qualifying the scope of measures as “simply economic suicide”.¹⁴³⁶

Five E.U. countries—Bulgaria, the Czech Republic, Finland, Hungary, and Slovakia—operate 19 Soviet-designed VVER reactors, 15 of which are 440s and four are 1000s. These countries are dependent on the supply of specific fuel and, in parallel, have particularly high shares of nuclear power in their respective electricity mixes, ranging from around 40 percent to over 60 percent (see Table 16). From the start of their reactors' operations, these countries have almost exclusively received fuel assemblies from TVEL, a 100-percent subsidiary of Rosatom.

¹⁴³⁴ - Research by products “Fuel elements ‘cartridges’, non-irradiated (...)”, on Eurostat Database, 2025, see https://ec.europa.eu/eurostat/databrowser/view/ds-045409__custom_16755586/default/table, accessed 18 May 2025.

¹⁴³⁵ - Charles Digges, “Europe Doubled Its Import of Russian Nuclear Fuel for 2023, Data Say”, Bellona, 15 March 2024, see <https://bellona.org/news/nuclear-issues/2024-03-europe-russian-nuclear-fuel>, accessed 16 July 2024.

¹⁴³⁶ - Jason Hovet, Anita Komuves, and Alan Charlish “Slovakia and Hungary Reject EU Plan to Phase Out Russian Gas by End-2027”, *Reuters*, 7 May 2025, see <https://www.reuters.com/business/energy/slovakia-rejects-eu-plan-phase-out-russian-gas-by-end-2027-2025-05-07/>, accessed 21 May 2025.

Table 16 · Fuel Supply for Soviet-designed Reactors in the E.U. and Ukraine (as of mid-2025)

Country	Nuclear Share 2024	Unit	Type	TVEL (Russia)	Westinghouse (U.S./Canada)	Framatome (France)
Bulgaria	41%	Kozloduy-5	VVER-1000	- Contract until 2025, terminated early - Resumption of deliveries (March–April 2025)	10-year supply contract (Dec. 2022) - First load (May 2024) - Second load (May 2025)	- Preliminary Agreement for 10-year supply (Dec. 2022) - Supply contract for 2025–2034 (2023)
		Kozloduy-6	VVER-1000		Contract for Safety Analysis to License Alternative Nuclear Fuel Design (Dec. 2024)	
Czech Republic	40.2%	Dukovany-1–4	VVER-440	- Fuel reload in Oct. 2023 at Dukovany-4 - Fuel reserve until approx. 2028 - Contract until 2028	7-year supply contract starting 2024 (April 2023) - First delivery (June 2025)	Ongoing negotiations as of May 2025
		Temelín-1–2	VVER-1000	- Supply since 2010 - Contract until 2023 - Last delivery in 2024 - Fuel reload completed in June 2024	- Supply 2000–2010 6 lead test assemblies loaded in 2019 10+-year contract (June 2022), supply starting 2024 - First delivery (June 2025)	
Finland	39.2%	Loviisa-1	VVER-440	Contract until end 2027	- Supply 2001–2007 - Supply contract (Nov. 2022) - Lead test assembly loaded: 2023 - First reload (Sept. 2024)	
		Loviisa-2	VVER-440	Contract until end 2030		
Hungary	42.8%	Paks-1–4	VVER-440	“Lifetime” supply contract - Fuel reserve until 2026		- MoU, incl. fuel supply (Sept. 2023) - Supply contract for delivery starting 2027 (Oct. 2024)
Slovakia	61.5%	Bohunice-3–4	VVER-440	- Supply contract 2022–2026, with option until 2030 (June 2019) - Supply contract extended to 2030 - Fuel reserve until mid-2027	- Supply contract (Aug. 2023) - First delivery 2026, first load 2027	- MoU, incl. fuel supply (May 2023) - Supply contract for delivery starting 2027 (July 2024)
		Mochovce-1–3	VVER-440			
Ukraine	52.4%	Rivne-1–2	VVER-440	Supply contract for 8 reactors 2021–2025 (Dec. 2018)	- Since 2010, fuel supplied to 6 VVER-1000 - Full load to South Ukraine-3 (July 2018) - Supply contract for all Ukrainian reactors (June 2022) - First load Rivne (Sept. 2023) - First delivery Khmelnytskyi (March 2024)	
		Khmelnyskyi-1–2	VVER-1000			
		Rivne-3–4	VVER-1000			
		South Ukraine-1–3	VVER-1000			
		Zaporizhzhia-1–6	VVER-1000			

Sources: Various, compiled by WNISR, 2025; all available in Annex 3.

Table 16 provides an overview of publicly available information on fuel supply agreements for the VVERs in the E.U. The multiple diversification initiatives aiming at the phaseout of fuel deliveries from Russia are described in more detail in the respective country sections. All VVER-operating countries in the E.U. have agreements in place for alternative fuel supply as of mid-2025, including Hungary which signed an agreement with Framatome in October 2024 but which remains the only country without a Westinghouse contract. On the other hand, to date, neither Finland nor Ukraine has signed an agreement with Framatome. In November 2024, Slovakia extended its supply contract with TVEL until 2030.¹⁴³⁷

Diversifying fuel supply for these reactors is complex. Westinghouse started manufacturing VVER-1000 fuel assemblies in 1998 and supplied Czech reactors at Temelín in their first decade of operation, starting in 2000.¹⁴³⁸ Westinghouse has since become the sole supplier in Ukraine and, starting in 2023, also provided first loads to VVER-440 reactors in the Czech Republic, Finland, and Ukraine.¹⁴³⁹ Development of Westinghouse fuel is supported by a Euratom funded project named APIS (Accelerated Program for Implementation of secure VVER fuel Supply) that started in 2023 and runs until 31 December 2025.¹⁴⁴⁰ In 2023 Ukrainian energy company Energoatom announced its intention to manufacture nuclear fuel for its reactors in cooperation with Westinghouse.¹⁴⁴¹ In May 2025, Energoatom received a license from Westinghouse for manufacturing fuel assembly components and announced that the first Ukrainian fuel assembly from its own production line will be loaded into a reactor core in 2027.¹⁴⁴² In the long term, Energoatom plans to manufacture half of Ukrainian nuclear fuel, the other half being provided by Westinghouse. The difficulty and complexity of diversifying nuclear fuel supply may be illustrated by the fact that Finland, on one hand, cancelled the Hanhikivi reactor project with Rosatom in 2022, soon after Russia's invasion of Ukraine, on the other hand, it almost doubled its import of Russian nuclear fuel in 2024 (see Figure 55), despite a fuel supply contract with Westinghouse in place since 2022. Simply switching the supplier, therefore, does not seem possible in the short term as it can be assumed that Finland is eager to become independent of Russia.

In addition to Westinghouse, Framatome is expected to join the ranks of VVER fuel manufacturers, following a dual track approach for short-term and long-term solutions. In the short-term, Framatome intends to manufacture the existing Russian VVER fuel design

¹⁴³⁷ - For respective references, see Table 25.

¹⁴³⁸ - See Russia Nuclear Dependencies in WNISR2024 for a history of Westinghouse's VVER fuel development.

¹⁴³⁹ - Westinghouse, "Westinghouse Completes First VVER Fuel Deliveries to Temelín and Dukovany Nuclear Power Plants". Westinghouse, "Westinghouse Completes First VVER-440 Fuel Reload at Finland's Loviisa Nuclear Power Plant", Press Release, 2 September 2024, see <https://info.westinghousenuclear.com/news/westinghouse-completes-first-vver-440-fuel-reload-at-finlands-loviisa-nuclear-power-plant>, accessed 1 May 2025; also Westinghouse, "Westinghouse Delivers First VVER-440 Fuel Assemblies to Energoatom", Press Release, 12 September 2023, see <https://info.westinghousenuclear.com/news/westinghouse-delivers-first-vver-440-fuel-assemblies-to-energoatom>, accessed 17 November 2023.

¹⁴⁴⁰ - APIS, "Accelerated Program for Implementation of secure VVER fuel Supply—Home", Accelerated Program for Implementation of secure VVER fuel Supply, 2024, see <https://apis-project.eu/>, accessed 31 May 2024; and CORDIS, "Accelerated Program for Implementation of Secure VVER Fuel Supply", Community Research and Development Information Service, European Commission, Updated 31 December 2024, see <https://cordis.europa.eu/project/id/101114673>, accessed 15 August 2025.

¹⁴⁴¹ - Energoatom, "Energoatom Prepares to Launch In-House Manufacture of Nuclear Fuel Components", 17 March 2023, see <https://old.energoatom.com.ua/app-eng/eng-1703231.html>, accessed 28 June 2025.

¹⁴⁴² - Energoatom, "Westinghouse Electric Sweden AB Has Recognized Energoatom Branch 'SS 'Atomenergomas' as a Qualified and Approved Supplier of Fuel Components for VVER Reactors", 9 May 2025, see <https://energoatom.com.ua/en/news/westinghouse-electric-sweden-ab-viznav-filiu-energoatoma-vp-atomenergomas-kvalifikovanim-ta-zatverdzenim-postacalnikom-komponentiv-iadernogo-paliva-tvz-dlia-reaktoriv-vver>, accessed 1 July 2025.

under TVEL license. To this end, Framatome has established a joint venture with TVEL for manufacturing VVER fuel at its plant in Lingen, Germany. This plan has drawn widespread criticism and is pending because, as of mid-2025, it has not been approved by the German government (see the [following section](#) for details). If the government rejects the plan, Framatome will not be able to fulfill its supply contracts, for example, with the Czech Republic which should have started already in 2024 and with Bulgaria which should start in 2025, as can be seen from [Table 16](#).

Framatome has been progressing on its own long-term VVER fuel design since 2018. Framatome hopes to begin fabricating the first lead-test assemblies in 2026, and after a test phase, the technology could be available in the early 2030s, according to the head of Fuel Business at Framatome.¹⁴⁴³ In addition, Euratom project SAVE (Safe and Alternative VVER European Project), led by Framatome, gathers seventeen partners from seven E.U. Member States as well as Ukraine to develop the new, European VVER fuel design. The project started in June 2024 and will run until 30 June 2028.¹⁴⁴⁴

Framatome and the Lingen VVER Fuel Manufacturing Plant Project¹⁴⁴⁵

In contrast to Westinghouse, which has developed and manufactured fuel assemblies for VVER-type reactors at least since 1998, Framatome has been completely absent from this market. However, on 2 December 2021, twelve weeks before Russia invaded Ukraine, Framatome announced that it had signed a long-term strategic agreement with Rosatom aimed at “further expanding the companies’ efforts to develop fuel fabrication and instrumentation and control (I&C) technologies.”¹⁴⁴⁶ Regarding the joint “efforts to develop fuel fabrication”, Framatome and TVEL had already founded a joint company in France in 2019 which was later renamed to “European Hexagonal Fuel SAS”.¹⁴⁴⁷ In March 2022, Framatome’s subsidiary Advanced Nuclear Fuels (ANF) filed an application with the environment ministry in Lower Saxony, Germany seeking permission to modify ANF’s facilities in Lingen to enable the licensed manufacturing of VVER fuel assemblies.¹⁴⁴⁸

¹⁴⁴³ - Grace Symes, “Fuel Fabrication: Framatome Awaiting German Authorization to Produce VVER Fuel”, *Energy Intelligence*, 1 March 2024, see <https://www.energyintel.com/0000018d-f0dd-d9ab-adff-f2fd0d950000>, accessed 31 May 2024.

¹⁴⁴⁴ - European Commission, “A New Euratom Project Will Help Diversify Nuclear Fuel Supply”, 20 June 2024, see https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/new-euratom-project-will-help-diversify-nuclear-fuel-supply-2024-06-20_en, accessed 22 June 2024; and European Commission, “Safe and Alternative VVER European Fuel”, Updated 21 June 2024, see <https://cordis.europa.eu/project/id/101114771>, accessed 9 July 2024.

¹⁴⁴⁵ - For a more comprehensive account, see [Framatome and the Lingen VVER Fuel Manufacturing Plant Project](#) in [WNISR2024](#); and Dmitry Gorchakov, “This German Town Could Decide the Future of EU Reliance on Russian Nuclear Fuel”, *Bellona*, 9 January 2025, see <https://bellona.org/news/nuclear-issues/2025-01-this-german-town-could-decide-the-future-of-eu-reliance-on-russian-nuclear-fuel>, accessed 23 April 2025.

¹⁴⁴⁶ - Framatome, “Framatome and Rosatom Sign Long-Term Cooperation Agreement”, Press Release, 2 December 2021, see <https://www.framatome.com/medias/download/?id=6545&n=Framatome-Rosatom-sign-cooperation-agreement-pdf>, accessed 9 July 2024.

¹⁴⁴⁷ - *Le Figaro Emploi*, “European Hexagonal Fuel SAS (69007) : siret, siren, TVA, bilan gratuit...”, Registered 11 December 2019, Updated 29 April 2025, see <https://entreprises.lefigaro.fr/framatome-newco-92/entreprise-880033311>, accessed 26 June 2025.

¹⁴⁴⁸ - Advanced Nuclear Fuels GmbH, “Antrag auf Erteilung einer Genehmigung nach § 7 AtG und Antrag auf Vorprüfung nach § 9 UVPG—Fertigung von VVER-Brennelementen”, Framatome, filed with Ministry of the Environment, Energy and Climate Protection of Lower Saxony, 10 March 2022, see https://www.umwelt.niedersachsen.de/download/200676/BFL_-_Fertigung_von_VVER-Brennelementen_-_Antragsschreiben.pdf, accessed 26 June 2025.

Following German atomic law, ANF's request was subject to a public inquiry in early 2024 resulting in more than 11,000 comments.¹⁴⁴⁹ To consider these comments, the Lower Saxony Government held a public hearing in Lingen in November 2024. The main objections concerned TVEL's role in the manufacturing, raising issues of potential espionage risks and threats to national and energy security.¹⁴⁵⁰ As of mid-2025, no decision had been issued by the Lower Saxony Government. The environment minister, a Green Party member, is opposed to the project,¹⁴⁵¹ but he can only examine the application based on his mandate under federal atomic law and does not have a veto right. It is up to the federal government to approve or block the initiative.

ANF nevertheless started preparations for manufacturing VVER fuel assemblies in Lingen. In May 2024, ANF confirmed that production machinery had been set up at a separate facility outside the Lingen factory, and that it had been tested in April 2024.¹⁴⁵²

The apparent lack or delay of 'real' diversification away from Russia has raised the question why Framatome partnered with TVEL to enter the VVER fuel market, instead of Westinghouse which has developed and delivered VVER fuel assemblies for nearly three decades, and why it stuck to this decision even after February 2022, particularly given Rosatom's proactive role in the Ukraine war.¹⁴⁵³ An answer may lie in the assumption that Framatome regarded Westinghouse as its main competitor, so that after the start of the Ukraine war, Framatome, without a short-term solution, would have been overtaken by Westinghouse until having developed its own fuel, which would likely happen after 2030. Framatome therefore needed Rosatom to enter the market for VVER fuel in a timely manner.¹⁴⁵⁴

Another question is why TVEL entered into the joint venture with Framatome even *before* the Ukraine war because it effectively meant losing market share and revenues. Some hints

¹⁴⁴⁹ - Ministry for the Environment, Energy and Climate Protection of Lower Saxony, "Energienminister Meyer: „Der Einfluss Russlands auf den Atomsektor in Deutschland und Europa bereitet mir große Sorgen“", Press Release, 15 November 2024, see <https://www.umwelt.niedersachsen.de/startseite/aktuelles/pressemitteilungen/energienminister-meyer-der-einfluss-russlands-auf-den-atomsektor-in-deutschland-und-europa-bereitet-mir-grosse-sorgen-237252.html>, accessed 26 June 2025, and Ministry for the Environment, Energy and Climate Protection of Lower Saxony, "Öffentliche Bekanntmachung des Niedersächsischen Ministeriums für Umwelt, Energie und Klimaschutz (MU) Genehmigungsverfahren zur Fertigung hexagonaler Druckwasser-Brennelemente des Typs VVER nach § 7 Atomgesetz (AtG) in der Brennelement-Fertigungsanlage Lingen (BFL)", 20 December 2023, also and Reimar Paul, "Einstieg bei Nuklearfabrik im Emsland: Russen könnten „Fakten schaffen“", *Die Tageszeitung: taz*, 2 May 2024, see <https://taz.de/16004558/>, accessed 4 May 2024.

¹⁴⁵⁰ - *Norddeutscher Rundfunk*, "Brennelemente für Russland aus Lingen: Spionage und Sabotage befürchtet", 22 November 2024, see https://www.ndr.de/nachrichten/niedersachsen/osnabrueck_emsland/Rosatom-Einstieg-in-Lingen-Initiative-warnt-vor-Manipulationen,brennelementfabrik100.html, accessed 20 May 2025.

¹⁴⁵¹ - Andrea Rehmsmeier, "Im Kern russisch - So abhängig ist Europas Nuklearindustrie von Russland", Radioshow, *Deutschlandfunk*, 17 March 2023, see <https://www.deutschlandfunk.de/im-kern-russisch-europas-nuklearindustrie-und-die-abhaengigkeit-von-russland-dlf-1855dd23-100.html>, accessed 12 August 2023.

¹⁴⁵² - Claus Hecking, "Russische Atomtechniker bereiten Testanlage im Emsland vor", *Der Spiegel*, 9 May 2024, see <https://www.spiegel.de/wissenschaft/rosatom-russische-atomtechniker-bereiten-testanlage-im-emsland-vor-a-b0742276-a5a3-4da2-9130-434cbcbefc1c>, accessed 10 May 2024.

¹⁴⁵³ - Ibidem; and Charles Digges, "Rosatom's Role in the War in Ukraine", 2023, Bellona see <https://network.bellona.org/content/uploads/sites/3/2023/06/Rosatoms-role-in-the-war-in-Ukraine.pdf>, accessed 28 June 2024; also Shaun Burnie and Jan Vande Putte, "Russia's Atomic Partners: Framatome, Siemens Energy and Rosatom", Greenpeace, July 2023, see https://www.greenpeace.de/publikationen/Rosatom_Report_G.pdf, accessed 16 April 2024.

¹⁴⁵⁴ - Rather surprisingly, French nationals play a significant role in Westinghouse's top management, including Patrick Fragman, CEO—who resigned only in early 2025—an engineer of the elitist State Corps des Mines, former French top official who served in various positions, including as CEO of Alstom's Nuclear Business, a position that—according to his LinkedIn page—also made him Vice Chairman of the Alstom Atomenergomash Joint Venture between Alstom and Rosatom (see following section). Another Corps des Mines Engineer and former top official at dismantled AREVA, Jacques Besnainou, is the Executive Vice President, Global Markets and Chief Commercial Officer; see Westinghouse, "Leadership", Undated, see <https://westinghousenuclear.com/about/leadership/>, accessed 27 June 2025.

might be contained in the overall strategic cooperation agreement signed between Framatome and Rosatom in December 2021 which aims, among other things, “to develop fuel fabrication and instrumentation and control (I&C) technologies.”¹⁴⁵⁵ Thus, Rosatom and Framatome’s cooperation covers far more than fuel manufacturing. Possibly in return for sacrificing market shares in VVER fuel manufacturing, Rosatom could have gained further access to Framatome’s I&C or other technologies, while Framatome could enter the VVER fuel market and extend its business with I&C technology. This may also partially answer the earlier question as to why Framatome stood by its decision to undertake a joint venture with TVEL even after February 2022: strong mutual business interests between Framatome and Rosatom.

RUSSIA’S DEPENDENCIES AND POTENTIAL SANCTIONS

The long-standing business relations between Framatome, its partner Siemens Energy, and Rosatom create a mutual dependency, including significant Russian dependence on the West which may get increasingly relevant when further sanctions are considered. I&C technology discussed in the preceding paragraph is “the brain and central nervous system” of a power plant, according to Framatome.¹⁴⁵⁶ For a decade Russia has received from Framatome and Siemens Energy (spun off from Siemens in April 2020) I&C technology not only for the initial construction but also modernization and servicing of existing reactors which last long into the future. The most recent reported case involves a Framatome I&C system, due to be fully installed at the newbuild Kursk II nuclear power plant (two units under construction) by the end of 2025.¹⁴⁵⁷

The I&C systems provided by Framatome and Siemens Energy cover different aspects of the operation of a nuclear power plant so that the companies are not competitors but partners.

Framatome offers Teleperm XS (where the S stands for security), i.e., a security system, also called reactor protection system, performing automatization functions relevant to security.¹⁴⁵⁸ It is based on the digital automation system Teleperm which was developed by Siemens in the 1980s. In 2000, Framatome and Siemens formed a joint venture for nuclear technology (in which Siemens had a minority share of 34 percent) that was later named AREVA NP. After Siemens announced its exit from AREVA NP in 2009, Teleperm XS became a product of AREVA NP alone and later of AREVA NP’s successor Framatome.

The I&C system offered by Siemens Energy, on the other hand, is SPPA-T2000/T3000 (earlier named Teleperm XP), a process control system for a power plant’s operation, including monitoring and control of the whole plant in a control room.¹⁴⁵⁹

¹⁴⁵⁵ - Framatome, “Framatome and Rosatom Sign Long-Term Cooperation Agreement”, Press Release, 2 December 2021, op. cit.

¹⁴⁵⁶ - Framatome, “Instrumentation & Control: The Brain and Central Nervous System of the Plant”, Undated, see <https://www.framatome.com/en/expertise/instrumentation-and-control/>, accessed 6 July 2024.

¹⁴⁵⁷ - *NEI Magazine*, “Framatome to Deliver Reactor Protection System for Kursk II”, *Nuclear Engineering International*, 9 April 2020, see <https://www.neimagazine.com/news/framatome-to-deliver-reactor-protection-system-for-kursk-ii-7865990/>, accessed 18 May 2025; NDR, “Brennelemente für Russland aus Lingen: Spionage und Sabotage befürchtet”, 22 November 2024, op. cit.

¹⁴⁵⁸ - See AREVA, “TELEPERM® XS Systemübersicht—Leittechnik”, Undated, see <https://cdn03.plentymarkets.com/evlxcyoplb75/propertyItems/530/Leittechnik.%20TELEPERM%20XS%20System%C3%BCbersicht.pdf>, accessed 30 June 2025.

¹⁴⁵⁹ - Ibidem.

Framatome and Siemens Energy have contracted their respective I&C systems as a consortium to Rosatom for the Paks II project in Hungary (see section on [Hungary](#)) as well as for a range of other Russian reactor projects around the world, including in Russia itself, e.g., for the new build projects Novovoronezh 2-1 and 2-2, Leningrad 2-1 and 2-2, and the modernization of Kola-3 and -4 that were carried out between 2009 and 2016 together with Framatome's predecessor AREVA NP.¹⁴⁶⁰ Since the I&C systems are deeply engrained into the operation of these reactors, their continuous service and modernization needs create a strong, long-lasting Russian dependency on its western partners.

Siemens Energy terminated their business with Russia after the start of the Ukraine war and claimed in 2023 that their turnover with Rosatom was “in the one-digit million range” in 2022.¹⁴⁶¹ In January 2025, a Siemens Energy spokesperson reportedly stated that “Siemens Energy ended all activities in Russia earlier and no longer has any contractual relationships there” and “now only has to fulfill older, outstanding contracts, concluded before the start of the war in Ukraine.”¹⁴⁶² This statement could be interpreted to mean that Siemens Energy still provides service and modernization of I&C systems of reactors in Russia “to fulfill older, outstanding contracts” which apparently would violate E.U. sanctions. In response to corresponding questions from WNISR, a Siemens Energy representative responded that the company would not provide services to reactors in Russia and therefore also would not circumvent sanctions.¹⁴⁶³

However, Siemens Energy's operations in Moscow are apparently continued by the company Energy Management LLC, which is run by former Siemens manager Oleg Titov¹⁴⁶⁴ and claims on its website to “continue the traditions of Siemens.”¹⁴⁶⁵ To perform its operations, this company needs spare parts, new parts, new software versions etc., which earlier were delivered by Siemens Energy. Meanwhile, these products are allegedly offered by other companies via other channels. For example, the company Industrial Technologies LLC in Sverdlovsk, Russia, runs a website “Siemens.B2B”, which offers to provide Siemens products as an “an official dealer of SIEMENS in Russia” and claims to have its “own logistics solutions for the supply of products to the Russian Federation, limited or prohibited for sale through the sanctions policy of European manufacturers.”¹⁴⁶⁶

In response to corresponding questions from WNISR, Siemens Energy declared to have “no ongoing transactions or other business activities with the two companies mentioned”, (i.e., Energy Management LLC and Industrial Technologies LLC) and to have “taken all

¹⁴⁶⁰ - *NEI Magazine*, “Hungary Expects France and Germany to Supply I&C Equipment for Paks II”, 14 October 2022, see <https://www.neimagazine.com/news/newshungary-expects-france-and-germany-to-supply-ic-equipment-for-paks-ii-10086599>; and Greenpeace, “Russia's Atomic Partners: Framatome, Siemens Energy and Rosatom”, July 2023, op. cit.

¹⁴⁶¹ - Marc Dimpfel, “Siemens Energy bleibt Russlands Atomkonzern treu”, *n-tv.de*, 22 July 2023, see <https://www.n-tv.de/wirtschaft/Siemens-Energy-bleibt-Russlands-Atomkonzern-treu-article24277291.html>, accessed 7 July 2024.

¹⁴⁶² - Andrey Gurkov, “Germany's Siemens Energy in Legal Spat with Russia's Rosatom”, *Deutsche Welle*, 21 January 2025, see <https://www.dw.com/en/germany-siemens-energy-in-legal-battle-with-russias-rosatom-over-delivery-delay/a-71258707>, accessed 19 May 2025.

¹⁴⁶³ - Time Proll-Gerwe, Head of External Communication, personal communication by email, Siemens Energy, 22 July 2025.

¹⁴⁶⁴ - Oleg Titov, LinkedIn profile, CEO, Энерджи Менеджмент ООО, as of 21 May 2025, see <https://ru.linkedin.com/in/oleg-titov-003a1497>, accessed 21 May 2025.

¹⁴⁶⁵ - Энерджи Менеджмент, “«Энерджи Менеджмент»: компания”, 21 May 2025, see <https://energy-management.ru/company>, accessed 21 May 2025.

¹⁴⁶⁶ - Industrial Technologies LLC, “О компании”, 16 July 2025, see <https://siemensb2b.ru/about.html>, accessed 16 July 2025.

necessary measures and established processes to comply with the relevant provisions of German, European, and US (re-)export control law”, including “careful checks and measures to protect against the circumvention of sanctions”, wherein “[e]very order is checked independently of the country of destination based on the applicable goods lists, the final destination, and the intended use of the goods.”¹⁴⁶⁷

In the past decade, Russia turned into the world’s dominant international reactor technology supplier. With the exception of one Chinese project in Pakistan and one “first concrete” in South Korea, the Russian industry implemented all other 13 construction starts in the world outside China between December 2019, when EDF officially began construction at the U.K.’s Hinkley Point C Unit 2, and mid-2025 (see [Overview of Current Newbuild](#)).

A major participant in Rosatom’s reactor projects is Arabelle Solutions (formerly known as GEAST, for GE-Alstom), the Arabelle turbine manufacturer in France. In 2024, Framatome’s majority owner, EDF, acquired the company from GE¹⁴⁶⁸ after a lengthy process of over two years.¹⁴⁶⁹ The company produces turbines for nuclear power plants and is highly dependent on the niche market virtually entirely controlled by the Russian nuclear industry over the past five and a half years. Reportedly, Rosatom represented about half of Arabelle Solutions’ turnover as of 2022,¹⁴⁷⁰ implemented through a joint venture with Rosatom in Russia, Turbine Technologies AAEM LLC, which supplies turbine islands for Rosatom reactor projects (see box [hereunder](#)). It was therefore no surprise that just before Russia’s invasion of Ukraine the French government had offered to sell Rosatom a 20-percent share in the company.¹⁴⁷¹

¹⁴⁶⁷ - Oliver Sachgau, personal email communication, Spokesperson Finance, D&I, Siemens Energy, 14 July 2025.

¹⁴⁶⁸ - EDF, “EDF Acquires GE Steam Power’s Nuclear Activities from GE Vernova”, Press Release, 31 May 2024, see <https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-acquires-ge-steam-powers-nuclear-activities-from-ge-vernova>, accessed 9 July 2024.

¹⁴⁶⁹ - EDF, “EDF Signs an Exclusive Agreement to Acquire Part of GE Steam Power’s Nuclear Activities”, Press Release, 10 February 2022, see <https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-signs-an-exclusive-agreement-to-acquire-part-of-ge-steam-power-s-nuclear-activities>; and Marc Endeweld, “EXCLUSIF. EDF s’apprête à racheter les activités nucléaires de GE”, *La Tribune*, 27 August 2021, see <https://www.latribune.fr/entreprises-finance/industrie/energie-environnement/exclusif-edf-s-apprete-a-racheter-les-activites-nucleaires-de-ge-891258.html>; both accessed 9 July 2024.

¹⁴⁷⁰ - *La Tribune*, “Nucléaire : pourquoi le géant russe Rosatom pourrait prendre 20% des turbines Arabelle”, 9 March 2022, see <https://www.latribune.fr/entreprises-finance/industrie/energie-environnement/nucleaire-pourquoi-le-geant-russe-rosatom-pourrait-prendre-20-des-turbines-arabelle-905779.html>, accessed 9 July 2024.

¹⁴⁷¹ - Guillaume Guichard, “Nucléaire: l’État prêt à céder 20% d’Arabelle au russe Rosatom”, *Le Figaro*, 8 March 2022.

Turbine Technologies AAEM LLC – EDF’s Outpost in Russia

In 2007, French industrial giant Alstom and Rosatom subsidiary Atomenergomash JSC (AEM) formed the joint venture Alstom Atomenergomash LLC (shortened as AAEM), in which Alstom owned 49 percent and Atomenergomash 51 percent.¹⁴⁷² The company was later renamed to “Turbine Technology AAEM LLC” and is headquartered in St. Petersburg, Russia.¹⁴⁷³ After several transitions involving the U.S. company General Electric (GE), Alstom’s share is now owned by France’s Arabelle Solutions, which in 2024 was acquired by the French utility (and Framatome owner) EDF.¹⁴⁷⁴ The purpose of AAEM is to provide turbine hall equipment of VVER reactors—the largest part of a nuclear reactor’s equipment except for the nuclear island itself—based on the Arabelle turbine. The manufacturer considers his steam turbine to be best-in-class with regard to efficiency and reliability,¹⁴⁷⁵ and therefore provides a significant competitive advantage. AAEM will supply the turbine islands for Rosatom reactor projects including four at Akkuyu in Türkiye, four at El Dabaa in Egypt, and two at Paks II in Hungary.¹⁴⁷⁶ Therein, Arabelle Solutions will provide the turbines, GIGATOP four-pole generators, and condenser vacuum systems, while pumps, heat-exchange, and other auxiliary equipment will be manufactured by Atomenergomash and its subsidiaries in Russia.¹⁴⁷⁷ Earlier, AAEM won contracts for reactor projects in Kaliningrad (Russia), Belene (Bulgaria), and Hanhikivi (Finland), but those were cancelled.

Arabelle Solutions’ “heavy order book with Rosatom”¹⁴⁷⁸ for projects with AAEM amounted to €1.36 billion (US\$₂₀₂₃ 1.5 billion) at the end of 2023, wherein the revenue already recorded on these projects was €571 million (US\$₂₀₂₃ 617 million), according to the company’s auditor report.¹⁴⁷⁹ This figure is to be compared with Arabelle Solutions’ turnover of €437 million (US\$₂₀₂₃ 472.5 million) in 2023.¹⁴⁸⁰

¹⁴⁷² - Alstom, “Alstom and Atomenergomash Finalise Strategic Partnership in Nuclear Power Plant Market”, Press Release, 3 July 2007, see <https://www.alstom.com/press-releases-news/2007/7/Alstom-and-Atomenergomash-finalise-strategic-partnership-in-nuclear-power-plant-market-20070703>, accessed 15 August 2025.

¹⁴⁷³ - AAEM, “About Us”, Undated, see <https://aaemturbines.com/en/about-us/>, accessed 30 June 2025.

¹⁴⁷⁴ - EDF, “EDF Acquires GE Steam Power’s Nuclear Activities from GE Vernova”, Press Release, 31 May 2024, see <https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-acquires-ge-steam-powers-nuclear-activities-from-ge-vernova>, accessed 10 July 2024.

¹⁴⁷⁵ - Arabelle Solutions claims that the Arabelle steam turbine produces 2 percent more power than a traditional configuration and has a 99.96 percent reliability rate, i.e., an outage rate of 0.04 percent; see Arabelle Solutions, “Arabelle Nuclear Steam Turbine”, Undated, see <https://www.arabellesolutions.com/our-technology/pioneering-steam-turbines/arabelle-turbine-for-large-reactors>, accessed 30 June 2025.

¹⁴⁷⁶ - Grace Symes, “France: Nuclear Industry Retains Ties with Rosatom”, *Energy Intelligence*, 1 March 2024, see <https://www.energyintel.com/0000018d-f041-d9ab-adff-f26da88c0000>, accessed 31 May 2024; and Mechanical Engineering Division, “AAEM LLC and ZIO-Podolsk PJSC Had Designed, Manufactured and Shipped Condenser Embedded Parts for Akkuyu NPP”, Rosatom, 21 July 2020, see <https://rosatommd.ru/en/mediacenter/news/aaem-llc-and-zio-podolsk-pjsc-had-designed-manufactured-and-shipped-condenser-embedded-parts-for-akkuyu-npp.html>, accessed 15 August 2025.

¹⁴⁷⁷ - Klaus Gufler and Franz Meister, “Rosatom Aktivitäten und Verflechtungen mit der EU—Hintergrundpapier”, Austrian Federal Environment Agency, 2022; and Alexander Nikitin and Dmitry Gorchakov, “Rosatom In The War Years of 2023 and 2024—Main Events, Projects, Decisions, Facts and Problems”, Bellona, 18 December 2024, see <https://etc.bellona.org/publication/rosatom-in-the-war-years/>, accessed 25 May 2025; also Mechanical Engineering Division, “AAEM LLC and ZIO-Podolsk PJSC Had Designed, Manufactured and Shipped Condenser Embedded Parts for Akkuyu NPP”, Rosatom, 21 July 2020, op. cit.

¹⁴⁷⁸ - Grace Symes, “France: Nuclear Industry Retains Ties with Rosatom”, *Energy Intelligence*, 1 March 2024, op. cit.

¹⁴⁷⁹ - Arabelle Solutions, “Arabelle Solutions France—Rapport du commissaire aux comptes sur les comptes annuels”, July 2024, see <https://www.verif.com/en/company/GE-STEAM-POWER-SYSTEMS-283f28396c052b4d445ffd43e4a91b94e9e93924dd7392a344dcb17a51c9ebd/>, accessed 29 June 2025.

¹⁴⁸⁰ - Ibidem.

The relevance of the Arabelle turbines for Rosatom's business is highlighted by Norwegian think tank Bellona's study which analyzed the drop in electricity generation in Russia in 2023. The study identified that a major reason for this—based on publicly available information—were defects of Russian made turbines, notably in new reactors such as Leningrad 2-1. Bellona notes that compared to these Russian turbines, Rosatom offers a “more competitive product”, namely the Arabelle turbine, in its foreign projects (in particular in Hungary, Türkiye, and Egypt), which increases the chances of winning tenders. Bellona concluded:

If the West is seriously concerned about how to limit Rosatom's activity in third countries, then reducing cooperation in the supply of turbine units for new projects could be a serious and significant step.¹⁴⁸¹

¹⁴⁸¹ - Bellona, “Rosatom's output dropped over the last year. We look at three reasons why”, 13 March 2024, see <https://bellona.org/news/nuclear-issues/2024-03-rosatoms-output-dropped-over-the-last-year-we-look-at-three-reasons-why>, accessed 16 April 2024. See also Mark Hibbs, “Turkey's Nuclear Turbines”, Arms Control Wonk, 16 September 2024, see <https://www.armscontrolwonk.com/archive/1219822/turkeys-nuclear-turbines/>, accessed 18 September 2024; and Le Figaro Emploi, “Arabelle Solutions (92000) : siret, siret, TVA, bilan gratuit...”, 26 June 2025, see <https://entreprises.lefigaro.fr/c109-75/entreprise-907877369>, accessed 29 June 2025.

SMALL MODULAR REACTORS (SMRs)

The Merriam-Webster dictionary defines the term “Potemkin village” as “an impressive facade or show designed to hide an undesirable fact or condition.”¹⁴⁸² The state of Small Modular Reactors (SMRs) today might well be described as a Potemkin Village. Even as the evidence for the high costs and the long timelines for potential future construction becomes clearer, and what is most on display are numerous announcements about future SMRs, usually held out for some time in the 2030s, the industry, politicians, investors, and, last but not least, the media continue to portray SMRs as an indispensable and sure way to solve the climate emergency crisis, and more recently, as a sound way to provide energy for proliferating data centers and demand from generative AI (Artificial Intelligence).

One reason why these claims become more widely believed is the continued financial and political support offered to SMRs by multiple governments, some venture capitalists, and the nuclear industry itself. The OECD’s Nuclear Energy Agency (NEA) reports that “private capital is playing an increasingly important role [in SMR financing], often complementing public matching grants”, and there is approximately “USD₂₀₂₃ 15.4 billion of financing towards SMRs worldwide”; of this, roughly “USD₂₀₂₃ 10 billion has come from public sources, alongside approximately USD₂₀₂₃ 5.4 billion” from private sources.¹⁴⁸³ But the NEA has also “identified 127 SMR designs around the world” of which 74 are included in the third edition of its SMR Dashboard. In other words, the US\$₂₀₂₃ 15.4 billion of funding is spread out thinly, and most designs have insufficient resources to be developed into ones that can be licensed and built. To put this amount into perspective, as of 2023, just one SMR company, NuScale, years away from construction, had already invested US\$1.8 billion (of various origins, including a big portion of public funds) on research and development.¹⁴⁸⁴

This chapter offers brief updates on programs in all those countries developing their own SMR designs (for details, see respective individual **Focus Countries** sections or dedicated sections in **Annex 1**) This overview of SMRs in different countries shows that the reality about SMRs is far from the vision portrayed widely. In Argentina, for example, the SMR design that dates back to the 1980s and has been “under construction” since 2014, was officially abandoned in 2024. The SMR design that was to be the first to be built in Canada is no longer under consideration; indeed, the parent company filed for bankruptcy protection in 2024.

¹⁴⁸² - Merriam-Webster Dictionary, “Definition of Potemkin Village”, Updated 5 July 2025, see <https://www.merriam-webster.com/dictionary/Potemkin+village>, accessed 9 July 2025.

¹⁴⁸³ - NEA, “The NEA Small Modular Reactor Dashboard: Third Edition”, NEA No. 7737, Nuclear Energy Agency, Organisation for Economic Co-Operation and Development, 22 July 2025, see https://www.oecd-neo.org/jcms/pl_108326/the-nea-small-modular-reactor-dashboard-third-edition?details=true, accessed 28 July 2025.

¹⁴⁸⁴ - Rachael Rajan, “Earnings Call: NuScale Reports Q3 2023 Results, Announces Strategic Partnerships and Progress in SMR Technology”, *Investing.com*, 9 November 2023, see <https://ca.investing.com/news/stock-market-news/earnings-call-nuscale-reports-q3-2023-results-announces-strategic-partnerships-and-progress-in-smr-technology-93CH-3173418>, accessed 1 August 2024.

ARGENTINA

Argentina's CAREM (Central Argentina de Elementos Modulares) continues to be the oldest SMR design that actually started building. Under development by the National Atomic Energy Commission (CNEA) since the 1980s,¹⁴⁸⁵ at construction start in 2014, the 25-MW CAREM was “scheduled to begin cold testing in 2016 and receive its first fuel load in the second half of 2017”.¹⁴⁸⁶ As with all other SMR designs so far, that deadline was not met.

In September 2024, due to severe budget cuts, 153 construction workers involved in the CAREM project were reportedly laid off, bringing the total number of layoffs that year till that point to 470.¹⁴⁸⁷ The report went on to state that there were “only 160 builders still in their position” and that “only 30 will remain by November [2024].” The new CNEA president, Germán Guido Lavalle, declared the end of the CAREM project in late 2024. CAREM would not fit into the “commercially viable” category, as he reportedly said in an internal statement “let’s be intellectually honest, we are not going to sell 50 CAREMs, we know that...this reactor is not economically competitive. You only have to stand in front of the construction site to realize that this is not a small modular reactor.”¹⁴⁸⁸

Then, in December 2024, Argentina's President Javier Milei announced that Argentina aimed to be a pioneer in nuclear power's “triumphant return”.¹⁴⁸⁹ Reportedly, this involved building an SMR at the existing Atucha site. But rather than CAREM, the reactor to be built would involve “a new conceptual design for a 300-MW SMR developed by Invap”, a company based in Argentina.¹⁴⁹⁰

More details were revealed on 30 May 2025. At an event organized by the CNEA, the chairman of the board of Nucleoeléctrica stated:

The ACR-300, a 300 MW technological marvel designed by Argentine engineers, is a cornerstone of the Nuclear Plan that will position our country at the forefront of the new energy revolution...We are going to begin construction of four modules at the Atucha site, which will nearly double the country's installed nuclear capacity. Next, we will license this

¹⁴⁸⁵ - Dario F. Delmastro, “Small modular reactors (SMRs): The case of Argentina”, National Atomic Energy Commission and Universidad Nacional de Cuyo, in “Handbook of Small Modular Nuclear Reactors”, ed. by Daniel T. Ingersoll and Mario D. Carelli, Woodhead Publishing, November 2020, see <https://www.sciencedirect.com/science/article/pii/B978012823916200014X>, accessed 7 August 2023; and U.S. House of Representatives, “Oversight Review of South American Science, Space, and Technology: Report to the Committee on Science, Space, and Technology, U.S. House of Representatives, One Hundredth Congress, Second Session”, U.S. Government Printing Office, 1988.

¹⁴⁸⁶ - WNN, “Construction of CAREM Underway”, *World Nuclear News*, 10 February 2014, see <http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html>, accessed 7 May 2021.

¹⁴⁸⁷ - Martina Jauregui, “Construction of first Argentine-made nuclear power reactor halted amid layoffs”, *The Buenos Aires Herald*, 14 September 2024, see <https://buenosairesherald.com/business/construction-of-first-argentine-made-nuclear-reactor-halted-amid-layoffs>, accessed 24 August 2025.

¹⁴⁸⁸ - Nicolás Deza, “La CNEA descarta el proyecto CAREM y explora otros diseños de reactores modulares pequeños”, *Econo Journal*, 30 December 2024, see <https://econojournal.com.ar/2024/12/la-cnea-descarta-el-proyecto-carem/>, accessed 29 July 2025.

¹⁴⁸⁹ - Casa Rosada, “El Presidente de la Nación realizó anuncios en materia nuclear”, Presidency of Argentina, 21 December 2024, see <https://www.caserosada.gob.ar/slider-principal/50826-el-presidente-de-la-nacion-realiza-anuncios-en-materia-nuclear>, accessed 23 December 2024.

¹⁴⁹⁰ - *Nucleonics Week*, “Argentina Unveils New Nuclear Plan, Eyes Smrs and Domestic Uranium Reserves”, Vol. 66, Issue 1, 2 January 2025; and Nicolás Deza, “El gobierno creará un consejo nuclear para desarrollar reactores modulares de tecnología nacional y la minería de uranio”, *Econo Journal*, 20 December 2024, see <https://econojournal.com.ar/2024/12/el-gobierno-creara-un-consejo-nuclear-para-desarrollar-reactores-modulares-de-tecnologia-nacional-y-la-mineria-de-uranio/>; also Nicolás Deza, “La CNEA descarta el proyecto CAREM y explora otros diseños de reactores modulares pequeños”, *Econo Journal*, 30 December 2024, see <https://econojournal.com.ar/2024/12/la-cnea-descarta-el-proyecto-carem/>, both accessed 29 July 2025.

technology worldwide. This will not only transform our energy matrix – it will also reshape Argentina’s export profile.¹⁴⁹¹

INVAP, in the meanwhile, has obtained a patent from the U.S. Patent and Trademark Office, on the ACR-300 which it initially filed in 2018.¹⁴⁹²

If Argentina were to move forward on the ACR-300, it would be starting from a much earlier point in the development cycle for an SMR. The timeline projected by officials—building the first ACR-300 by 2030—is highly unlikely to materialize, especially given the long history of failed promises with the CAREM design. Indeed, even Adriana Serquis, former CNEA president reportedly argued that “this kind of announcement of the Argentine government is to say something for people [to] cheer” because the ACR-300 “has no engineering detail of any kind.”¹⁴⁹³

CANADA

Government entities in Canada have continued to promote and support small modular reactors, as has been the case since the publication of the 2018-SMR Roadmap.¹⁴⁹⁴ The province of Ontario is the main source of support for what might be Canada’s first SMR construction project. Ontario Power Generation (OPG) is planning for four BWRX-300 reactors designed by GE-Hitachi at the Darlington site.¹⁴⁹⁵ However, in its October 2022 application to the Canadian Nuclear Safety Commission (CNSC), OPG only asked for a license to construct a single BWRX-300 unit.¹⁴⁹⁶ This was approved in April 2025.¹⁴⁹⁷ According to OPG’s website the goal is to “complete construction of the first SMR by the end of this decade, and connect to the grid by the end of 2030.”¹⁴⁹⁸ GE-Vernova’s annual report, released in February 2025, stated that

¹⁴⁹¹ - Nucleoeléctrica Argentina SA, “Commemorating 75 Years of the CNEA: Nucleoeléctrica Took Part in the Atomic Energy Day Ceremony”, Press Release, 30 May 2025, see <https://www.na-sa.com.ar/en/prensa/commemorating-75-years-of-the-cnea-nucleoelectrica-took-part-in-the-atomic-energy-day-ceremony>, accessed 6 June 2025; and Pablo Florido, Rodolfo Carlevaris and Alberto Patrignani, “United States Patent—Compact Reactor with Horizontal Steam Generators and Pressurizer”, Patent No. 12,057,240 B2, INVAP S.E., 6 August 2024.

¹⁴⁹² - Nicolás Deza, “Exclusivo: INVAP Explora El Desarrollo De Un Reactor Modular Compacto De 300 MW De Potencia Eléctrica”, *EconoJournal*, 16 December 2024, see <https://econojournal.com.ar/2024/12/invap-explora-desarrollo-reactor-nuclear/>, accessed 9 July 2025.

¹⁴⁹³ - Catherine Cartier and Facundo Iglesia, “Argentina Hopes to Attract Big Tech with Nuclear-Powered AI Data Centers”, *Rest of World*, 6 May 2025, see <https://restofworld.org/2025/argentina-hopes-to-attract-big-tech-with-nuclear-powered-ai-data-centers/>, accessed 24 August 2025.

¹⁴⁹⁴ - Canadian Small Modular Reactor Roadmap Steering Committee, “A Call to Action: A Canadian Roadmap for Small Modular Reactors”, November 2018, see https://smrroadmap.ca/wp-content/uploads/2018/11/SMRroadmap_EN_nov6_Web-1.pdf, accessed 14 June 2019.

¹⁴⁹⁵ - Government of Ontario, “Ontario Building More Small Modular Reactors to Power Province’s Growth”, 7 July 2023, see <https://news.ontario.ca/en/release/1003248/ontario-building-more-small-modular-reactors-to-power-provinces-growth>, accessed 9 July 2025.

¹⁴⁹⁶ - CNSC, “Darlington New Nuclear Project”, Canadian Nuclear Safety Commission, 11 January 2023, see <http://www.nuclearsafety.gc.ca/eng/resources/status-of-new-nuclear-projects/darlington/index.cfm>, accessed 11 January 2023.

¹⁴⁹⁷ - CNSC, “Decision by the Commission to Authorize Ontario Power Generation Inc. to Construct 1 BWRX-300 Reactor at the Darlington New Nuclear Project Site”, Updated 4 April 2025, see <https://www.canada.ca/en/nuclear-safety-commission/news/2025/04/decision-by-the-commission-to-authorize-ontario-power-generation-inc-to-construct-1-bwrx-300-reactor-at-the-darlington-new-nuclear-project-site.html>, accessed 4 April 2025.

¹⁴⁹⁸ - OPG, “OPG Ready to Begin Building North America’s First Small Modular Reactor—Questions & Answers—When Will the SMRs Start Producing Power?”, 8 May 2025, see <https://www.opg.com/story/opg-ready-to-begin-building-north-americas-first-small-modular-reactor/>, accessed 24 August 2025.

commissioning of the first unit was scheduled for 2029.¹⁴⁹⁹ In 2021, OPG projected it to “be completed as early as 2028”.¹⁵⁰⁰

In May 2025, the Ontario government approved OPG’s plan to spend CAD7.7 billion (US\$5.6 billion) to construct the first BWRX-300 unit, which includes CAD6.1 billion (US\$4.4 billion) for the actual unit and an additional CAD1.6 billion (US\$1.2 billion) “on common infrastructure such as administrative buildings and cooling water tunnels the new reactor will share with three additional BWRX-300s to be built later.”¹⁵⁰¹ If OPG goes ahead with the remaining three units, the total estimated cost for the project is CAD₂₀₂₄ 20.9 billion (US\$₂₀₂₄ 15.2 billion), including “interest charges and contingencies”.

It is not clear if this total includes CAD970 million (US\$708 million) provided in 2022 for site preparation by the government’s Canada Infrastructure Bank.¹⁵⁰² The funding announcement stated that it “covers all preparation required prior to nuclear construction, including project design, site preparation, procurement of long lead-time equipment, utility connections, implementation of a digital strategy, and related project management costs.”¹⁵⁰³

There is also a SMR engineering and service centre to be built near the Darlington site, for which GE Vernova Hitachi Nuclear Energy “has announced an investment of [CAD]\$70 million [US\$51 million]”.¹⁵⁰⁴ According to GE-Vernova, the proposed facility will “include a state-of-the-art virtual reality simulator and provide training capabilities to support safe and efficient SMR refueling and maintenance evolutions.”¹⁵⁰⁵

When the CAD970 million announced in 2022 is included, funding for SMRs from various federal and provincial government sources in Canada totals at least CAD1.5 billion (US\$1.1 billion) so far.

Among the larger contributions since mid-2024 are CAD80 million (US\$58 million) to Saskatchewan government’s Crown Investments Corporation to carry out “pre-engineering work and technical studies, environmental assessments, regulatory studies and community and Indigenous engagement,” CAD55 million (US\$40 million) to OPG to “support site planning, site preparation, various procurements and regulatory approvals for the three new SMRs” at the Darlington New Nuclear Project (Units 2, 3, and 4), CAD25 million (US\$18 million)

¹⁴⁹⁹ - GE Vernova, “2024 Annual Report”, February 2025, see https://www.gevernova.com/sites/default/files/gevernova_2024_annual_report.pdf, accessed 24 August 2025.

¹⁵⁰⁰ - OPG, “OPG Advances Clean Energy Generation Project”, Press Release, 2 December 2021, see https://www.opg.com/media_releases/opg-advances-clean-energy-generation-project/, accessed 14 July 2025.

¹⁵⁰¹ - Matthew McClearn, “Ontario’s Darlington SMR Project to Cost Nearly \$21-Billion, Significantly Higher Than Expected”, *The Globe and Mail*, 8 May 2025, see <https://www.theglobeandmail.com/business/article-ontarios-darlington-smr-project-to-cost-nearly-21-billion/>, accessed 15 May 2025.

¹⁵⁰² - Matthew McClearn, “Federal Infrastructure Bank commits \$970-million for small nuclear reactor”, *The Globe and Mail*, 26 October 2022.

¹⁵⁰³ - Canada Infrastructure Bank, “CIB Commits \$970 Million Towards Canada’s First Small Modular Reactor”, Press Release, as published on *Cision Newswire*, 25 October 2022, see <https://www.newswire.ca/news-releases/cib-commits-970-million-towards-canada-s-first-small-modular-reactor-888306153.html>, accessed 9 July 2025.

¹⁵⁰⁴ - Government of Ontario, “Ontario Welcomes GE Vernova Hitachi’s \$70 Million Investment to Build World’s First Small Modular Reactor Engineering & Service Centre”, Press Release, 23 June 2025, see <https://news.ontario.ca/en/release/1006084/ontario-welcomes-ge-vernova-hitachis-70-million-investment-to-build-worlds-first-small-modular-reactor-engineering-service-centre>, accessed 24 August 2025.

¹⁵⁰⁵ - GE Vernova, “GE Vernova Hitachi Nuclear Energy to Establish Canadian Small Modular Reactor Engineering and Service Centre in Ontario”, Press Release, 23 June 2025, see <https://www.gevernova.com/news/press-releases/ge-vernova-hitachi-nuclear-energy-canada-small-modular-reactor-engineering-service-centre-ontario>, accessed 24 August 2025.

to NB Power “for up to 600 megawatts of new small modular reactor (SMR) capacity at the Point Lepreau Nuclear Generation Station”, and CAD13 million (US\$9.4 million) to Capital Power Limited Partnership to assess the “potential suitability of three locations in Alberta as potential host locations for SMR deployment.”¹⁵⁰⁶ But there were also large streams of funding for research into various aspects of SMRs, including CAD13.6 million (US\$₂₀₂₄9.9 million) to eight entities, mostly private companies.¹⁵⁰⁷

The Canadian Nuclear Safety Commission (CNSC) offers an optional three-phase “vendor design review” for nuclear vendors to enable CNSC staff “to provide feedback early on in the design process.” The review “does not involve the issuance of a licence and does not certify a reactor design,” and it “is not required as part of the licensing process for a new NPP [Nuclear Power Plant], and its conclusions do not bind or otherwise influence decisions made by the Commission.”¹⁵⁰⁸

CNSC completed the Phase 2 pre-licensing review of the ARC-100 in early July 2025 that identified “no fundamental barriers to licensing” but it required the company “to perform additional work to address” eight “technical clarifications and findings” if the company or another proponent were to “pursue future VDR [Vendor Design Review] work or licence application reviews”.¹⁵⁰⁹ The CNSC identified some challenges that could pose safety risks if not addressed; for example, the “effectiveness of the proposed means of reactor control and shutdown”. Currently, the only SMR design in the review process is Westinghouse’s eVinci (since June 2023).

The 5-MW Micro Modular Reactor (MMR) design was listed last year as being “on hold”, but is no longer listed.¹⁵¹⁰ The design’s developer, Ultra Safe Nuclear Corporation (USNC), announced in February 2024 that it was involved in “a reduction of USNC staff and the concentration of efforts on selected markets and customers” because “only a subset” of potential customers for the reactor design “have shown the resolve to incorporate advanced reactors in the near term.”¹⁵¹¹ The company’s financial troubles continued since then; in October 2024, USNC filed a Chapter 11 petition for bankruptcy protection.¹⁵¹² According to one of the documents submitted

¹⁵⁰⁶ - Natural Resources Canada, “Ensuring Access to Affordable, Reliable and Clean Electricity in New Brunswick”, Government of Canada, 8 December 2024, see <https://www.canada.ca/en/natural-resources-canada/news/2024/12/ensuring-access-to-affordable-reliable-and-clean-electricity-in-new-brunswick.html>; and Natural Resources Canada, “Canada Invests in the Next Generation of Canadian-Made, Clean, Affordable Nuclear Energy”, 5 March 2025, see <https://www.canada.ca/en/natural-resources-canada/news/2025/03/canada-invests-in-the-next-generation-of-canadian-made-clean-affordable-nuclear-energy.html>; both accessed 9 July 2025.

¹⁵⁰⁷ - Natural Resources Canada, “Government of Canada Advances Small Modular Reactor Research and Development With \$13.6-Million Investment”, Press Release, Government of Canada, 3 October 2024, see <https://www.canada.ca/en/natural-resources-canada/news/2024/10/government-of-canada-advances-small-modular-reactor-research-and-development-with-136-million-investment.html>, accessed 9 July 2025.

¹⁵⁰⁸ - CNSC, “Pre-Licensing Vendor Design Review”, Updated 8 July 2025, see <https://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm>, accessed 27 August 2025.

¹⁵⁰⁹ - CNSC, “Vendor Design Review—Phase 2 Pre-Licensing Vendor Design Review: ARC Clean Technology Canada”, 8 July 2025, see <https://www.cnsccsn.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/arc-nuclear-canada-executive-summary-phase-2/>, accessed 14 July 2025.

¹⁵¹⁰ - CNSC, “Vendor Design Review”, Updated 21 May 2024 and 8 July 2025, see <https://www.cnsccsn.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/>, accessed 12 August 2024 and 24 August 2025.

¹⁵¹¹ - Ultra Safe Nuclear Corporation, “USNC Focuses Its Operations to Accelerate Development and Delivery of its Nuclear Systems”, 28 February 2024, see <https://www.usnc.com/usnc-focuses-its-operations-to-accelerate/>, accessed 31 July 2024.

¹⁵¹² - USNC, “Ultra Safe Nuclear Corporation (‘USNC’) Files Chapter 11 Petition to Facilitate Sale”, Press Release, 29 October 2024, archived 16 June 2025, see <https://web.archive.org/web/20250616055530/https://www.usnc.com/ultra-safe-nuclear-corporation-usnc-files-chapter-11-petition-to-facilitate-sale/>, accessed 24 August 2025.

to the Bankruptcy Court in the State of Delaware, U.S., USNC and its subsidiaries owed over US\$16 million to various entities, including US\$647,308 to the CNSC.¹⁵¹³

In December 2024, another startup company called Nano Nuclear acquired the patent for the Micro Modular Reactor design and another reactor technology with associated intellectual property rights for US\$8.5 million.¹⁵¹⁴ Although Nano Nuclear has announced that it “is actively preparing to construct a KRONOS demonstration reactor in Canada, where it will enter the licensing process under Canadian Nuclear Safety Commission (CNSC) oversight,”¹⁵¹⁵ as of July 2025, it had not done so.

Besides Ontario, the other province that has been at the center of SMR activity in Canada is New Brunswick. The province’s electricity company, NB Power, applied to the CNSC in June 2023 for a license to prepare the Point Lepreau site to construct and operate an ARC-100 sodium-cooled fast reactor by the early 2030s.¹⁵¹⁶ As detailed in earlier WNISR editions, ARC faces financial challenges. In July 2025, following the conclusion of CNSC’s Phase 2 VDR, a company spokesperson announced that the company’s “current focus is on advancing strategic partnership and investment discussions to set the stage for the next phase of design work to support a license to construct application” but when asked by a local newspaper about cost estimates, the spokesperson said “we continue to evaluate the going forward cost estimate through current discussions with strategic partners” and “we are not sharing specific numbers.”¹⁵¹⁷ But a former ARC CEO put the figure as “likely...between US\$500 and \$700 million”. In March 2025, New Brunswick’s Finance and Energy Minister reportedly admitted that the province was not planning to invest any more in ARC-100 without “a clear indication that it’s moving forward fast enough.”¹⁵¹⁸

The other SMR designer that has received significant financial support from the government of New Brunswick and the federal government is Moltex (see [Small Modular Reactors: Canada in](#)

¹⁵¹³ - Ultra Safe Nuclear Corporation, et al., “Notice of Possible Assumption and Assignment of Certain Executory Contracts and Unexpired Leases in Connection with Sale”, Case 24-12443-KBO, Doc 152, U.S. Bankruptcy Court for the District of Delaware, filed 26 November 2024, see <https://cases.stretto.com/public/x363/13086/PLEADINGS/130861127248000000014.pdf>, accessed 13 July 2025.

¹⁵¹⁴ - NANO Nuclear Energy, “NANO Nuclear Energy Enters into Agreement to Acquire Ultra Safe Nuclear Corp.’s Patented Micro Modular Reactor MMR® and Pylon Space Reactors for \$8.5 Million along with Worldwide Demonstration Partnerships”, 24 December 2024, see <https://nanonuclearenergy.com/nano-nuclear-energy-enters-into-agreement-to-acquire-ultra-safe-nuclear-corp-s-patented-micro-modular-reactor-mmrm-and-ylon-space-reactors-for-8-5-million-along-with-worldwide-demonstr/>, accessed 3 March 2025.

¹⁵¹⁵ - NANO Nuclear Energy, “NANO Nuclear Energy Launches Recruitment Drive to Build Full-Scale KRONOS MMR Reactors”, 16 April 2025, see <https://ir.nanonuclearenergy.com/news-releases/news-release-details/nano-nuclear-energy-launches-recruitment-drive-build-full-scale/>, accessed 16 April 2025.

¹⁵¹⁶ - NB Power, “NB Power Submits Environmental Impact Assessment Registration and Licence to Prepare Site Application for Advanced Small Modular Reactor Project”, Press Release, 30 June 2023, see <http://www.nbpower.com/en/about-us/news-media-centre/news/2023/nb-power-submits-environmental-impact-assessment-registration-and-licence-to-prepare-site-application-for-advanced-small-modular-reactor-project/>; and NB Power, “License to Prepare Site Application— 930-00581-0001-001-LPA-A-00”, 30 June 2023, see <https://www.nbpower.com/media/1492441/licensetopreparesiteapplication.pdf>, accessed 7 August 2023.

¹⁵¹⁷ - Adam Huras, “N.B. SMR Company’s Focus Turns to Raising \$500+ Million”, *Telegraph-Journal*, 10 July 2025, see <https://tj.news/new-brunswick/smr-companys-focus-turns-to-raising-millions-to-finish-design-work>, accessed 14 July 2025.

¹⁵¹⁸ - Adam Huras, “NB Power CEO Now ‘Unsure’ If First SMR Will Be Ready by ‘Late 2030s’”, *Telegraph-Journal*, 2 March 2025, see <https://tj.news/new-brunswick/nb-power-ceo-now-unsure-if-first-smr-will-be-ready-by-late-2030s>, accessed 14 July 2025.

WNISR2022). In April 2025, Moltex also admitted to financial problems because its U.K.-based parent company Moltex Energy Ltd. faced “a risk of insolvency”¹⁵¹⁹ and is currently for sale.¹⁵²⁰

Given these problems, it is not surprising that NB Power is unsure that any of these two SMRs, in particular ARC-100, which was more favored for earlier deployment, will be available by even the late 2030s.¹⁵²¹ New Brunswick’s government is now also considering building a large CANDU reactor at Point Lepreau and is seeking federal government support for this effort.¹⁵²²

CHINA

China is operating or building two kinds of SMRs, a high-temperature gas-cooled reactor design called the HTR-PM and an integral pressurized water reactor design, the ACP100 (or Linglong One).

HTR-PM Design

The HTR-PM is often described in superlative terms. When the reactors were declared as operating commercially in December 2023, roughly 10 years after the first pour of concrete (see *HTR-PM Design* in WNISR2023), the China National Nuclear Corporation (CNNC) announced that China had “completed the world’s first commercially operational modular nuclear power plant with fourth-generation nuclear technology, marking the transition of fourth-generation nuclear technology from experiments to the commercial market.”¹⁵²³ But any objective evaluation of the commercial viability of this technology would come to a rather negative conclusion.

To start with, the power output of the reactors was reduced by 25 percent of the design power capacity, from 200 MW to 150 MW. There is no publicly available explanation about why the power output has been reduced. At even this lowered output level, the HTR-PM reactors reportedly have been generating only a fraction of what they could have theoretically produced, with a cumulative load factor of only 26.9 percent according to the IAEA’s PRIS database. However, this calculation is misleading on two counts or simply incorrect. First, the 2023 load factor is given as 100 percent even though the units were online only for the month of December 2023.¹⁵²⁴ Second, and more importantly, the load factor has been calculated on the lowered power rating rather than what the owners paid for, namely the design power rating. In summary, the HTR-PM’s performance—as published—does not suggest that the design is reliable or profitable.

¹⁵¹⁹ - Jacques Poitras, “‘Risk of Insolvency’ at Parent Company of N.B. Nuclear Developer”, *CBC News*, 17 April 2025, see <https://www.cbc.ca/news/canada/new-brunswick/moltex-canada-parent-potential-sale-1.7512014>, accessed 14 July 2025.

¹⁵²⁰ - Matthew McClearn, “New Brunswick’s Moltex Canada Pushes on with Nuclear Project as U.K. Parent Struggles”, *The Globe and Mail*, 14 April 2025.

¹⁵²¹ - Adam Huras, “N.B. SMR Company’s Focus Turns to Raising \$500+ Million”, *Telegraph-Journal*, 10 July 2025, op. cit.

¹⁵²² - Adam Huras, “Second Nuclear Reactor at Lepreau Part of N.B.’s Nation-Building Pitch”, *Telegraph-Journal*, 10 June 2025, see <https://tj.news/new-brunswick/second-nuclear-reactor-at-lepreau-part-of-n-b-s-nation-building-pitch>, accessed 9 August 2025.

¹⁵²³ - CNNC, “The World’s First HTR-PM Starts Commercial Operation”, China National Nuclear Corporation, 7 December 2023, see https://subsites.chinadaily.com.cn/cnnc/2023-12/07/c_1023364.htm, accessed 22 August 2025.

¹⁵²⁴ - IAEA, “Operating Experience with Nuclear Power Stations in Member States—2024 Edition”, International Atomic Energy Agency, August 2024, see https://www-pub.iaea.org/MTCD/Publications/PDF/OPEX_2024_web.pdf, accessed 21 July 2024.

It is thus somewhat surprising that the Chinese technology promoters plan to address the challenges of the first HTR-PM through the HTR-PM600 project that would see the expansion of the modular concept to six 100-MW modules driving a single turbine. This demonstration project is planned to supply industrial steam to nearby petrochemical facilities in Lianyungang.¹⁵²⁵ See *China Focus*.

ACP100 Design

The ACP100 integrated Pressurized Water Reactor (PWR), also referred to as Linglong One, has been in the developmental phase since 2010, and its initial design was finalized in 2014.¹⁵²⁶ Construction of the 100-MW Linglong One started in July 2021 at the Changjiang site in Hainan province, where two CNP-600 PWRs are operating and two Hualong One units are being built.¹⁵²⁷ As detailed in *WNISR2022*, the start of construction was delayed by at least six years. The planned construction period is 58 months, which would mean that the reactor is to become operational by May 2026.¹⁵²⁸ The projected construction period is typical for Chinese nuclear reactors, which does not suggest any advantage resulting from building an SMR.

FRANCE

France continues to develop the Nuward design, first revealed in September 2019.¹⁵²⁹ The initial design was a plant with two modules of 170 MW capacity each.¹⁵³⁰ However, this design was not a high priority, at least in the early years. Indeed, in 2020, *Nuclear Intelligence Weekly* reported that Électricité de France (EDF) “remains almost exclusively focused on developing a more economic version of the EPR in the EPR2,” including the fact that there were “as many as 1,000 engineers involved” in developing the EPR2 in comparison to “10-15 engineers” on Nuward.¹⁵³¹

¹⁵²⁵ - CNNC, “Nuclear Power Heating Plant Approved to Be Built in Jiangsu”, 23 August 2024, see https://en.cnncc.com.cn/2024-08/23/c_1023406.htm, accessed 25 June 2025; and Alina Constantin, “Advances in HTGR Development and IAEA Activities to Support Member States on HTGR Technology Development”, Project Officer for HTGR Technology Development, Nuclear Power Technology Development Section, Division of Nuclear Power, IAEA, presented at “Technical Meeting on the Management of Spent Fuel (Pebbles and Compacts) from High Temperature Reactors”, July 2025, see [https://conferences.iaea.org/event/414/attachments/20592/34683/Hadid%20Subki%20-%20IAEA-\(NPTDS\).pdf](https://conferences.iaea.org/event/414/attachments/20592/34683/Hadid%20Subki%20-%20IAEA-(NPTDS).pdf), accessed 5 August 2025.

¹⁵²⁶ - WNN, “Rapid Construction of Chinese SMR Containment Shell Continues”, 7 July 2022, see <https://www.world-nuclear-news.org/Articles/Rapid-construction-of-Chinese-SMR-containment-shel>, accessed 17 July 2022; and Bin Xu, “CNNC’s ACP100 SMR: Technique Features and Progress in China”, China National Nuclear Corporation, Nuclear Power Institute of China, presented at the 13th INPRO Dialogue Forum on Legal and Institutional Issues in the Global Deployment of Small Modular Reactors, IAEA, 18–21 October 2016, see https://nucleus.iaea.org/sites/INPRO/df13/Presentations/011_CNNC%27s%20ACP100%20SMR-Technique%20Features%20and%20Progress%20in%20China.pdf, accessed 8 August 2023.

¹⁵²⁷ - CNNC, “World’s first commercial Linglong One onshore small reactor starts construction”, Press Release, China National Nuclear Corporation, 14 July 2021, see https://en.cnncc.com.cn/2021-07/14/c_642603.htm; and WNA, “Changjiang SMR-1, China”, Undated, World Nuclear Association, see <https://www.world-nuclear.org/reactor/default.aspx/CHANGJIANG%20SMR>; also NS Energy, “Hainan Changjiang Nuclear Power Plant Phase Two”, Undated, see <https://www.nsenergybusiness.com/projects/hainan-changjiang-nuclear-power-plant/>; all accessed 8 August 2023.

¹⁵²⁸ - National Energy Administration, “小身躯、大用途 玲龙一号不只是核能‘充电宝’”, Government of China, 18 September 2021, see https://www.nea.gov.cn/2021-09/18/c_1310196316.htm, accessed 12 August 2024.

¹⁵²⁹ - CEA, “CEA, EDF, Naval Group and TechnicAtome unveil NUWARD: jointly developed Small Modular Reactor (SMR) project”, Press Release, Commissariat à l’énergie atomique et aux énergies alternatives/French Alternative Energies and Atomic Energy Commission, 17 September 2019, see <https://www.cea.fr/english/Pages/News/Nuward-SMR-CEA.aspx>, accessed 8 August 2023.

¹⁵³⁰ - IAEA, “Advances in Small Modular Reactor Technology Developments—A Supplement to IAEA Advanced Reactors Information System (ARIS)—2020 Edition”, September 2020, see https://aris.iaea.org/publications/smr_book_2020.pdf, accessed 25 August 2025.

¹⁵³¹ - Phil Chaffee, “Atmea1 Abandoned as French-Japanese Cooperation Withers”, *Nuclear Intelligence Weekly*, 17 April 2020.

In July 2024, EDF announced that Nuward was to become “a design based on proven technology bricks only” with the hope that this “orientation will provide better conditions for success by facilitating technical feasibility and reducing risks.”¹⁵³² There were technical problems with the earlier design and its market viability.¹⁵³³ *Reuters* traced the design changes to feedback from “prospective clients such as Vattenfall, CEZ and Fortum” who wanted to be confident about cost projections and delivery deadlines so that the “levelised cost of electricity for the SMRs would be in the range of 70 to 100 euros per megawatt-hour [about US\$80–115].”¹⁵³⁴ Four days after the announcement about the change in the design’s orientation, TechnicAtome, which makes France’s nuclear submarine reactors, decided to stop its participation in the Nuward project.¹⁵³⁵

In January 2025, Nuward announced that its new design “will deliver 400 MW of power and offer an option for cogeneration, up to approximately 100 MWth”, and a new Executive President, Julien Garrel, an EDF veteran, would drive this “new phase” working towards finalizing the conceptual design by mid-2026.¹⁵³⁶

The Nuclear Energy Agency’s SMR dashboard now describes the Nuward design as an “Integrated pressurised water-cooled SMR providing up to 400 MWe” and generating up to 1000 megawatts of thermal power.¹⁵³⁷ Despite these changes and a completely new design being developed, in February 2025, the Nuward President declared in a webinar that the schedule envisioned a “conceptual design” by 2026, a “basic design” by 2029 and from 2030, the company would start working on the “detailed design”.¹⁵³⁸ Implementation of a Nuward prototype seems far away.

¹⁵³² - Nuward, Post, LinkedIn, July 2024, see https://fr.linkedin.com/posts/nuward_smr-activity-7215987924771684352-dIc6, accessed 13 August 2024.

¹⁵³³ - Sharon Wajsbrot, “Mini-réacteur nucléaire : EDF change ses plans pour son projet Nuward”, *Les Echos*, 1 July 2024, see <https://www.lesechos.fr/industrie-services/energie-environnement/mini-reacteur-nucleaire-edf-change-ses-plans-pour-son-projet-nuward-2105042>, accessed 1 July 2024.

¹⁵³⁴ - America Hernandez, “France’s EDF to Redraft Small Modular Reactor Design Amid Cost, Technology Concerns”, *Reuters*, 1 July 2024, see <https://www.reuters.com/business/energy/frances-edf-drops-plans-develop-its-own-small-nuclear-reactor-technology-2024-07-01/>, accessed 1 July 2024.

¹⁵³⁵ - Paul Messad, “TechnicAtome quitte le projet Nuward de petit réacteur nucléaire d’EDF”, *Euractiv*, 2 December 2024, see <https://www.euractiv.fr/section/energie-climat/news/technicatome-quitte-le-projet-nuward-dedf-de-petit-reacteur-nucleaire/>, accessed 2 December 2024.

¹⁵³⁶ - Nuward, Post, LinkedIn, 6 January 2025, see https://www.linkedin.com/posts/nuward_nuward-relaunches-the-development-of-its-activity-7282013908419186689-m4PU, accessed 23 April 2025.

¹⁵³⁷ - NEA, “The NEA Small Modular Reactor Dashboard: Third Edition”, NEA No. 7737, July 2025, op. cit.

¹⁵³⁸ - French Nuclear Society, “[Exclusive] Discover Nuward’s New SMR Concept”, 3 March 2025, see <https://sfeninenglish.org/nuward-new-smr-design/>, accessed 23 August 2025.

INDIA

As with other countries, India's government too has extolled small modular reactors, making claims about building many of them.¹⁵³⁹ In March 2025, the government announced in parliament that the Department of Atomic Energy (DAE) was developing three kinds of reactors:

- ➔ one termed Bharat Small Modular Reactors (BSMR-200) that is intended to repurpose “retiring thermal power plants & captive power plants for energy intensive industry such as aluminum, steel, metal,”
- ➔ one termed Small Modular Reactors (SMR-55) for “providing energy for remote as well as off-grid location(s)” and
- ➔ one “High Temperature Gas Cooled Reactor of capacity 5 MWth for hydrogen generation”.¹⁵⁴⁰

Although the government indicated these purpose-oriented locations, it also specified that lead units of these reactors are “planned to be set up at DAE sites” and also promised that these “demonstration reactors are likely to be constructed in 60 to 72 months” once they are funded.¹⁵⁴¹ This followed the government's announcement the previous month, during the presentation of the 2025–2026 budget, that there would be “at least five indigenously developed SMRs... operationalized by 2033.”¹⁵⁴²

In addition, there have also been announcements about non-indigenous, imported SMRs. During Prime Minister Modi's visit to France in February 2025, both countries signed a Declaration of Intent on Establishment of Partnership on Advanced Modular Reactors and Small Modular Reactors.¹⁵⁴³ Earlier, in March 2024, a Rosatom spokesperson was quoted as saying that the company was “in talks with India for small modular reactors”.¹⁵⁴⁴

Another company that has been seeking a market in India is Holtec. The CEO of the U.S.-based business met with the Indian Prime Minister in November 2024 and the company announced in March 2025 that it had received U.S. Government authorization to sell its SMR-300 design and that “three Indian companies – Larsen & Tubro (Mumbai), Tata Consulting Engineers

¹⁵³⁹ - Press Information Bureau, “Union Minister Dr Jitendra Singh Says, India Taking Steps for Development of Small Modular Reactors (SMR), with Up to 300 MW Capacity to Fulfill its Commitment to Clean Energy Transition”, Press Release, Department of Atomic Energy, Government of India, 27 November 2022, see <https://pib.gov.in/Pressreleaseshare.aspx?PRID=1879298>; and Press Information Bureau, “Government Is Working on New Technologies such as Small Nuclear Reactors to Make Clean Energy Transition”, Press Release, Department of Atomic Energy, Government of India, 6 December 2023, see <https://pib.gov.in/PressReleasePage.aspx?PRID=1982958>; both accessed 12 August 2024.

¹⁵⁴⁰ - Department of Atomic Energy, “Lok Sabha: Unstarred Question No- 4189—Nuclear Mission—Answered on 26/03/2025”, Government of India, 26 March 2025, see https://sansad.in/getFile/loksabhaquestions/annex/184/AU4189_CvIMJO.pdf?source=pqals, accessed 22 August 2025.

¹⁵⁴¹ - Ibidem.

¹⁵⁴² - Nirmala Sitharaman, “Budget 2025-2026—Speech”, Minister of Finance, Government of India, February 2025, see https://www.indiabudget.gov.in/doc/Budget_Speech.pdf, accessed 17 June 2025.

¹⁵⁴³ - Ministry of External Affairs, “List of Outcomes: Visit of the Prime Minister to France (10-12 February 2025)”, 12 February 2025, see https://www.mea.gov.in/bilateral-documents.htm?dtl/39072/List_of_Outcomes_Visit_of_the_Prime_Minister_to_France_1012_February_2025; and Ministry of External Affairs, “India – France Joint Statement on the Visit of Shri Narendra Modi, Hon'ble Prime Minister of India to France (10-12 February 2025)”, 12 February 2025; both accessed 25 August 2025.

¹⁵⁴⁴ - M. Ramesh, “Rosatom in Talks with India for Small Modular Reactors”, Business Line, 26 March 2024, see <https://www.thehindubusinessline.com/news/rosatom-in-talks-with-india-for-small-modular-reactors/article67994176.ece>, accessed 13 July 2024.

(Mumbai) and the Company’s own subsidiary, Holtec Asia (Pune)” were eligible to receive technical information.¹⁵⁴⁵

The listing of private companies by Holtec is not coincidental. As discussed in the [section on India](#), the government aims to attract private companies to invest in nuclear power and build SMRs. However, private companies are unwilling to be held liable for potential accidents and would like to be completely indemnified.¹⁵⁴⁶ Holtec, in its announcement about U.S. government authorization, complained about India’s liability law labelling it a “legal barrier”.¹⁵⁴⁷

Whether it is small or large reactors, India’s plans to import technology have mostly not materialized. Nor has it achieved its targets for nuclear energy deployment. These factors, and the many challenges confronting SMRs, in particular their lack of economic viability, render the ambitious plans about building SMRs also quite unrealistic.

RUSSIA

Russia is building both light water and fast neutron SMRs, with a special focus on barge-mounted reactors for coastal locations also referred to as “floating” nuclear reactors or power plants.

Light Water Reactor Designs

Russia operates two KLT-40S SMRs loaded on a barge called the Akademik Lomonosov that were commissioned in May 2020 after lengthy delays and cost overruns that have been detailed in [earlier WNISR editions](#). The two reactors have not been operating very efficiently, with lifetime load factors of just 36 and 28 percent until the end of 2024, as reported by the IAEA-PRIS database.

At least two more SMR projects based on light water reactor designs are underway. The first is in the Chukotka Autonomous region and involves four 55 MW RITM-200S reactors, and the second is in Yakutia involving a (land-based) RITM-200N reactor design.¹⁵⁴⁸ However, as explained in [Russia Focus](#), it is “difficult to determine the exact number of floating nuclear units currently under active construction” because there is no “established terminology and clear milestones for floating nuclear plants.” None of these SMR projects are listed as under construction by the PRIS database.

¹⁵⁴⁵ - Holtec International, “The USG Authorizes Holtec International Under 10CFR810 to Provide SMR-300 Walk-Away-Safe Nuclear Plants to India with the Concurrence of the Nation’s Government”, 31 March 2025, see <https://holtecinternational.com/2025/03/31/hh-40-07/>, accessed 21 April 2025.

¹⁵⁴⁶ - M. V. Ramana and Suvrat Raju, “The Impasse Over Liability Clause in Indo-U.S. Nuclear Deal”, *India Ink*, 15 October 2013, see http://india.blogs.nytimes.com/2013/10/15/the-impasse-over-liability-clause-in-indo-u-s-nuclear-deal/?_r=0; and M. V. Ramana and Suvrat Raju, “Profitability without accountability”, *The Hindu*, 16 February 2015, see <http://www.thehindu.com/opinion/op-ed/comment-profitability-without-accountability/article6898851.ece>, accessed 16 February 2015.

¹⁵⁴⁷ - Holtec International, “The USG Authorizes Holtec International Under 10CFR810 to Provide SMR-300 Walk-Away-Safe Nuclear Plants to India with the Concurrence of the Nation’s Government”, 31 March 2025, op. cit.

¹⁵⁴⁸ - Rosatom, “World’s Only Operational Floating Nuclear Power Plant Generates 978 Million KWh of Electricity in Five Years”, Press Release, 19 December 2024, see <https://www.rosatom.ru/en/press-centre/news/world-s-only-operational-floating-nuclear-power-plant-generates-978-million-kwh-of-electricity-in-fi/>, accessed 22 April 2025.

That said, the start date for the first of the RITM-200S reactors has been announced variously as 2028,¹⁵⁴⁹ and “by 2029”.¹⁵⁵⁰ Keel laying for the barge that is to hold two RITM-200S reactors commenced in August 2022.¹⁵⁵¹ The barge is being built in China, by Wison (Nantong) Heavy Industries, which in 2021 won the contract at a reported price of US\$226 million.¹⁵⁵²

As of mid-2024, the Yakutia SMR project was projected for start in 2028,¹⁵⁵³ however in October 2024, the target date was revised as 2031.¹⁵⁵⁴ Back in 2020, Rosatom had projected a commissioning date of 2027 for a domestic land-based RITM.¹⁵⁵⁵ In March 2025, Rosatom was reported to be producing eight RITM series reactors at its ZIO-Podolsk plant, but some of these are for icebreaker vessel propulsion.¹⁵⁵⁶ However, as detailed in *Russia Focus*, Russian news agency TASS announced two months later that there were ten RITM series reactors, including six RITM-200 and four reactors for icebreakers, being manufactured.¹⁵⁵⁷

Fast Neutron Reactor Design

Russia has long been interested in fast neutron reactor designs and breeder reactors.¹⁵⁵⁸ But, when it comes to SMRs, the only design it is building is the lead-cooled BREST-300, which has been under construction since June 2021 at the Siberian Chemical Combine (SCC) in Seversk.¹⁵⁵⁹ Originally, the reactor was to have started *operating* in 2020.¹⁵⁶⁰ As of the end of 2024, the anticipated grid-connection date for the reactor was 2028,¹⁵⁶¹ and the cost of the

1549 - Страна РОСАТОМ, “В Генсхему размещения объектов электроэнергетики до 2042 года внесли коррективы”, Rosatom, 24 October 2024, see <https://strana-rosatom.ru/2024/10/24/v-genshemu-razmeshheniya-obektov-elekt/>, accessed 25 August 2025.

1550 - Rosatom, “ROSATOM Demonstrates Progress in Implementing Low-Capacity Nuclear Power Projects at the SMR Day”, Press Release, 4 December 2023, see <https://www.rosatom.ru/en/press-centre/news/rosatom-demonstrates-progress-in-implementing-low-capacity-nuclear-power-projects-at-the-smr-day/>, accessed 13 August 2024.

1551 - Rosatom, “Keel-laying Ceremony for the First Arctic-type Floating Power Unit with RITM-200 Transport Reactor Vessels”, Press Release, 30 August 2022, see <https://rosatom-mena.com/press-centre/news/keel-laying-ceremony-for-the-first-arctic-type-floating-power-unit-with-ritm-200-transport-reactor-v/>, accessed 5 October 2022.

1552 - Amber Wang, “First Chinese Firm Wins Contract for Russian Floating Nuclear Power Project”, *South China Morning Post*, 16 September 2021, see <https://www.scmp.com/news/china/diplomacy/article/3148884/first-chinese-firm-wins-contract-russian-floating-nuclear>, accessed 8 August 2023.

1553 - S. Saha, A. Anishchenkov et al., “The RITM-200N Reactor as a Terrestrial Unit”, Afrikantov OKBM JSC, Atomenergomash/Rosatom, as published in *Nuclear Engineering International*, 26 June 2024, see <https://www.neimagazine.com/analysis/the-ritm-200n-as-a-terrestrial-unit/>, accessed 28 June 2024.

1554 - Страна РОСАТОМ, “В Генсхему размещения объектов электроэнергетики до 2042 года внесли коррективы”, Rosatom, 24 October 2024, op. cit.

1555 - Elena Pashina, “Rosatom RITM Series SMRs”, Marketing Director, Rusatom Overseas, presented at the International Framework for Nuclear Energy Cooperation, “SMR Vendor Forum – An Open Discussion with Global Vendors to Review Designs and Benefits”, 23 June 2020, see https://www.ifnec.org/ifnec/upload/docs/application/pdf/2020-06/slides_deck_-_webinar_4.pdf, accessed 6 July 2020.

1556 - WNN, “Eight RITM reactors currently under production”, 12 March 2025, see <https://world-nuclear-news.org/articles/eight-ritm-reactors-currently-under-production>, accessed 14 May 2025.

1557 - TASS, “Росатом в настоящий момент одновременно изготавливает 10 реакторов серии РИТМ”, 20 May 2025, see <https://tass.ru/ekonomika/23994309>; accessed 24 May 2025.

1558 - Thomas B. Cochran et al., “Fast Breeder Reactor Programs: History and Status”, International Panel on Fissile Materials, February 2010.

1559 - Darrell Proctor, “Nuclear First—Work Starts on Russian Fast Neutron Reactor”, *POWER Magazine*, 8 June 2021, see <https://www.powermag.com/nuclear-first-work-starts-on-russian-fast-neutron-reactor/>, accessed 27 June 2021.

1560 - Anatoli Diakov, “Status and Prospects for Russia’s Fuel Cycle”, *Science & Global Security*, 2013.

1561 - Rosatom, “В Северске запустили завод по производству топлива для реактора БРЕСТ-ОД-300”, 25 December 2024, see <https://strana-rosatom.ru/2024/12/25/v-severske-zapustili-zavod-po-proizvo/>, accessed 27 August 2025.

reactor, according to one source, was RUB100 billion (US\$₂₀₂₁ 1.4 billion).¹⁵⁶² There seem to be no plans to build more BREST-300 units and Rosatom is contemplating following up with a 1200 MW unit, i.e., not an SMR.

Export Prospects

Rosatom also continues with its plans to export SMRs. Over the past year, Rosatom has made numerous announcements about specific countries that it envisions exporting SMRs to, including Mongolia, Indonesia, and Kyrgyzstan.¹⁵⁶³ However, the only contract it has to build SMRs is with Uzbekistan that was signed in 2024.¹⁵⁶⁴ Initially, the project envisioned constructing six RITM-200 SMR units.¹⁵⁶⁵ However, in June 2025, Rosatom announced that the project had been reconfigured to building two RITM-200 units and two large (gigawatt scale) units.¹⁵⁶⁶

SOUTH KOREA

According to an October 2024 IAEA report, South Korea now has “two notable SMR designs”, namely the System-integrated Modular Advanced Reactor (SMART) design and the innovative SMR (i-SMR) design.¹⁵⁶⁷

As detailed in earlier WNISR editions, SMART is a 100-MW pressurized water reactor design that was licensed in 2012, but has failed to win any domestic orders because of its high estimated construction cost per unit of capacity. Nothing has come so far either of South Korea’s attempts to export the SMART design.¹⁵⁶⁸

¹⁵⁶² - TASS, “Cost of BREST Fast Reactor Construction Estimated at \$1.3 bln, Says Rosatom”, 8 June 2021, see <https://tass.com/economy/1300401>, accessed 14 August 2024.

¹⁵⁶³ - *Interfax*, “Rosatom Aims to Deliver First Floating Nuclear Plants Abroad in 2030”, 20 May 2025, see <https://interfax.com/newsroom/top-stories/111520/>, accessed 15 July 2025; and TASS, “Mongolia mulls operation of small NPP on its territory by Russian specialists — Rosatom”, 3 September 2024, see <https://tass.com/economy/1837467>, accessed 23 October 2024; also *Interfax*, “Rosatom Suggests Constructing Floating NPP at First Stage with Indonesia, High-Power NPP at Second Stage”, 20 June 2025, see <https://interfax.com/newsroom/top-stories/112159/>, accessed 23 August 2025; and *Interfax*, “Rosatom Submits Preliminary Feasibility Study for Small-Scale NPP Construction to Kyrgyzstan”, 22 April 2025, see <https://interfax.com/newsroom/top-stories/111120/>, accessed 23 June 2025.

¹⁵⁶⁴ - Rosatom, “The Russian Federation and Uzbekistan sign an agreement on the construction of a small nuclear power plant”, Press Release, 27 May 2024, see <https://www.rosatom.ru/en/press-centre/news/-the-russian-federation-and-uzbekistan-sign-an-agreement-on-the-construction-of-a-small-nuclear-powe/>, accessed 13 August 2024; and Catherine Putz, “Uzbekistan, Russia to Start Construction of Small Nuclear Power Plants”, *The Diplomat*, 29 May 2024, see <https://thediplomat.com/2024/05/uzbekistan-russia-to-start-construction-of-small-nuclear-power-plants/>, accessed 31 May 2024.

¹⁵⁶⁵ - Rosatom, “First SMRs for Export”, Newsletter #278, June 2024, see <https://rosatomnewsletter.com/2024/06/28/first-smrs-for-export/>, accessed 14 July 2024.

¹⁵⁶⁶ - *Interfax*, “Rosatom, Uzbekistan Agree to Reconfigure Nuclear Power Plant Construction Project”, 20 June 2025, see <https://interfax.com/newsroom/top-stories/112158/>, accessed 17 July 2025.

¹⁵⁶⁷ - IAEA, “Small Modular Reactors—Advances in SMR Developments”, October 2024, see https://www-pub.iaea.org/MTCD/publications/PDF/p15790-PUB9062_web.pdf, accessed 24 October 2024.

¹⁵⁶⁸ - Sang-Gyu Lim, “Overall Introduction to the SMR Development in Korea”, Director, System Integration Division, Innovative SMR Development Agency, presented at Regional Workshop on Safety Benefits and Challenges in the Development of the Adoption of Small Modular Reactors, IAEA, 31 March 2025, see [https://gnssn.iaea.org/main/ansn/Activity%20Documents%20%20Public/Regional%20Workshop%20on%20Safety%20Benefits%20and%20Challenges%20in%20the%20Development%20of%20the%20Adoption%20of%20Small%20Modular%20Reactors/Presentation/PO4-Overall%20introduction%20to%20the%20SMR%20development%20in%20Korea\(Final\)-Sang-Gyu%20Lim.pdf](https://gnssn.iaea.org/main/ansn/Activity%20Documents%20%20Public/Regional%20Workshop%20on%20Safety%20Benefits%20and%20Challenges%20in%20the%20Development%20of%20the%20Adoption%20of%20Small%20Modular%20Reactors/Presentation/PO4-Overall%20introduction%20to%20the%20SMR%20development%20in%20Korea(Final)-Sang-Gyu%20Lim.pdf), accessed 26 July 2025.

A modified version of the SMART, called SMART100, was then developed. In December 2019, the Korea Atomic Energy Research Institute (KAERI), Korea Hydro & Nuclear Power (KHNP) and Saudi Arabia's King Abdullah City for Atomic and Renewable Energy (KA-CARE) applied to South Korea's Nuclear Safety and Security Commission (NSSC) for a standard design approval of the SMART100. The NSSC began its review of the application in August 2021 and granted the approval in September 2024.¹⁵⁶⁹

The other design the “i-SMR”, has become more prominent in recent years. Over the past year, this design has been the focus of government funding. As detailed in *South Korea Focus*, the government allocated KRW85.9 billion (US\$₂₀₂₄ 81 million) towards the i-SMR and unspecified SMRs. Earlier, in July 2023, the Ministries of Trade, Industry and Energy, and Science and ICT [Information and Communication Technologies] announced KRW399 billion (US\$₂₀₂₃ 306 million) in funding to establish the “Innovative [SMR] Technology Development Project” with the goal of obtaining the Standard Design Approval (SDA) by 2028.¹⁵⁷⁰ The i-SMR Development Agency envisions approval by 2028, site preparation to start by 2029 and construction taking place from 2031 to 2034. The “standard design” of the i-SMR is to be completed by December 2025.¹⁵⁷¹

Even before the design is completed, KHNP signed MoUs with Indonesia's PLN Nusantara Power and the Jordan Atomic Energy Commission to explore deploying i-SMRs in these countries.¹⁵⁷² In April 2025, at a conference in Amman, the head of KHNP's Central Research Institute went as far as to claim that the i-SMR “offers the optimal solution for Jordan's future energy needs.”¹⁵⁷³ That seems unlikely, especially since Jordan's policymakers have, in the past, expressed goals of having economically competitive electricity generation costs and not wanting their country to be a guinea pig for new designs.¹⁵⁷⁴

The other SMR designs that South Korean organizations have pursued are ones aimed at marine propulsion and floating nuclear power plants.¹⁵⁷⁵ None of these have been submitted to the NSSC for safety evaluation or licensing so far. But in February 2025, a Danish company announced that it was “ready to start licensing activities in South Korea.”¹⁵⁷⁶ Saltfoss (then Seaborg), had formed a consortium with KHNP and Samsung Heavy Industries in April 2023

¹⁵⁶⁹ - NSSC, “SMART100 표준설계인가(안)”, 26 September 2024, see https://www.nssc.go.kr/attach/namo/files/000002/20241106160352794_QTKOEL7.pdf, accessed 25 August 2025; and KAERI, “Korea's SMART100 Achieves Standard Design Approval, Paving the Way for Global SMR Deployment”, 27 September 2024, see <https://www.kaeri.re.kr/eng/board/view?linkId=12113&menuId=MENU00718>, accessed 27 July 2025.

¹⁵⁷⁰ - *Yonhap*, “Korea Launches Project Team to Foster Small Modular Reactor”, as published in *The Korea Times*, 10 July 2023, see https://www.koreatimes.co.kr/www/tech/2023/07/419_354648.html, accessed 18 July 2023; and MOTIE, “Korea Kicks Off Project Team for Innovative SMRs”, Press Release, Ministry of Trade, Industry and Energy, 14 July 2023, see https://english.motie.go.kr/en/pc/pressreleases/bbs/bbsView.do?bbs_cd_n=2&bbs_seq_n=1358, accessed 8 August 2023.

¹⁵⁷¹ - Sang-Gyu Lim, “Overall Introduction to the SMR Development in Korea”, Innovative SMR Development Agency, 31 March 2025, op. cit.

¹⁵⁷² - WNN, “KHNP Touts i-SMR to International Audience”, 4 December 2023, see <https://world-nuclear-news.org/Articles/KHNP-touts-i-SMR-to-international-audience>, accessed 27 May 2024.

¹⁵⁷³ - KHNP, “KHNP Hosts Korea-Jordan Technical Conference to Strengthen Coop”, 9 April 2025.

¹⁵⁷⁴ - M.V Ramana and Ali Ahmad, “Wishful Thinking and Real Problems: Small Modular Reactors, Planning Constraints, and Nuclear Power in Jordan”, *Energy Policy*, Vol. 93, June 2016, see <https://www.sciencedirect.com/science/article/abs/pii/S0301421516301136>, accessed 11 April 2020.

¹⁵⁷⁵ - WNN, “Korean SMR-Powered Container Ship Design Revealed”, 13 February 2025, see <https://www.world-nuclear-news.org/articles/korean-smr-powered-container-ship-design-revealed>, accessed 23 August 2025.

¹⁵⁷⁶ - Seaborg, “Seaborg Gets New Capital and New Chairman!”, 27 February 2025, see <https://saltfoss.com/elementor-1711/>, accessed 25 August 2025.

to develop floating nuclear power plants, and as of early 2025 the partners planned for a “first reactor to be ready in the first half of the 2030’s, followed by series production from the mid-2030’s.”¹⁵⁷⁷

UNITED KINGDOM

In June 2025, the British government picked Rolls-Royce “as the preferred bidder to partner with Great British Energy–Nuclear to develop small modular reactors, subject to final government approvals and contract signature.”¹⁵⁷⁸ As part of the announcement, the U.K. Government also pledged “over £2.5 billion (US\$3.4 billion) for the overall small modular reactor programme”. The funding for this will come out of the £8.3 billion (US\$11.2 billion) budget of Great British Energy that was originally viewed as a vehicle for investing in renewable energy.¹⁵⁷⁹ Earlier in the year, Siemens announced that it would be “the sole supplier of steam turbines, generators, and other auxiliary systems” for the SMRs to be built by Rolls-Royce.¹⁵⁸⁰ A final contract is to be concluded by the end of 2025.

The selection process was announced in July 2023 by then Energy Security Secretary, who called upon companies to “register their interest with GBN [Great British Nuclear] to participate in a competition to secure funding support to develop their products” which could “result in billions of pounds of public and private sector investment in small modular reactor (SMR) projects in the UK.”¹⁵⁸¹ The process was meant “to identify the best, most appropriate, SMR technologies” and the financial support was to help companies whose designs are selected to further develop their technologies in preparation for “a Final Investment Decision” to be made by 2029.¹⁵⁸²

The Rolls-Royce SMR design dates back to 2017 and it was initially rated at 440 MW of electricity,¹⁵⁸³ i.e., not really meeting the definition of a small reactor as one designed to generate under 300 MW of power. By 2021 the Rolls-Royce SMR design was further updated to

¹⁵⁷⁷ - Ibidem; and Seaborg, “Korea Hydro & Nuclear Power, Samsung Heavy Industries and Seaborg Technologies Form Consortium to Develop CMSR-Based Floating Nuclear Power Plants”, Press Release, 21 April 2023, see <https://saltfoss.com/korea-hydro-nuclear-power-samsung-heavy-industries-and-seaborg-technologies-form-consortium-to-develop-cmsr-based-floating-nuclear-power-plants/>, accessed 25 August 2025.

¹⁵⁷⁸ - Department for Energy Security and Net Zero, and Great British Energy – Nuclear, “Rolls-Royce SMR Selected to Build Small Modular Nuclear Reactors”, Press Release, U.K. Government, 10 June 2025, see <https://www.gov.uk/government/news/rolls-royce-smr-selected-to-build-small-modular-nuclear-reactors>, accessed 11 June 2025.

¹⁵⁷⁹ - Nils Pratley, “Great British Energy’s Budget Has Been Nuked”, *The Guardian*, 11 June 2025, see <https://www.theguardian.com/business/nils-pratley-on-finance/2025/jun/11/great-british-energys-budget-has-been-nuked>; and Alan Walker, Suzanna Hinson and Nikki Sutherland, “Making Britain a Clean Energy Superpower”, Debate Pack 2024/0110, House of Commons, 25 July 2024, see <https://researchbriefings.files.parliament.uk/documents/CDP-2024-0110/CDP-2024-0110.pdf>, both accessed 23 June 2025.

¹⁵⁸⁰ - Siemens Energy, “Siemens Energy to Supply Rolls-Royce with Turbines for Small Modular Reactors (SMR)”, Press Release, 28 February 2025, see <https://www.siemens-energy.com/global/en/home/press-releases/siemens-energy-to-supply-rolls-royce-with-turbines-for-small-mod.html>, accessed 25 August 2025.

¹⁵⁸¹ - Department for Energy Security and Net Zero, Great British Nuclear, and Nuclear Decommissioning Authority, “British Nuclear Revival to Move Towards Energy Independence”, Press Release, U.K. Government, 18 July 2023, see <https://www.gov.uk/government/news/british-nuclear-revival-to-move-towards-energy-independence>, accessed 4 July 2024.

¹⁵⁸² - Great British Nuclear, “Small Modular Reactors: Competitive Technology Selection Process”, U.K. Government, 19 July 2023, see <https://www.gov.uk/guidance/small-modular-reactors-competitive-technology-selection-process>, accessed 3 August 2023.

¹⁵⁸³ - Rolls Royce, “UK SMR: A National Endeavour”, September 2017, see <https://nuclear.foe.org.au/wp-content/uploads/Rolls-Royce-2017-SMR-national-endeavour-see-p22.pdf>, accessed 6 July 2019.

470 MW, and its then-Chief Technical Officer traced the increase to a desire “to minimise the cost of energy coming out...the cost being the historical challenge of nuclear power.”¹⁵⁸⁴

Even before the government’s decision to choose Rolls-Royce, Westinghouse, one of four companies still in the running at the time, reportedly withdrew from the competition.¹⁵⁸⁵ Westinghouse’s decision did prompt surprise because of its announcement, from only a few months earlier, in September 2024, that its design had been “downselected for the final phase” of the British competitive SMR technology selection process, claiming that this amounted to a recognition of “the advantages of the AP300 SMR design” that ensure that the “AP300 can get to market quickly, economically and with certainty.”¹⁵⁸⁶ However, one analyst has calculated that the U.K. Government’s financial commitment was insufficient to allow for “fleet mode” factory production of SMRs, and this might be a factor in Westinghouse’s decision.¹⁵⁸⁷ Earlier, in July 2024, EDF withdrew its Nuward design from the competition.¹⁵⁸⁸

Last year, in April 2024, the Office for Nuclear Regulation (ONR) was “currently carrying out Generic Design Assessments (GDAs) on Small Modular Reactor (SMR) technologies proposed by Rolls-Royce SMR Ltd, Holtec International and GE-Hitachi Nuclear Energy International LLC.”¹⁵⁸⁹ ONR announced in July 2024 that the Rolls-Royce design had completed the second step of the GDA process and that it could “now continue into Step 3 assessing in more detail the evidence that supports the claims made about the design in the Step 2 submissions.”¹⁵⁹⁰ The next month, ONR announced that Holtec’s SMR design had completed the first step of the GDA process, and that it would “begin the technical assessments of the reactor” as part of Step 2.¹⁵⁹¹ A nearly identical announcement about GE-Hitachi’s BWRX-300 came in December 2024 and ONR explained that during Step 2 “regulatory activity will be targeted on assessing the fundamental adequacy of the GE-Hitachi BWRX-300 design for deployment in Great Britain” and this will “consider the suitability of the methodologies, approaches, codes, standards and philosophies identified by GE-Hitachi in the generic safety, security, safeguards and environment cases for securing future regulatory permissions and permits.”¹⁵⁹²

¹⁵⁸⁴ - WNN, “Rolls-Royce on Track for 2030 Delivery of UK SMR”, 11 February 2021, see <https://world-nuclear-news.org/Articles/Rolls-Royce-on-track-for-2030-delivery-of-UK-SMR>, accessed 27 June 2021.

¹⁵⁸⁵ - Matt Oliver, “US Nuclear Giant Pulls Out of Race to Build Britain’s First Mini-Nukes”, *The Telegraph*, 26 April 2025, see <https://www.telegraph.co.uk/business/2025/04/26/us-company-pulls-out-race-build-britains-first-mini-nuke/>, accessed 25 August 2025.

¹⁵⁸⁶ - Westinghouse Electric Company, “Westinghouse AP300™ SMR Downselected by Great British Nuclear for Final Round of UK Newbuild Programme”, Press Release, 25 September 2024, see <https://info.westinghousenuclear.com/news/westinghouse-ap300-smr-downselected-by-great-british-nuclear-for-final-round-of-uk-newbuild-programme>, accessed 26 September 2024.

¹⁵⁸⁷ - Dan Yurman, “UK SMR Competition May Unravel Over Budget”, *Neutron Bytes*, 27 April 2025, see <https://neutronbytes.com/2025/04/27/uk-smr-competition-may-unravel-over-budget/>, accessed 24 August 2025.

¹⁵⁸⁸ - WNN, “EDF Withdraws from UK’s SMR Selection Competition”, 9 July 2024, see <https://world-nuclear-news.org/Articles/EDF-pulls-out-of-British-SMR-competition>, accessed 9 July 2024.

¹⁵⁸⁹ - ONR, “ONR News April 2024”, Office for Nuclear Regulation news, 19 April 2024, see <https://news.comms.onr.gov.uk/p2h8/send/mj-te43>, accessed 21 July 2024.

¹⁵⁹⁰ - ONR, “Rolls-Royce Small Modular Reactor Design Completes Second Step of Regulatory Assessment”, 30 July 2024, see <https://www.onr.org.uk/news/all-news/2024/07/rolls-royce-small-modular-reactor-design-completes-second-step-of-regulatory-assessment>, accessed 24 August 2025.

¹⁵⁹¹ - ONR, “Holtec International’s Small Modular Reactor Completes First Step of Design Assessment”, 1 August 2024, see <https://www.onr.org.uk/news/all-news/2024/08/holtec-international-s-small-modular-reactor-completes-first-step-of-design-assessment>, accessed 24 August 2025.

¹⁵⁹² - ONR, “GE-Hitachi’s BWRX-300 completes the first step of generic design assessment”, 12 December 2024, see <https://www.onr.org.uk/news/all-news/2024/12/ge-hitachi-s-bwrx-300-completes-the-first-step-of-generic-design-assessment>, accessed 24 August 2025.

UNITED STATES

The U.S. Government has been the single largest funder of SMRs, in particular on research and development. Over the past year, the U.S. Department of Energy (DOE) was the largest source of funding. As detailed in **United States Focus**, a combined US\$2.8 billion in matching grants has been awarded to X-energy, TerraPower, and Kairos Power through the DOE's Advanced Reactor Demonstration Program. In March 2025, the DOE reissued a US\$900 million solicitation to support the deployment of light-water SMRs, with US\$800 million earmarked for “up to two first-mover teams of utility, reactor vendor, constructor, and end-users or power off-takers committed to deploying a first plant while at the same time facilitating a multi-reactor, Gen III+ [Generation III+] SMR orderbook” and up to US\$100 million to fix “key gaps” troubling the domestic nuclear industry in areas including “design, licensing, supplier development and site preparation”, with the goal of spurring additional Gen III+ SMR deployments.¹⁵⁹³ The funding was first announced in June 2024 by the earlier Biden administration.¹⁵⁹⁴

Based in part on this large amount of public funding, there is growing interest by other stakeholders in building SMRs. In May 2025, the Tennessee Valley Authority (TVA) submitted a permit application to the U.S. Nuclear Regulatory Commission (NRC) to build a GE Hitachi BWRX-300 SMR design at the Clinch River site near Oak Ridge, Tennessee.¹⁵⁹⁵ TVA is also part of a coalition applying to the DOE for US\$800 million “to accelerate BWRX-300 development” as well as US\$8 million to support the NRC license review cost. This is not TVA's first attempt to plan for SMRs. Back in 2011, it planned to construct the leading SMR model of that time, the mPower SMR design, at the Clinch River site and two years later it signed a contract with Babcock & Wilcox, the company developing the mPower design, to prepare and submit a construction permit application to the NRC.¹⁵⁹⁶ However, the project was terminated in 2017.¹⁵⁹⁷

Also, in the state of Tennessee, Kairos Power started the first pour of concrete in May 2025 for the Hermes low-power demonstration reactor.¹⁵⁹⁸ Hermes, which will not generate any

¹⁵⁹³ - Office of Nuclear Energy, “\$900 Million Available to Unlock Commercial Deployment of American-Made Small Modular Reactors”, U.S. DOE, U.S. Government, 24 March 2025, see <https://www.energy.gov/ne/articles/900-million-available-unlock-commercial-deployment-american-made-small-modular-reactors>, accessed 21 April 2025.

¹⁵⁹⁴ - U.S. DOE, “DOE Announces \$900 Million to Accelerate the Deployment of Next-Generation Light-Water Small Modular Reactors”, U.S. Department of Energy, United States Government, 17 June 2024, see <https://www.energy.gov/articles/doe-announces-900-million-accelerate-deployment-next-generation-light-water-small-modular>, accessed 14 August 2024; and Diana DiGangi, “DOE Offers \$900M for Next-Generation Small Modular Reactors”, *Utility Dive*, 18 June 2024, see <https://www.utilitydive.com/news/energy-department-900-million-dollar-nuclear-small-modular-reactors-doe/719243/>, accessed 6 July 2024.

¹⁵⁹⁵ - TVA, “TVA Submits Nation's First Construction Permit Application for BWRX-300 SMR”, Press Release, Tennessee Valley Authority, 20 May 2025, see <https://tva.com/news-media/releases/tva-submits-nation-s-first-construction-permit-application-for-bwr-300-smr>, accessed 20 May 2025.

¹⁵⁹⁶ - BWXT, “B&W, TVA Sign Contract for Clinch River mPower Construction Permit”, BWX Technologies, 20 February 2013, see <http://www.bwxt.com/news/2013/02/20/BW-TVA-Sign-Contract-for-Clinch-River-mPower-Construction-Permit>, accessed 27 April 2017; and *Enerdata*, “TVA and B&W Sign Small Modular Reactor Deal Under US DOE Programme”, 22 February 2013, see <https://www.enerdata.net/publications/daily-energy-news/tva-and-bw-sign-small-modular-reactor-deal-under-us-doe-programme.html>, accessed 24 August 2025.

¹⁵⁹⁷ - Seungjin Kim, “Study on Small Modular Reactor Technology and Its Impact for Indiana”, Prepared for Indiana Office of Energy Development, 31 October 2024, see https://www.in.gov/oed/files/IOED-SMR-Report_Final_2024.pdf, accessed 27 August 2025.

¹⁵⁹⁸ - Kairos Power, “Kairos Power Begins Nuclear Safety-Related Construction of Hermes Low-Power Demonstration Reactor”, 8 May 2025, see https://kairopower.com/external_updates/kairos-power-begins-nuclear-construction-of-hermes-demonstration-reactor/, accessed 8 May 2025.

electricity, received the permit for construction from the NRC in December 2023.¹⁵⁹⁹ However, Kairos Power has also received a permit in November 2024 to build a facility with two 35-megawatt thermal test reactors called Hermes-2 with a shared power conversion unit.¹⁶⁰⁰

In May 2025, the NRC issued a Standard Design Approval for the 77-MW NuScale design US-460.¹⁶⁰¹ This design represents a more than 50 percent increase in power compared to the 50-MW NuScale design that received the more stringent Standard Design Certification from the NRC in 2023.¹⁶⁰²

Earlier, in March 2025, Long Mott Energy LLC, a subsidiary of Dow—which now describes itself as a “Materials Science company” rather than a Chemical company—and X-Energy applied for a construction permit to the NRC to build four 80-MWe X-energy SMR units in Seadrift, Texas.¹⁶⁰³ In 2022, when Dow entered into an agreement with X-energy, the announcement said that the X-100 reactors were “expected to be operational by approximately 2030,”¹⁶⁰⁴ whereas the filed application reads “the completion date for construction is expected to be no later than 2033.”¹⁶⁰⁵

Another SMR design that is being evaluated by the NRC is TerraPower, which submitted a construction permit application in 2024.¹⁶⁰⁶ The NRC listed around 50 items that needed to be addressed.¹⁶⁰⁷ In the meanwhile, as described in *United States Focus*, the developer broke ground on a “test and fill facility” for the reactor’s sodium coolant/moderator in June 2024.

Media coverage about SMRs in the United States has largely focused on their potential use for powering data centers used for computations related to Artificial Intelligence (AI). This has been fueled by investment and partnership announcements by cloud companies, in particular

¹⁵⁹⁹ - Kairos Power, “Nuclear Regulatory Commission Approves Construction Permit for Hermes Demonstration Reactor”, Press Release, 12 December 2023, see https://kairopower.com/external_updates/nuclear-regulatory-commission-approves-construction-permit-for-hermes-demonstration-reactor/, accessed 23 August 2024.

¹⁶⁰⁰ - U.S. NRC, “New Facility Licensing—Hermes 2 – Kairos Application”, Updated 3 March 2025, see <https://www.nrc.gov/reactors/non-power/new-facility-licensing/hermes2-kairos.html>, accessed 8 May 2025.

¹⁶⁰¹ - U.S. NRC, “NRC Approves Standard Design for NuScale US460 Small Modular Reactor”, Press Release 25-033, 29 May 2025, see <https://www.nrc.gov/cdn/doc-collection-news/2025/25-033.pdf>, accessed 1 June 2025.

¹⁶⁰² - U.S. NRC, “NuScale Small Modular Reactor Design Certification”, *Federal Register*, Vol. 88, No. 12, 19 January 2023, see <https://www.federalregister.gov/documents/2023/01/19/2023-00729/nuscale-small-modular-reactor-design-certification>, accessed 3 February 2023.

¹⁶⁰³ - Dow and X-energy, “Dow and X-energy Submit Construction Permit Application to the U.S. Nuclear Regulatory Commission for Proposed Advanced Nuclear Project in Texas”, Press Release, as published by X-energy, 31 March 2025, see <https://x-energy.com/media/news-releases/dow-and-x-energy-submit-construction-permit-application-to-the-us-nuclear-regulatory-commission-for-proposed-advanced-nuclear-project-in-texas>, accessed 19 April 2025; and U.S. NRC, “Advanced Reactor Application Projects—Long Mott Energy, LLC – Long Mott Generating Station Xe-100 Power Reactor Application”, Updated 4 April 2025, see <https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/applicant-projects/long-mott.html>, accessed 13 May 2025.

¹⁶⁰⁴ - Dow, “Dow, X-energy to Drive Carbon Emissions Reductions Through Deployment of Advanced Small Modular Nuclear Power”, 9 August 2022, see <https://corporate.dow.com/en-us/news/press-releases/dow-x-energy-to-drive-carbon-emissions-reductions-through-deplo.html>, accessed 24 August 2025.

¹⁶⁰⁵ - Long Mott Energy LLC, “Long Mott Generating Station—Construction Permit Application—Part I—General and Financial Information”, filed with U.S. NRC, submitted 31 March 2025, see <https://www.nrc.gov/docs/ML2509/ML25090A059.pdf>, accessed 25 August 2025.

¹⁶⁰⁶ - TerraPower, “TerraPower Submits Construction Permit Application to the U.S. Nuclear Regulatory Commission for the Sodium Reactor Demonstration Project”, Press Release, 29 March 2024, see <https://www.terrapower.com/terrapower-submits-cpa-nrc/>, accessed 1 April 2024.

¹⁶⁰⁷ - U.S. NRC, “Subject: TerraPower, LLC - Preapplication Readiness Assessment Report for Kemmerer Power Station Unit 1 Preliminary Construction Permit Application”, addressed to TerraPower, 19 March 2024, see <https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML24060A227>, accessed 7 July 2024; and Timothy Gardner, “US Says Gates-backed Reactor Company’s Planned Application Needs Work”, *Reuters*, 22 March 2024, see <https://www.reuters.com/business/energy/us-says-gates-backed-reactor-companys-planned-application-needs-work-2024-03-22/>, accessed 8 July 2024.

Amazon, Google, Microsoft, and Meta.¹⁶⁰⁸ However, the levels of announced investments are small and completely inadequate with relation to how much is needed to build a nuclear reactor.¹⁶⁰⁹

CONCLUSION

Despite much hype, Small Modular Reactors are not living up to the ensuing expectations. The evidence from the cost estimates of SMR projects produced so far show that they are not to be expected to produce economically competitive electricity. One authoritative estimate of the cost of electricity from SMRs comes from Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) showing that SMRs would be by far the most expensive way to generate power in the country; for example, the Levelized Cost of Energy (LCOE) for an SMR project starting to deliver power in 2030 was estimated at AUD328–619/MWh (US\$211–399/MWh); in comparison, solar PV and onshore wind were estimated at AUD35–63/MWh (US\$22.5–41/MWh) and AUD 64–107/MWh (US\$41–69/MWh) respectively.¹⁶¹⁰ When integration costs are included to account for the variability of wind and solar power, the cost of electricity in 2030 was estimated to be in the range of AUD90–131/MWh (US\$58–84/MWh) even when variable resources constitute high levels of the electricity supply. According to the energy economist who led CSIRO's analysis, the capital costs for SMRs used by CSIRO closely matches the estimates for the BWRX-300 reactors to be built at the Darlington site in Canada.¹⁶¹¹

SMR advocates often look to factory production to make reactors cheaper in their models. For example, the IAEA claims that SMRs “show the prospect of significant cost reduction through modularization and factory construction which should further improve the construction schedule and reduce costs.”¹⁶¹² Likewise, a NuScale official told a conference on SMRs in 2016 that the company's vision was “to see NuScale Power Modules rolling off production lines in British factories and generating power for British homes in the 2020s”.¹⁶¹³

¹⁶⁰⁸ - John Stang, “Amazon Offers \$334M for Nuclear Reactors to Be Built at Hanford”, *Cascade PBS*, 26 November 2024, see <https://www.cascadepbs.org/news/2024/11/amazon-offers-334m-nuclear-reactors-be-built-hanford>; and Brian Martucci, “Google, Kairos Power Ink 500-MW Advanced Nuclear Reactor Deal”, *Utility Dive*, 15 October 2024, see <https://www.utilitydive.com/news/google-kairos-power-advanced-nuclear-reactor-data-center-electricity-demand-ai/729876/>; also Brian Martucci, “Meta Seeks up to 4 GW of New Nuclear Power to Help Meet AI, Sustainability Objectives”, *Utility Dive*, 4 December 2024, see <https://www.utilitydive.com/news/meta-seeks-up-to-4-gw-of-new-nuclear-power-to-help-meet-ai-sustainability/734599/>; all accessed 19 May 2025; and Tim De Chant, “Laurene Powell Jobs Joins Amazon in Backing Nuclear Startup X-Energy In \$700M Round”, *TechCrunch*, 7 February 2025, see <https://techcrunch.com/2025/02/07/laurene-powell-jobs-joins-amazon-in-backing-nuclear-startup-x-energy-in-700m-round/>, accessed 25 February 2025.

¹⁶⁰⁹ - M. V. Ramana, “Dangerous Hype: Big Tech's Nuclear Lies”, *Counterpunch*, 1 November 2024, see <https://www.counterpunch.org/2024/11/01/big-techs-nuclear-lies/>, accessed 2 November 2024.

¹⁶¹⁰ - Paul Graham, Jenny Hayward and James Foster, “GenCost: Cost of Building Australia's Future Electricity Needs”, Commonwealth Scientific and Industrial Research Organisation, National Science Agency of Australia, 29 July 2025, see <https://www.csiro.au/en/research/technology-space/energy/Electricity-transition/GenCost>, accessed 11 August 2025.

¹⁶¹¹ - Giles Parkinson, “Angry Nuclear Lobby Backs Off as Landmark SMR Deal Confirms CSIRO's Bleak Cost Estimates”, *RenewEconomy*, 28 July 2025, see <https://reneweconomy.com.au/angry-nuclear-lobby-backs-off-as-landmark-smr-deal-confirms-csiros-bleak-cost-estimates/>, accessed 12 August 2025.

¹⁶¹² - IAEA, “Advances in Small Modular Reactor Technology Developments—A Supplement to IAEA Advanced Reactors Information System (ARIS)—2020 Edition”, September 2020, op. cit.

¹⁶¹³ - NuScale, “NuScale Power Offers UK Deployability and Opportunity”, Press Release, 8 June 2016, see <https://www.nuscalepower.com/press-releases/2016/nuscale-power-offers-uk-deployability-and-opportunity>, accessed 10 August 2025.

In reality, the production lines are likely to be much slower than can be described as “rolling off”. When Holtec announced in May 2025 that they had selected a site for their U.K. factory, the press release revealed their proposed factory would produce “2 SMR units annually”,¹⁶¹⁴ which sounds a lot more like crawling off than rolling off. At this slow rate of production, it is unlikely that there will be significant cost savings because reductions in cost through learning depends in large part on numbers of units produced.

¹⁶¹⁴ - Holtec Britain, “US Nuclear Giant Selects Doncaster’s Gateway-East as Home of New UK Factory”, 30 May 2025, see <https://holtecbritain.com/us-nuclear-giant-selects-doncasters-gateway-east-as-home-of-new-uk-factory/>, accessed 10 August 2025.

CHALLENGES OF INTEGRATING NUCLEAR POWER INTO THE ENERGY SYSTEM

INTRODUCTION

For years, proponents of nuclear energy have been pushing for a revival, claiming it is both imminent and necessary. The validity of this assertion can be verified by observing the development of the nuclear industry, technological advancements, and relevant investments. The WNISR has been accomplishing this task for many years by delivering detailed ex post or real-time analysis. In order to better understand the underlying reasons for current and likely future trends, this chapter undertakes a more fundamental comparison of the characteristics of nuclear technology and its competitors.

Setting the Stage

Assessments of future developments depend on the understanding of their historical context. Economic and technological developments follow their own trajectories, so it is essential to consider the historical evolution of this context. The next section of this chapter clearly shows that the context for civil nuclear power has indeed changed dramatically in the seventy years since its first commercial deployments.

Reframing the Question

After an early period of rapid, policy-driven growth, for decades, nuclear power deployment and economics have stagnated or declined in most countries. Nuclear power is facing new competition from new renewable technologies, especially photovoltaics and batteries, supported by power electronics, which are experiencing relentless cost reductions and massive deployment. Is this difference due to fundamental factors and will it persist, or is a revival of nuclear power at least conceivable in principle, perhaps depending on a boost from political and financial support?

The Approach Taken

This chapter endeavors to answer this question by means of two comparisons.

In a first step, nuclear and renewable technologies are compared in terms of their fundamental technological and physical characteristics and the systemic implications of their characteristics. This comparison will provide an overview of the actual energy supply units and their supporting systems in terms of their characteristics, costs, and development prospects.

The second step involves comparing the roles of these individual energy production systems within the overall energy supply and consumption system. This will provide insight into the ability of the two fundamentally different types of technology to meet the needs of the emerging overall energy system and their compatibility with each other—i.e., the extent to which they can coexist.

This chapter does not compare nuclear power with end-use efficiency—another formidable competitor.

Key Findings

A thorough examination reveals that nuclear energy exhibits notable drawbacks when contrasted with renewable energy technologies across both comparative levels. Examining the underlying physics of the two technologies shows that significant disparities between them render nuclear inherently more costly, both in its present state and in the future. An analysis of the system characteristics of the emerging overall energy system indicates that photovoltaics, batteries, and power electronics are already modifying the logic of the overall system in a manner that renders it increasingly challenging for nuclear power to be integrated into. Time horizons play a key role: until a nuclear power plant, decided upon today, will start producing electricity, new technologies will have thoroughly transformed the energy system.

RADICAL CHANGES IN THE CONTEXT OF THE COMMERCIAL USE OF NUCLEAR POWER

The technological, economic, and institutional foundations of the global energy system have undergone profound changes in recent decades, especially in the past ten to fifteen years. These changes form a radically different context from that in which the nuclear industry first emerged and developed. Understanding this changing landscape is essential for any comparative assessment of energy technologies and their respective roles in future energy systems.

The Context Sixty Years Ago

The conceptual and institutional architecture of nuclear energy was largely formed during the 1950s, 60s, and 70s. This period was marked by expectations of ever-increasing energy demand and a strong belief in the ability of large-scale engineering projects to deliver progress.

In the formative decades of nuclear power, electricity generation was dominated by large power plants: coal- and oil-fueled thermal power stations as well as hydroelectric power generation. Both technologies strongly favored large units due to their intrinsic physical properties. Coal prices were rising. Oil reserves seemed limited and were concentrated in a few countries. The discovery and use of natural gas was growing. A new power source was welcome.

Electricity supply was organized by strong monopolies, in many countries under state control or state regulation. Power generation costs were not transparent to the public. Grid stability

was ensured by adapting the generation in large units to variable demand and by significant safety margins in operating essentially untransparent grids.

The commercial use of nuclear power was originally developed and promoted by state agencies as a further and more publicly acceptable use of military nuclear technology. Large subsidies and liability exemptions were necessary to convince private companies to engage in the development and deployment of civilian nuclear technologies.¹⁶¹⁵ However, the development of military and civilian uses of nuclear energy remained strongly interlinked.

While nuclear power was not cost-effective, it was widely hoped that costs would come down with learning and that safety challenges could be managed. A broad range of reactor concepts was developed in different countries. However, since the 1960s, there has been growing criticism against nuclear power—first mainly motivated by the link to military technologies, then increasingly by safety issues and concerns over radioactive waste. Public debate and increasing insight caused research and state institutions to develop major research programs into nuclear safety and detailed licensing procedures contributing to increasing costs.

Increasing Climate Awareness and the Urge for Decarbonization

Already in the 1970s, the problem of human-made climate change was known and used as an argument for developing nuclear power. However, even in the heydays of nuclear power deployment, it could not live up to this challenge: By 1997, when the UN Framework Convention on Climate Change was finally set up with the signature of the Kyoto Protocol, the construction of nuclear power plants had already declined to its late 1950s levels (see Figure 8). The share of nuclear power in primary energy consumption then reached 6.5 percent. In 2023, 26 years later, primary energy consumption had risen by 64 percent, and nuclear power had not contributed to the meagre reduction of the share of fossil fuels (from 86 to 82 percent): It was instead solar and wind that rose from zero to 6 percent, while nuclear declined from 6.5 to 4 percent with a stagnating absolute input.¹⁶¹⁶

In the past two decades, the climate problem has climbed to the top of the energy agenda with “energy security” concerns increasingly driving policy decisions. Most countries and industries are considering decarbonization as an urgent necessity. After having suggested nuclear power as a solution to the oil crisis in the 1970s, to air pollution in the 1980s, to alleviate global poverty in the 1990s, and to fuel scarcity in the 2000s, nuclear proponents are proposing their technology as a key solution to decarbonization, despite its poor track record in combating climate change and its ongoing cost increases. Indeed, the carbon footprint of nuclear power is much lower than that of fossil fuels. But do advocates of nuclear energy have new arguments vis-à-vis the upcoming clean alternatives? The key questions are whether nuclear power is more cost-effective in reducing emissions and how fast it can be implemented.

¹⁶¹⁵ - Ben Wealer, Simon Bauer et al., “Nuclear Power Reactors Worldwide – Technology Developments, Diffusion Patterns, and Country-by-Country Analysis of Implementation (1951–2017)”, German Institute for Economic Research, Berlin University of Technology, April 2018, see https://www.diw.de/documents/publikationen/73/diw_01.c.583365.de/diw_datadoc_2018-093.pdf, accessed 28 May 2025.

¹⁶¹⁶ - Energy Institute, “Statistical Review of World Energy 2024—Data”, 2024, see https://www.energyinst.org/_data/assets/excel_doc/0020/1540550/EI-Stats-Review-All-Data.xlsx, accessed 24 June 2024.

Step-by-Step Liberalization of Electricity Markets

In the 1970s, the upcoming use of combined heat and power (CHP) generation in industry started to undermine the power of monopolies. While large thermal power plants lose half to two thirds of the input energy as waste heat that needs to be cooled away, new small gas turbines offered cheaper electricity by simultaneously delivering heat for industrial purposes. In 1978, new U.S. energy legislation permitted independent electricity producers to sell electricity to the existing monopolies. This led to the emergence of a growing number of independent power producers, who utilized not only combined heat and power or cogeneration but also early versions of wind power. Increasingly, prices were being decided using market-based tools like auctions. This development was not unique to the United States. Denmark and the Netherlands are outstanding examples of an early and intensive adoption of cogeneration schemes.¹⁶¹⁷

While in the U.S. electricity system, the growing fragmentation of political and economic power led to inconsistent and divergent approaches across the states, the European Union embarked on a much more ambitious liberalization. As in the U.S., the emergence of efficient distributed generation technologies, combined with a growing environmental movement on the one hand, and the increasing influence of neoliberalism on the other, led to an increasingly untenable position for the old electricity monopolies. Meanwhile, Western European electricity markets had become increasingly interconnected, and with the opening of the Iron Curtain in 1989, the integration of Central and Eastern European countries into the European single market was on the horizon. From the late 1990s, this led to the gradual liberalization of European electricity markets and the introduction of national and European regulators, thereby creating the largest liberalized electricity market worldwide. However, the implemented market mechanisms were still designed with the old technologies and control logics in mind.¹⁶¹⁸

In recent years, it has become increasingly clear that shaping liberalized markets in an environment where natural monopolies (electricity grids) and security of supply play a central role requires sophisticated market design and highly competent oversight. An additional objective has gained importance with the increasing push for decarbonization. Moreover, the very different characteristics of new energy technologies require a recalibration and redesign of markets designed for a traditional technological environment. As a result, the role of regulators and an intense political debate on the objectives and modalities of the energy transition have become more important.

New Energy Technologies Start to Disrupt Markets and Systems

The chapter **Nuclear Power vs. Renewable Energy Deployment** illustrates the unprecedented momentum with which solar power, wind energy, and batteries are being deployed and

¹⁶¹⁷ - Richard F. Hirsh, “Power Loss—The Origins of Deregulation and Restructuring in the American Electric Utility System”, MIT Press, 2002; and Ruggero Schleicher-Tappeser, “50 years of restructuring the electricity system - From central control to network cooperation”, *Sustainable Strategies*, on Substack, 21 June 2023, see https://open.substack.com/pub/sustainablestrategies/p/50-years-of-restructuring-the-electricity?r=cm8qk&utm_campaign=post&utm_medium=web&showWelcomeOnShare=false, accessed 25 August 2025.

¹⁶¹⁸ - This included an overestimation of the advantages of central control even within the context of traditional technologies; see Amory B. Lovins, E. Kyle Datta et al., “Small Is Profitable—The Hidden Economic Benefits of Making Electrical Resources the Right Size”, Rocky Mountain Institute, 2002, see <https://rmi.org/insight/small-is-profitable/>, accessed 24 July 2025.

disrupting markets. The declines in unsubsidized costs observed in photovoltaics, batteries, and power electronics over the past decade are unparalleled in the history of energy technologies. Costs have declined for decades, but only recently have competitiveness thresholds been crossed, leading to disruptive transformations in the energy economy. **Figure 59** in that chapter is a snapshot of how fast solar power generation is outpacing nuclear power and shows the remarkable complementarity between solar and wind. The reason for the new technologies' capability to achieve such progress compared to fossil fuels and nuclear power is rooted in fundamental physical properties, which will be explored in the next section.

Moreover, the new energy technologies, unlike nuclear power, are not simply substitutes for the old, well-known fossil power plants. They are fundamentally changing the logic of the energy system. The combination of unprecedented characteristics of photovoltaics, batteries, and power electronics leads to a transformation of the whole energy supply system, involving not only generation but all steps until the end use:

- ➔ Electricity generation becomes more and more decentralized, involving millions of investors and operators. Generating technologies shift from giant and bespoke to modular and mass-produced.
- ➔ Electricity becomes the central, universal energy carrier in the overall energy system.
- ➔ Electricity generation with sunlight and wind depends on varying weather, daytime, and seasons, requiring the use of new flexibility and storage options across the entire energy system.
- ➔ Increasing difficulties in controlling this complex system with centralized approaches give way to new bottom-up control logics.

The section after next will further explore these changes in the systemic context brought about by new energy technologies, and how they affect the prospects of nuclear power.

Widening International Competition

The liberalization of electricity markets and international trade for equipment, in combination with new technological developments, opened opportunities for new actors in the electricity and technical equipment markets.

- ➔ New competitors emerged in the national electricity markets: independent power producers, traders, providers of special services to utilities, and large consumers (today, European energy market regulations distinguish 49 different market roles¹⁶¹⁹).
- ➔ Neighboring industries using innovative technologies entered the equipment and services markets: producers of cogeneration engines, wind turbines, digital controls and corresponding software, energy-efficient consumer products, and home energy management systems.
- ➔ Competitors from Asian countries, in particular China, started to conquer equipment markets with new energy technologies. Today, China controls over 75 percent of the

¹⁶¹⁹ - ENTSO-E, "The Harmonised Electricity Market Role Model", Version 2025-01, European Network of Transmission System Operators for Electricity, December 2024, see <https://www.entsoe.eu/data/cim/role-models/>, accessed 26 May 2025.

world's production of solar panels, batteries, and LEDs, as well as important parts of global markets for power electronics and control device components.¹⁶²⁰

The entrance of new actors in the energy technology markets has upended historical oligopolies of European and American companies and has accelerated competitive innovation.

Not only has technological and market competition between companies and industrial sectors increased, but also regulatory competition between countries. Energy policy has become a key element in the competition between political and economic blocs. However, business competition and regulatory competition operate on different time scales. Large public infrastructures have a long-lasting influence. Creating long-lasting dependencies can also be a geopolitical objective—as can be observed in Russian export efforts for nuclear power plants.

Accelerating Change

The number of construction starts of nuclear power plants peaked in 1976. Consequently, the installed nuclear power capacity exhibited the most substantial growth between 1980 and 1985, attaining an average annual growth rate of 13 percent.¹⁶²¹ At a time when nuclear energy competed with coal power plants, this was an exceptional occurrence. Meanwhile, change has accelerated: Between 2019 and 2024, the installed capacity of photovoltaics reached an average annual growth rate of 28 percent.¹⁶²²

From 2015 to 2024, the average construction time of a nuclear power plant—from first concrete for the reactor-building base-slab to grid connection—was 9.4 years, representing an increase from less than eight years in the 1980s. In contrast, it takes approximately two years to commission a PV plant—the actual construction time may often be only a few months.¹⁶²³

The International Energy Agency's (IEA) Net Zero Emissions scenario, which aims to fully decarbonize the energy system, requires non-fossil power generation to grow by an average of 14.5 percent between 2023 and 2030.¹⁶²⁴ In such a context, increasing or even maintaining its electricity market share is out of reach for a nuclear industry that, over the past decade, has struggled to sustain its generating capacity and on average takes almost a decade to build a new plant—much more if planning, licensing, public inquiries, and site preparation

¹⁶²⁰ - IEA, “Solar PV Global Supply Chains—Executive Summary”, International Energy Agency, July 2022, see <https://www.iea.org/reports/solar-pv-global-supply-chains/executive-summary>; and Teo Lombardo, Leonardo Paoli et al., “The Battery Industry Has Entered a New Phase”, IEA, 5 March 2025, see <https://www.iea.org/commentaries/the-battery-industry-has-entered-a-new-phase>; both accessed 25 June 2025.

¹⁶²¹ - WNISR calculation based on IAEA-PRIS annual net capacity.

¹⁶²² - WNISR calculation on the basis of data from SolarPower Europe, “Global Market Outlook for Solar Power 2025-2029—Focus on India”, May 2025, see https://api.solarpowereurope.org/uploads/Global_Market_Outlook_2025_v1_aaebd9698b.pdf, accessed 9 May 2025.

¹⁶²³ - On average 2.3 years in the OECD countries, 1.6 years in non-OECD countries. Commissioning times have increased over the past few years. See Anurag Gumber, Riccardo Zana and Bjarne Steffen, “A Global Analysis of Renewable Energy Project Commissioning Timelines”, ETH Zurich, and Massachusetts Institute of Technology, *Applied Energy*, 9 January 2024.

Acciona shows in a video how in Mexico more than one million panels (404 MW) are being installed in two months; see Acciona, “How a Large-Scale Photovoltaic Plant Is Built in Record Time”, 27 June 2025, see <https://experience.acciona.com/renewable-energy/how-photovoltaic-plant-built-record-time/>, accessed 27 June 2025.

The construction of large plants in China takes even less: 3.5 GW in nine months; see CDS SOLAR, “Record-Breaking Solar Power Station Connected to Grid: Xinjiang’s 3.5 GW Solar Plant”, 15 October 2024, see <https://cdssolar.com/record-breaking-solar-power-station-connected-to-grid-xinjiang-s-3-5-gw-solar-plant/>, accessed 24 July 2025.

¹⁶²⁴ - WNISR calculation based on IEA, “World Energy Outlook 2024”, International Energy Agency, October 2024, p. 311, see <https://iea.blob.core.windows.net/assets/47a9a222-78e4-4c43-9bab-977b4ad5326b/WorldEnergyOutlook2024.pdf>, accessed 16 October 2024.

are included. Even the IEA's assumption that nuclear capacity could grow by an average of 4.2 percent per year from 2023 to 2030 (still resulting in a 48 percent decline in its share of non-fossil electricity) seems far from realistic.

As a result of all these changes, decision-making in the electricity and the broader energy sector has considerably evolved. Planning horizons have shrunk, decisions need to be taken faster, the regulatory environment is changing rapidly, and old oligopolies have lost control.

In the aftermath of Russia's full-scale invasion of Ukraine, there has been a shift in energy policy goals: Energy supply security has gained weight over economic and climate change concerns. System resilience, the avoidance of dependencies, and the role of large infrastructures are seen in a new light. This means that both longer-term considerations and higher flexibility are getting more attention.

PHYSICAL PRINCIPLES UNDERLYING THE TECHNOLOGIES

Nuclear Energy

Two Fundamental Dangers of Exploiting the Bonding Forces in Atomic Nuclei

Nuclear energy is the only energy generation technology that deals with the bonding forces in atomic nuclei, mainly the so-called strong interaction, one of the four elementary forces in physics. This fact has far-reaching consequences.

All other technical energy sources rely on harnessing the forces of gravity and electricity. Wind energy and hydro collect mechanical energy of natural phenomena at the macroscopic scale that originate in the transformation of solar electromagnetic radiation into heat. In combustion, chemical reactions change the bonds between atoms provided by the electric forces in the electron shells of atoms and molecules, and then deliver heat (random movement of molecules), which in further steps may be converted into mechanical and electric energy. In photovoltaics, the input of sunlight (electromagnetic radiation) liberates electrical charge carriers in the electron shells, which, if appropriately collected, directly provide electrical current.

Some Essential Nuclear Physics

Nuclear energy, indeed, touches forces that have never been dealt with before. In 1911, Ernest Rutherford concluded from a series of experiments that the matter in an atom is not evenly distributed. Rather, it is concentrated in an extremely small, positively charged nucleus, which is surrounded by a much larger shell of orbiting, nearly massless, negatively charged electrons. Step by step, it became clear that the nucleus was essentially composed of positively charged "protons" and electrically neutral "neutrons" (discovered in 1932), and that the electric repulsion among the protons must be overcome by a new, until then unknown, extremely strong cohesion force with much shorter reach than electrical forces.

This early model of nuclear physics, supported by a series of revolutionary scientific discoveries of that time and the evolving mathematical formulation of quantum physics, enabled the explanation of the perplexing phenomenon of radioactivity—a new kind of radiation discovered in 1896. It occurs when unstable atomic nuclei decay, emitting alpha particles (two protons and two neutrons), beta-radiation (electrons), gamma-radiation (hard electromagnetic waves), neutrons, or combinations of these. The timeline of radioactive decay processes follows stochastic laws: every kind of nucleus, or isotope (characterized by the number of protons and neutrons it contains), has a specific, constant half-life (the amount of time after which half of the original material has decayed) ranging from microseconds to millions of years. In particular, this radioactive decay can be observed in all nuclei heavier than lead, which are unstable because of their high proportion of neutrons. They may even split into several larger parts (nuclear fission), releasing kinetic energy of the fission products and emitting neutrons. These neutrons are being absorbed by other nuclei, which consequently may become unstable themselves.

As early as 1933, the Hungarian physicist Leó Szilárd, who had emigrated from Berlin to London, conceived the idea of a self-sustaining nuclear chain reaction that could unleash vast quantities of energy from relatively small amounts of fissile material. In 1936, he filed a patent for this concept, which was kept secret due to its military significance. Later, joined by the more famous Albert Einstein, he warned U.S. President Roosevelt that Germany could build a nuclear bomb. This motivated the huge effort of the Manhattan Project. It was only in the aftermath of the nuclear bombings of Hiroshima and Nagasaki—when the global community realized the potential of self-destruction and both sides in the Cold War were heavily engaged in nuclear armament—that the idea of a civilian use of nuclear power was intensely propagated.

The chain reaction used in most nuclear power reactors today relies on the fission of Uranium-235. Upon absorbing a neutron, it transforms into Uranium-236 and splits into a range of radioactive fission products, emitting three neutrons. Such a self-sustaining chain reaction was first realized by Enrico Fermi in 1942 under strict secrecy, accomplishing a key milestone in the Manhattan Project.

Dealing with Unavoidable Long-Term Radiation

Exploiting nuclear forces by splitting and thereby changing the configuration of atomic nuclei inevitably involves the release of intense radiation. More importantly, the fission products, whose kinetic energy makes up for most of the energy released, are radioactive themselves. Their half-lives extend over an extremely large range, from tiny fractions of a second up to millions of years. Moreover, the absorption of excess neutrons by neighboring nuclei results in the transformation of stable material into unstable isotopes. This phenomenon increases the quantity of radioactive material. As a result, the use of nuclear power is inevitably accompanied by

- ➔ radiation of different kinds, which, depending on its intensity, can be extremely harmful to living beings;
- ➔ radioactive material in solid, liquid, and gaseous forms, which, depending on the isotopes involved, may radiate for up to millions of years.

Depending on the type of radiation (alpha, beta, gamma, neutron), quite different barriers are needed to shield against its effects. In some cases, it is even more challenging to prevent the inhalation or ingestion of small amounts of radioactive material that may be incorporated into living organisms and radiate there directly for many years or until the end of life of the said organism. However, far more difficult than shielding or containing radioactive materials in current operations is ensuring their safe isolation from living beings for many millennia.

Radiating isotopes cannot be destroyed by chemical processes, such as burning, as these do not alter the atomic nuclei. The decades-old discussion of concepts to transmute long-lasting radioactive isotopes into ones with shorter half-lives, for example, by bombarding them with neutrons, has not led to encouraging results: Just reducing the necessary high-safety storage time for a selection of particularly long-lived isotopes—still to several hundred years—would require considerable efforts involving risky separation processes, complex plants with high energy consumption, many decades of additional reactor operation, as well as additional lower-level radioactive waste.¹⁶²⁵ In most cases, it would also lead to increased proliferation risks. According to a major 1996 U.S. National Academy of Sciences study, coordinated by nuclear engineering icons Norman Rasmussen and Thomas Pigford, in the real world, it would take centuries to obtain the theoretical results of transmutation, notwithstanding the fact that a significant share of long-lived wastes is not in a physical or chemical form apt for enhanced reprocessing, separation, and transmutation.¹⁶²⁶

The inevitable radioactivity involved in nuclear power generation results in a series of burdensome and costly challenges:

- ➔ Operating a nuclear power plant requires adequate shielding from radioactive radiation around all components that are in direct or indirect contact with radioactivity.
- ➔ Maintaining a nuclear power plant necessitates specialized equipment, methodologies, and shielding measures, as construction elements exposed to neutron radiation become radioactive themselves. Thus, even simple repairs that would require little effort in a conventional power plant become cumbersome, time-consuming, and costly.
- ➔ Not only spent fuel containing fission products, but all materials exposed to radiation or radioactive material must be tightly contained and controlled; this requires special logistics, cooling, and surveillance.
- ➔ Depending on their category, nuclear wastes must be safely stored for up to a million years. This requires not only safe containment over long periods, but also protection from

¹⁶²⁵ - Jochen Ahlswede, “Accelerator-Driven Transmutation Technologies Reviewed – a Solution for Nuclear Waste Disposal?”, German Federal Office for the Safety of Nuclear Waste Management, presented at the AT-OM Workshop, Berlin University of Technology, 23 May 2024; and Federal Office for the Safety of Nuclear Waste Management, “Fachstellungnahme zur „Umsetzungsstudie über eine beschleunigergetriebene Neutronenquelle am Standort eines ehemaligen Kernkraftwerks“ der Bundesagentur für Sprunginnovationen (SPRIN-D)”, March 2025, see https://www.base.bund.de/shareddocs/downloads/de/fachinfo/fa/fachstellungnahme-umsetzungsstudie-sprin-d.pdf?__blob=publicationFile&v=4, accessed 31 May 2025; also Emma Aneheim, Christian Ekberg et al., “Partitioning and Transmutation—Annual Report 2008”, 3-09-03, Chalmers University of Technology, commissioned by the Swedish Nuclear Fuel and Waste Management Co, January 2009; and Frank von Hippel, “The Uncertain Future of Nuclear Energy. A Research Report of the International Panel on Fissile Materials”, International Panel on Fissile Materials, September 2010. Only France still has an operational reprocessing plant for civilian purposes but has discontinued its breeder program. Plants in Russia and India are untransparent; see IPFM, “Reprocessing Plants”, International Panel on Fissile Materials, 28 April 2025, see https://fissilematerials.org/facilities/reprocessing_plants.html, accessed 14 May 2025.

¹⁶²⁶ - National Research Council, “Nuclear Wastes—Technologies for Separations and Transmutation”, *The National Academies Press*, 1996, see <https://doi.org/10.17226/4912>, accessed 15 June 2025.

malicious attacks. Fissile or radiating material at all stages is a potentially attractive target for military and criminal ends.

These specific requirements, which have become increasingly stringent with the advancement of knowledge, contribute to the construction and operation expenses of private nuclear facilities. However, the temporal extent of the risks associated with nuclear waste far exceeds the temporal scope of liability legislation applicable to other industrial activities. The inevitable result was the assumption of long-term civil responsibility by nation-states (see [Nuclear Economics and Finance](#) in [WNISR2023](#)).

Controlling a Potentially Explosive Nuclear Chain Reaction

Exploiting nuclear power for civilian purposes relies on maintaining a self-sustaining, stable nuclear chain reaction that produces heat at a constant rate. Appropriate control can be exercised by regulating the absorption of neutrons by nuclei other than the fissile fuel. In standard reactors, this is realized by inserting control rods of neutron-absorbing material into the reactor core. In large reactors, the process must be meticulously regulated in all sections of the reactor core to avert local overheating, a phenomenon that could result in the melting of structural components and loss of control. In the case of local malfunctions, ensuring sufficient cooling is essential for avoiding further damage.

Over the years, reactor safety studies have identified many actual and potential concatenations of incidents. In particular, the severe nuclear accidents at Three Mile Island (U.S., 1979), Chernobyl (USSR, 1986), and Fukushima (Japan, 2011) have spurred reactor safety research. Subsequently, redundant systems and multiple safety layers have been added to the design of nuclear power stations, raising complexity and costs. This also encompasses the periodic and meticulous inspection of all critical components, along with their timely replacement in the event of signs of potential failure, such as the presence of microscopic cracks. Such inspections and replacements increase nuclear plants' downtime compared to conventional power plants and compete with the economic incentive of steady operation of the plant. Steep load changes may cause wear on the non-nuclear parts and thermal strain on critical components. The power output of nuclear power plants, therefore, is less flexible than that of conventional plants.

As nuclear bomb explosions and nuclear reactor accidents have demonstrated, potential risks in the case of accidents are not only given by the amount of energy released and the immediate destructive effects of radiation, but mainly by the dispersion of radioactive material with long-term effects. Risk is a product of the probability of an event and the potential damage. Even if probabilities of heavy accidents may have been lowered by adding multiple control, emergency, and protection systems, the magnitude of their destruction potential remains such that usual liability and insurance mechanisms are incapable of coping with them. Moreover, there are doubts whether risks have effectively been reduced as increasing complexity and new kinds of dangers (for example, through cyber or drone attacks) have added new challenges. All countries seeking nuclear power have had to introduce exemptions from normal liability rules for industrial operations, thereby socializing risks and reducing operators' incentives to mitigate them.

A Key Reason for the Rising Costs of Nuclear Power

These interlinked challenges of radioactive radiation and nuclear chain reaction are unique to power generation in nuclear reactors and are intrinsically linked to the manipulation of strong forces within atomic nuclei. With increasing experience and knowledge, risk awareness and the complexity of protective measures have increased. Repeated attempts to reduce complexity with new designs have only had very limited success, as the basic problems are rooted in fundamental physical laws.

Nuclear Power Plants Need to Be Large

Nuclear reactors are built to produce heat. In a subsequent step, the heat is partially converted into mechanical energy using turbines and then into electricity using generators. These turbines and generators are of the same kind as those developed for conventional coal power plants. Temperatures produced by usual nuclear reactors, however, are lower than those reached by burning fossil fuels. The conversion efficiency of heat into electricity, therefore, amounts only to 35 percent or less compared to 46 percent for advanced coal plants and up to 60 percent for gas-fired turbines, whose waste heat then drives steam turbines in “combined-cycle” plants.

Thermomechanical Engines Are Intrinsically More Efficient at a Larger Scale

Due to several physical laws, thermal and mechanical devices are intrinsically more efficient when they are larger. Larger thermal installations have relatively smaller heat losses as volume (heat content) grows more strongly than the surface (losses)—when doubling a sphere’s diameter, the heat content increases eightfold, while the losses rise only fourfold. Moreover, larger hydraulic systems have smaller friction losses: doubling the diameter of an endless pipe reduces flow resistance to 1/16 (or 6.25 percent).¹⁶²⁷ In real pipe systems, the effect is even larger, resulting in a reduction by over 96 percent. Moreover, larger turbines allow for higher steam pressures since larger components (e.g., turbine blades) are more robust. The consequence of these and more effects is that steam turbine efficiencies, which essentially reached their maximum in the 1970s, are highly dependent on size.¹⁶²⁸

For these reasons, the usual size of conventional coal power plants has reached around 800 MW. Building larger units than these would have too large operational disadvantages in the grid, since substituting the regular output when the plant is stopped for maintenance or other reasons gets more difficult with size. As described above, smaller units can be economical, if not only the power but also the heat output is used (combined heat and power). This, however, presupposes the presence of district heating systems or industrial heat clients in the vicinity. Due to safety concerns, nuclear power plants have invariably been constructed at such a distance from densely populated areas that the economical transportation of heat has not been feasible (with a very few exceptions).

¹⁶²⁷ - According to the physical law of Hagen-Poiseuille, friction in an endless pipe with diameter d is proportional to $1/d^4$.

¹⁶²⁸ - Andreas Poullikkas, Constantinos Rouvas et al., “Optimum Sizing of Steam Turbines for Concentrated Solar Power Plants”, Electricity Authority of Cyprus, *International Journal of Energy and Environment*, 2012, Table 1, see https://www.ijee.ieefoundation.org/vol3/issue1/IJEE_02_v3n1.pdf, accessed 15 May 2025.

Specific Nuclear Challenges Bring Additional Economies of Scale

Nuclear reactors have additional costs that do not directly depend on the power rating, which is roughly proportional to the volume of the reactor core. Radiation protection, safety containment, etc., depend more on surface than on volume. The costs of operation control systems, access control, or security depend even less on the power rating of the plant. The push for size in nuclear plants is therefore stronger than in conventional thermal power plants. Per kilowatt-hour produced, both operational and capital costs are lower for larger units. The latest generation of European reactors (European Pressurized Water Reactor or EPR) even reaches 1600 MW or more. The two most recent Korean plants are rated at 1340 MW, while Chinese ones are at an average of around 1200 MW.

In addition to being less efficient than fuel-based power plants, this means that nuclear plants must be able to handle unprecedented heat throughputs: the turbine of an EPR has to digest about 2.5 times as much heat energy as the turbines of a large, advanced coal plant.¹⁶²⁹

The idea of “Small Modular Reactors”, although not new, has gained significant attention in recent years, with many different design ideas being suggested. The proponents of these concepts claim that smaller, less complex plants with more inherent safety and some degree of serial production can drive down costs. The reality, however, does not yet confirm these hopes. The OECD’s Nuclear Energy Agency has identified 127 SMR technologies.¹⁶³⁰ While most of these ideas attempt to revive old concepts from the 1960s and 1970s that have already been extensively discussed and abandoned, the size of the more realistic designs has been increased, and some now approach power ratings of 400 MW—the size of the first serious nuclear power plants in the 1960s. Estimated costs for SMRs keep increasing (for details, see chapter on **Small Modular Reactors**).

Until now, there is no initiative, the proposed simplification of which has passed detailed planning and all regulatory safety checks without cost increases, which makes a compensation of the physical disadvantages of size reduction illusory. Even if a new SMR concept were to successfully deal with the need for containing radioactivity and the need for preventing a destructive chain reaction more efficiently than traditional large nuclear power plants, its cost would not be able to compete with photovoltaic power plants which do not have these problems at all.

¹⁶²⁹ - EPR: 1600 MWe, $\eta=35\%$, advanced coal plant: 800 MWe, $\eta=46\%$.

¹⁶³⁰ - NEA, “The NEA Small Modular Reactor Dashboard: Third Edition”, No. 7737, 2025, see https://www.oecd-neo.org/jcms/pl_108326/the-nea-small-modular-reactor-dashboard-third-edition?details=true, accessed 28 July 2025.

The increasing amount of critical research on SMRs points to several areas of concern compared to traditional nuclear power plants:¹⁶³¹

- ➔ Safety gains are uncertain. Proposed simplifications often lead to unexplored problems or well-known trade-offs.
- ➔ Dispersion of the reduced inventory of smaller reactors would still lead to unacceptable destruction—a substantial lowering of the safety level is therefore no option.
- ➔ Proliferation and terrorism risks grow with more sites. These risks further increase with higher uranium enrichment levels and the need for spent-fuel reprocessing in several SMR concepts.
- ➔ The amount of radioactive waste increases. Higher neutron leakage due to a less favorable surface to volume ratio of smaller reactor cores leads to more structural components being activated.
- ➔ Attempts to increase the exploitation of nuclear fuel increase risks and costs in separation processes. Attempts to raise energy efficiency by raising temperatures require the use of other coolants than water, involving new risks. Enabling a more flexible operation by reducing the energy density of the reactor core increases the size of the facility.

Also, selling the waste heat from small reactors (like in small fossil combined heat and power plants) will not make up for the economic penalties of making them smaller.¹⁶³² This is not to mention the risks and difficulties of operating such devices in densely populated areas that could use this heat.

Production Series Will Remain Small

Due to the size of nuclear power plants and the complexity of their safety systems, the possibilities of standardization are limited. Specific local conditions—such as options to dispose of large amounts of waste heat through effective cooling systems, the risk of earthquakes and flooding, logistical restrictions, specific security requirements, or the availability of skilled labor—necessitate that nuclear projects be adapted to the specific site

¹⁶³¹ - David Schlissel and Dennis Wamsted, “Small Modular Reactors Still Too Expensive Too Slow Too Risky”, Institute for Energy Economics & Financial Analysis, May 2024, see https://ieefa.org/sites/default/files/2024-05/SMRs%20Still%20Too%20Expensive%20Too%20Slow%20Too%20Risky_May%202024.pdf, accessed 30 July 2025; and Amory B. Lovins, “US Nuclear Power: Status, Prospects, and Climate Implications”, *The Electricity Journal*, Vol. 35, Issue 4, May 2022; also Christoph Pistner, Matthias Englert et al., “Sicherheitstechnische Analyse und Risikobewertung einer Anwendung von SMR-Konzepten (Small Modular Reactors)”, Öko-Institute, commissioned by the Federal Office for the Safety of Nuclear Waste Management, March 2021, see https://www.base.bund.de/SharedDocs/Downloads/BASE/DE/berichte/kt/gutachten-small-modular-reactors.pdf?__blob=publicationFile&v=6; and Federal Office for the Safety of Nuclear Waste Management, “BASE Expert Opinion on Small Modular Reactors (SMR): Doubts and a Plethora of Unanswered Questions”, Press Release, 6 December 2023, see <https://www.base.bund.de/shareddocs/pressemitteilungen/en/2023/smr-expert-opinion.html>, accessed 30 July 2025; also M. V. Ramana and Zia Mian, “One Size Doesn’t Fit All: Social Priorities and Technical Conflicts for Small Modular Reactors”, Nuclear Futures Laboratory and Program on Science and Global Security, Princeton University, *Energy Research & Social Science*, June 2014; and M. V. Ramana, “Small Modular and Advanced Nuclear Reactors: A Reality Check”, University of British Columbia, *IEEE Access*, 2021; also Edwin Lyman, “‘Advanced’ Isn’t Always Better – Assessing the Safety, Security, and Environmental Impacts of Non-Light-Water Nuclear Reactors”, Union of Concerned Scientists, March 2021, see <https://www.ucsusa.org/resources/advanced-isnt-always-better>, accessed 3 May 2021.

¹⁶³² - Very rough rule-of-thumb calculation. Assumptions: 1) Downsizing by factor 10 from 1600 MW to 160 MW; 2) Rule of thumb in traditional industrial engineering: $CAPEX_{small}/CAPEX_{large} = (Size_{small}/Size_{large})^{0.6}$. Result: the cost per MW of the small plant is 250% of the one for the large plant—neglecting transport costs, additional safety & security in populated areas, heat management/storage. Selling heat in addition to power will yield less than 100% more income. See Frederick T. Moore, “Economies of Scale: Some Statistical Evidence”, *Quarterly Journal of Economics*, Vol. 73, Issue 2, May 1959, see <https://msuweb.montclair.edu/~lebelp/MooreEcsScaleQJE1959.pdf>, accessed 30 July 2025.

and largely single-engineered. Consequently, industrial prefabrication in series is constrained to smaller components that can be standardized.

Chinese, French, and Korean manufacturers have effectively produced small series of nearly identical plants, resulting in cost reductions. These savings stemmed only from a more rational use of known equipment, not from a learning curve with improving technologies. However, this is still far from high-volume industrial production. Even if hundreds of nuclear power plants were to be completed each year, they would still constitute a very small series in terms of industrial mass production. For comparison, a modern solar factory can produce two billion photovoltaic cells per year. In critical areas of a nuclear power plant, while conventional technologies may be used for many parts, the need for specific safety, durability, and quality control requirements necessitates bespoke production from a select number of trusted, specialized vendors. Better cost structures may only apply where off-the-shelf components can be integrated in non-critical parts of the plant.

No Real Innovation on the Horizon

Harnessing revolutionary insights in physics for exploiting the fascinating and extremely powerful forces of atomic nuclei has proven to be loaded with a series of challenges due to fundamental physical principles. The above review shows that nuclear technology has essentially gotten stuck with the concepts of 75 years ago. While the quantum physics revolution has allowed progress in other fields, such as innovative materials, semiconductors, information technology, or artificial intelligence, it has only been marginally useful in advancing nuclear technologies. The share of conventional technology, where little progress is to be expected, remains overwhelming: conventional thermal power generation equipment, physical containment and shielding made of steel and concrete (even if reduced in “advanced concepts”), and cooling systems with pipes, tanks, heat exchangers and pumps make up for most of a nuclear plant’s cost. Recently so-called “new concepts” have mostly turned out to be based on older ideas that have already been discarded.¹⁶³³ Approaches that could lead to substantial cost reductions are not in sight.

Photovoltaics

The substantial cost reductions in photovoltaic (PV) devices and the electricity they produce have been astounding to most external observers and those who have not closely followed the extraordinary advancements in microelectronics since their invention. The real price of solar modules declined by 99.6 percent between 1976 and 2019.¹⁶³⁴ It was William B. Shockley, the 1947 co-inventor of the transistor, who succeeded in 1950 to theoretically explain the photovoltaic effect observed some years earlier in his laboratory when irradiating the boundary

¹⁶³³ - E.g., sodium-cooled high-temperature reactors, different types of breeder reactors, molten salt reactors etc.

¹⁶³⁴ - Max Roser, “Why Did Renewables Become So Cheap So Fast?”, *Our World in Data*, April 2025, see <https://ourworldindata.org/cheap-renewables-growth>, accessed 9 May 2025. This is an updated summary of an extended field of work, combining different data sets and strongly relying on François Lafond, Aimee Gotway Bailey et al., “How Well Do Experience Curves Predict Technological Progress? A Method for Making Distributional Forecasts”, *Technological Forecasting and Social Change*, March 2018, see <https://linkinghub.elsevier.com/retrieve/pii/S0040162517303736>, accessed 25 July 2025.

In the literature several differing numbers for the learning rate of PV are reported. The differences stem from the different endpoints of the observed period, the origins of the time series used, and the precise item (PV cells, PV modules, or PV systems) observed. See also Figure 56.

layer between differently doped layers of silicon. This quantum-mechanics-based explanation of a potential new energy source, simply using sunlight and semiconductors, motivated further research, resulting in the first two-square-centimeter solar cell in 1954—the same year the first nuclear power plant was connected to a power grid in Obninsk, in the then-Soviet Union.

An Essentially Electronic Technology

Against the backdrop of emerging semiconductor technology, solar energy's basic principle sounded familiar: solar radiation knocks electrons out of their specific atomic orbit, and electric fields between semiconductors help collect them in such a way that they become available as an electric current. The basic mechanism occurs at the nanometer scale; radiation is directly transformed into electricity, with heat produced only as a by-product of solar irradiation. There are no moving parts, and the atomic nucleus is not involved.

The initial efficiency of this conversion was 6 percent—about four times the efficiency of photosynthesis in plants when converting solar radiation into chemical energy. But the problem was how to manufacture large silicon areas of constant quality at acceptable prices. These problems were only solved later, when economic and political interests spurred serious development efforts.

However, essential advantages were obvious from the beginning: There were no specific dangers attached, so no unusual protection was needed.

Extreme Scalability Upwards and Downwards

The active layer of photovoltaic cells is nanometer-thin and has continuously decreased. All the rest is electrical contacts and packaging. The efficiency of the device does not depend on the size of the surface but only on the intrinsic properties of the specific technology chosen.

The necessary amount of active material was very small from the beginning and has decreased since. No unusual minerals are needed for mainstream silicon technologies. Silicon is available in abundance. Only relatively small amounts of silver, copper, or aluminum for the contacts need to be appropriately sourced and are worth being recovered after use.¹⁶³⁵ Different types of thin-film-based cells use even less material, which in some cases is toxic but can be recycled.¹⁶³⁶ Depending on the kind of installation, larger amounts of conventional glass, metal, and concrete may be needed for encapsulating the active layers and deploying the solar panels. New technologies for integrating an active photovoltaic layer into structural materials of buildings (roofs, facades, windows) or vehicles eliminate most encapsulation and all racking or mounting materials.

¹⁶³⁵ - Recycling of all kinds of materials is only starting to become relevant as decommissioning of old solar installations is only beginning and has not yet reached larger volumes.

¹⁶³⁶ - Thin-film photovoltaics make up for less than 10 percent of the market and their active layer is 50 to 500 times thinner (0.3 – 4 µm) than traditional PV. They use a wide variety of other materials, but in very small amounts: CIGS, as the name says, use copper, indium, gallium, selenium. Most problematic and discussed is the use of Cadmium in CdTe (Cadmium-Telluride) cells: They are being produced in larger quantities by First Solar which has developed a recycling system preventing the toxic element from ending up in the environment. Upcoming perovskites are complex crystal structures that can contain a variety of metals. A frequent component today is the heavy metal lead, which is not rare but an environmental poison. It is widely being used in traditional lead batteries. Both recycling and substitution are being discussed for the small amounts needed in perovskites.

Because of these basic physical properties of the power generation process, PV is extremely modular, i.e., deployable at very different scales. Basic units are solar cells with a power rating of 5-6 Watt each. Very large cell factories produce up to two billion PV cells per year.¹⁶³⁷ Cells are then encapsulated in modules (medium size ca. 1.8 x 1.0 meter) delivering 400–700 W_p (Watt peak). Such modules are used for all kinds of installations, from balconies to large ground-mounted power plants, although specialized sizes are now appearing. Further cost reductions through sophisticated mass production seem to be limited, but installation and balance-of-system continue to show major improvements. High modularity not only allows for extremely large production series but also for very rapid standard permitting and deployment.

High Innovation Rate and Strong Cost Reductions to Continue

The prevailing opinion is that the substantial cost reductions achieved by photovoltaics are primarily attributable to the advanced mass production techniques employed in China.¹⁶³⁸ Such calculations usually refer to the module costs (per W_p). More relevant, however, are the resulting electricity production costs. They encompass important surface-related installation expenses that decrease with lower surface requirements when efficiency rises. Fuller analysis shows that gains in efficiency caused by advances in nanoscience-based material sciences are the main driver of solar electricity cost reductions.¹⁶³⁹ While production costs per module area may not further decrease substantially, efficiency is expected to continue to improve considerably.

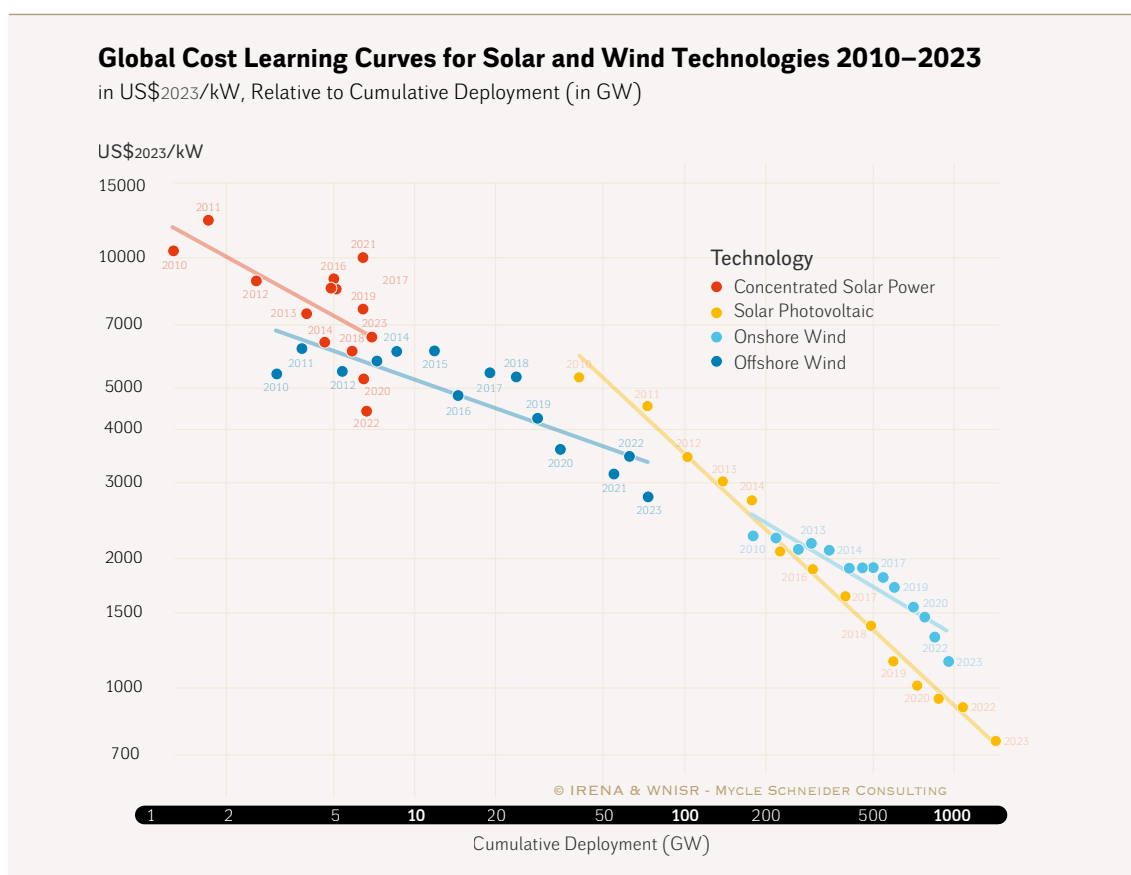
Learning curves illustrate how costs decrease with accumulated experience and over time. On a logarithmic scale, these curves can be approximated with straight lines. Figure 56 shows the learning curves in global weighted-average total cost of installed capacity for four technologies over the period 2010 to 2023. It illustrates that the costs of photovoltaics have come down much more rapidly than those of wind and CSP (a thermal technology). Advancements in nanoscale material science, on which PV technology essentially relies, have significantly contributed to this advantage and will likely continue to do so.

¹⁶³⁷ - Globally leading cell producer LONGI operates a 5-GW cell factory in Ohio; see LONGI, “2023 Annual Report: LONGI maintains Robust Financial Condition and Strong Risk Resistance Capabilities”, 30 April 2024, see <https://www.longi.com/us/news/2023-longi-annual-report/>, accessed 15 May 2025. Assuming a cell power of 5 W, it can produce 1 billion cells per year. Meanwhile, 10-GW factories are being constructed; see Vincent Shaw, “Chinese PV Industry Brief: SPIC Begins Work on 10 GW Heterojunction Cell, Module Factory”, *pV magazine*, 18 February 2025, see <https://www.pv-magazine.com/2025/02/18/chinese-pv-industry-brief-spic-begins-work-on-10-gw-heterojunction-cell-module-factory/>, accessed 15 May 2025.

¹⁶³⁸ - Goksin Kavlak, James McNerney and Jessika E. Trancik, “Evaluating the Causes of Photovoltaics Cost Reduction”, Massachusetts Institute of Technology, *Energy Policy*, revised 21 November 2018, see <http://www.ssrn.com/abstract=2891516>, accessed 1 September 2023.

¹⁶³⁹ - Ruggero Schleicher-Tappeser, “Photovoltaics: Increasing Cost Efficiency Through Dematerialisation”, *Sustainable Strategies*, 3 February 2023, see https://sustainablestrategies.substack.com/p/photovoltaics-increasing-cost-efficiency?utm_campaign=post&showWelcomeOnShare=false, accessed 16 May 2025.

Figure 56 · Learning Curves for Solar and Wind Technologies

Source: IRENA, 2024¹⁶⁴⁰

While the efficiency of silicon-based solar cells has increased beyond the expectations of only some years ago, new perovskite materials are approaching industrial maturity. These sophisticated materials are inexpensive and can be integrated into established production processes.¹⁶⁴¹ Changing the composition of solar cells can help tune the absorption spectrum. This would allow for the next big leap in efficiency: affordable multi-junction solar cells, where several layers are put one on top of the other to absorb different parts of the solar spectrum.¹⁶⁴²

¹⁶⁴⁰ - IRENA, “Renewable Power Generation Costs in 2023”, International Renewable Energy Agency, September 2024, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Sep/IRENA_Renewable_power_generation_costs_in_2023.pdf, accessed 16 May 2025.

¹⁶⁴¹ - Maia Benstead, “The Application Areas Driving the Uptake of Perovskite Photovoltaics”, IDTechEx, 21 February 2025, see <https://www.idtechex.com/en/research-article/the-application-areas-driving-the-uptake-of-perovskite-photovoltaics/32643>; and Abdulaziz S. R. Bati, Yu Lin Zhong et al., “Next-Generation Applications for Integrated Perovskite Solar Cells”, University of Queensland, Griffith University Nathan and École Polytechnique Fédérale de Lausanne, in *Communications Materials*, 5 January 2023, see <https://www.nature.com/articles/s43246-022-00325-4>; both accessed 16 May 2025; also Jiye Han, Keonwoo Park et al., “Perovskite Solar Cells”, in *Nature Reviews Methods Primers*, 16 January 2025, see <https://www.nature.com/articles/s43586-024-00373-9>, accessed 19 May 2025.

¹⁶⁴² - Hui Li and Wei Zhang, “Perovskite Tandem Solar Cells: From Fundamentals to Commercial Deployment”, *Chemical Reviews*, 23 September 2020, see <https://doi.org/10.1021/acs.chemrev.9b00780>; and Jaekeun Lim, Nam-Gyu Park et al., “All-perovskite Tandem Solar Cells: From Fundamentals to Technological Progress”, University of Stuttgart, Sungyunkwan University, Ulsan National Institute of Science and Technology, Forschungszentrum Jülich, *Energy & Environmental Science*, 2024, see <https://pubs.rsc.org/en/content/articlelanding/2024/ee/d3ee03638c>; both accessed 19 May 2025.

In the laboratory, tandem cells that combine silicon and perovskites have already achieved efficiencies of 34.9 percent.¹⁶⁴³

Another development that may lead to substantially reduced solar electricity costs is the integration of an active PV layer into building and vehicle structures that are necessary anyway. Ongoing massive cost reductions of standard modules have hindered earlier attempts in this direction. But now, with accelerating PV deployment, new demand, new efficient thin-film materials, new encapsulation materials, and new methods for integrating inconspicuous rectangular cells, new approaches are emerging.¹⁶⁴⁴

The Challenge: PV Transforms the Energy System, Brings a New Paradigm

Photovoltaic energy has the potential to provide electricity at a much lower cost than the predominant fossil fuel-based and nuclear power production methods currently employed on a global scale. However, it cannot simply substitute for conventional power plants. Within the present system, it faces a significant challenge: its ability to generate electricity depends upon the presence of sunlight or bright skies.

To overcome this limitation, solar power must be complemented by other energy sources, storage, and greater flexibility in the entire system, including consumption. Fortunately, new technologies appropriate to this purpose are evolving rapidly. The following pages will delineate the salient characteristics of these technologies. Together, they form an emerging renewable energy system, which will be further detailed in the following section (“The role of power generation technologies in energy systems”). This system operates differently from the old one and is driven by the increasing affordability of solar power, gradually leading to a new energy system paradigm.

New Batteries and Power Electronics

Neither new batteries nor power electronics are power generation technologies; rather, they are system technologies for the storage, transformation, and control of electricity. Together with photovoltaics and other distributed power generation technologies, such as wind power, they are about to deeply transform the whole energy system.

Both new batteries and power electronics, just as photovoltaics, have their origin in new material sciences enabled by quantum mechanics. As PV, they rely on processes in the electron shell of atoms, leaving the nucleus untouched. A bit later than microelectronics and photovoltaics, when advanced computing allowed for solving their intricate problems, they also experienced and still experience steep performance growth and cost decline.

¹⁶⁴³ - NREL, “Photovoltaic Research—Best Research-Cell Efficiency Chart”, Updated 14 May 2025, see <https://www.nrel.gov/pv/cell-efficiency>, accessed 16 May 2025.

¹⁶⁴⁴ - Fraunhofer Institute for Solar Energy Systems, “Pilot Production Line for Solar Roof Tiles with Matrix Shingle Technology Established”, Press Release, 6 May 2025, see <https://www.ise.fraunhofer.de/en/press-media/press-releases/2025/pilot-production-line-for-solar-roof-tiles-with-matrix-shingle-technology-established.html>; and Solarmarkt, “BIPV”, 2025, see <https://www.solarmarkt.ch/de/solarwissen/uebersicht/bipv>; also Andrew R. Smith, Mehrdad Ghamari et al., “Thin-Film Technologies for Sustainable Building-Integrated Photovoltaics”, Teesside University, *Energies*, 18 December 2024, see <https://www.mdpi.com/1996-1073/17/24/6363>; all accessed 16 May 2025.

Power Electronics—An Underestimated Key Component of the Energy Transition

Wind turbines, electric cars, photovoltaic devices, and efficient electric motors would not be possible or would have a hard time competing against traditional systems without modern, semiconductor-based power electronics. After the invention of the transistor, microelectronics specialized in treating digital information with ever smaller devices and minimal currents. Based on the same principles, power electronics were developed to control ever larger electric power flows. Using new materials and circuits able to deal with very large currents, voltages, and frequencies, power electronics learned to modify nearly every characteristic of power flows while steadily reducing power losses.

A key concept underlying power electronics is chopping up currents with semiconductor switches at very high frequencies and recomposing the parts to form currents with other characteristics. From tiny power supplies for everyday devices to house-high converters for high-voltage direct current power lines, from electric motors with variable speed to power control units in electric cars, power electronics has become widespread in all areas where electricity is needed.¹⁶⁴⁵ Thanks to an improving understanding of the processes involved at the nanoscale and the development of new materials, the power density of power electronics devices has increased by a factor of 1,000 over the past 25 years.¹⁶⁴⁶ And progress is not coming to a halt: presently, the stepwise substitution of predominant silicon with wide-bandgap semiconductors SiC (silicon carbide) and GaN (gallium nitride) is leading to considerable improvements.

Because of their common origin, digital data processing and communication technology can directly talk to power electronics without human intervention or old-fashioned electromechanical devices. Combined with innovative electronic sensors, this allows for far-reaching automation and robotics of all kinds. With these technologies, the traditionally “dumb” electrical grid, constructed with mechanical switches and heavy transformers for the top-down distribution of centrally produced power, is gradually being converted into a digitally controlled network that allows for highly efficient power flows in all directions, flexibly adapting to the demands and offers of millions of power producers and consumers.

New Batteries—A Game Changer for Flexibility

The most recent steep performance boost and cost decline among all major new energy technologies has been witnessed by rechargeable batteries, which are now starting to challenge conventional wisdom concerning the flexibility of power supply. Electrochemistry, allowing for the macroscopic transformation of chemical energy into electric energy and vice versa, has been developed since the early nineteenth century. But it was only with a deep quantum-mechanical understanding of the processes involved that a more powerful rechargeable battery based on lithium ions could be developed from the 1980s onwards.

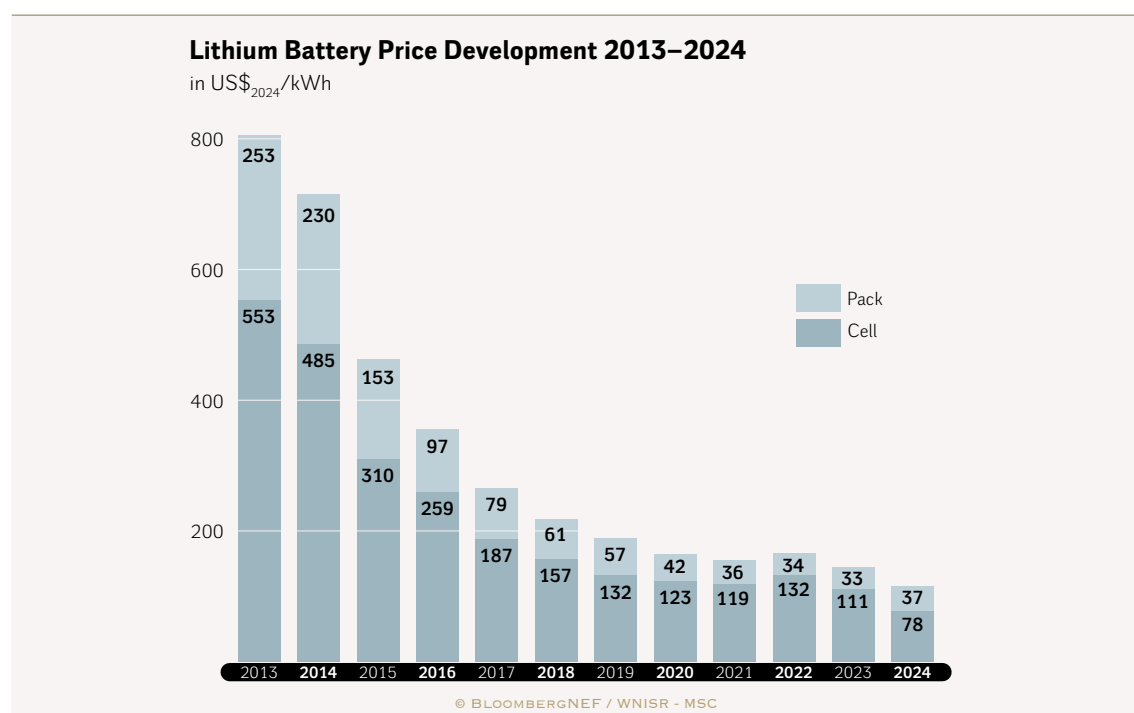
¹⁶⁴⁵ - Ruggero Schleicher-Tappeser, “Emancipation from Mechanics - The Long Road to Modern Power Electronics”, *Sustainable Strategies*, 31 August 2023, see <https://sustainablestrategies.substack.com/p/emancipation-from-mechanics-the-long>; and Ruggero Schleicher-Tappeser, “Power Electronics Turns Electricity into a Flexible Universal Energy”, *Sustainable Strategies*, 15 September 2023, see <https://sustainablestrategies.substack.com/p/power-electronics-turns-electricity>; both accessed 17 May 2025.

¹⁶⁴⁶ - Jeffrey Morroni and Pradeep Shenoy, “Understanding the Trade-offs and Technologies to Increase Power Density”, Texas Instruments, 2023, see <https://www.ti.com/lit/wp/slyy193c/slyy193c.pdf>, accessed 17 May 2025.

The challenge consists of achieving high energy densities and rapid energy flows in multifaceted interactions between ions, electrons, complex hosting structures, and interfaces. The sheer multitude of potential combinations of chemical reactions, complex materials, and spatial configurations is such that important research efforts can lead to considerable progress in the field. The systematic use of extensive test series, large databases, and advanced quantum mechanical modeling has resulted in a significant acceleration of performance improvements. Known chemistries have been extensively refined, and new, promising combinations have been identified. Significant investments have been primarily driven by the aspiration to secure a substantial market share in the global battery market for electric vehicles. Nonetheless, batteries for stationary storage are also gaining importance. CATL, the global battery market leader, has over 12,000 staff members involved in R&D activities and holds 13,000 issued or pending patents worldwide.¹⁶⁴⁷

Lithium-ion battery cell and battery pack prices have declined drastically over the past decade. Figure 57 represents the evolution of the volume-weighted average lithium-ion battery pack and cell price split over the years 2013 to 2024. The increase in 2022 was primarily due to a lithium shortage, which subsequently eased with the development of new lithium mines. The particularly strong price decline of 20 percent in 2024 was not expected and leads to an accelerated reevaluation of the role of batteries in the electricity system.

Figure 57 · Lithium Battery Price Development, 2013–2024



Source: BloombergNEF, 2024¹⁶⁴⁸

Note BloombergNEF: Historical prices have been updated to reflect real 2024 dollars.

¹⁶⁴⁷ - FISITA, “FISITA Directory—CATL - Contemporary Amperex Technology Co Limited”, Undated, see <https://www.fisita.org/directory/catl>, accessed 17 May 2025.

¹⁶⁴⁸ - BloombergNEF, “Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to \$115 per Kilowatt-Hour: BloombergNEF”, 10 December 2024, see <https://about.bnef.com/blog/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/>, accessed 17 May 2025.

Today, global battery markets are dominated by various lithium-based chemistries, which are still being improved. In addition, a wide variety of new approaches, involving other elements or sophisticated nano-structured electrodes, promise a series of advantages:

- much higher power densities enabling farther reach of electric vehicles and even powering electric airplanes;
- cheaper, abundant basic materials, and no need for problematic, rare, or toxic resources;¹⁶⁴⁹
- longer lifetime and lower costs;
- improved safety characteristics, new form factors, easier management, and cooling.

Given the numerous options, diverse approaches, and significant investments, further rapid progress in performance and reduction in cost is preordained. The potential for cost reductions through sophisticated mass production has also not yet been exhausted. This will have important consequences on all levels of the electricity system, from generation to consumption. Flexibility in time and space is increasing. As the section on system aspects demonstrates, significant price thresholds for widespread use in both public and private systems have been surpassed in 2024.

Game-changing Upgrades for Older Energy Technologies

Less spectacular progress has been made in other renewable energy sources and energy technologies that complement the disruptive dynamics of photovoltaics, new batteries, and power electronics. However, these technologies are essential components of the technology set that drives the emergence of a new energy system paradigm. As illustrated in the next section, together they can provide the flexibility needed to compensate for the least-cost but variable output of photovoltaics.

Wind Power's Breakthrough with Power Electronics

Wind energy is essentially based on mechanical technologies. Increasing aerodynamic knowledge in the nineteenth century led to a shift from slow windmills to high-speed wind turbines, later to optimized blade forms, taking advantage of aerodynamic competence developed in aviation. From the 1950s onwards, a three-blade construction with horizontal axis emerged as the preferred solution. This design revealed two key parameters for further efficiency gains: increasing the hub height to reach higher wind speeds and expanding the rotor diameter to improve the relationship between the catchment area and blade length. As always in mechanical power plants, size matters. New materials, such as composite blade materials, and innovative tower construction technologies have enabled the development of present turbine sizes, step by step. The largest ones are not tolerated onshore, so they are being built offshore instead. This requires additional large amounts of steel and concrete for deep

¹⁶⁴⁹ - Sodium batteries have reached such a degree of maturity that they are starting to be used in electric vehicles. Chinese manufacturers are building up large capacities. Sodium is abundantly available, each liter of seawater contains 11g of sodium; see *Batteries News*, "CATL Works on Development of 2nd-Gen Sodium-Ion Battery", 17 March 2025, see <https://batteriesnews.com/catl-works-on-development-of-2nd-gen-sodium-ion-battery/>; and *EEWORLD*, "A Project to Produce 50,000 Tons of Sodium-Ion Battery Electrolyte Per Year Was Signed in Hangzhou!", 24 April 2025, see <https://en.eeworld.com.cn/news/newenergy/eic695335.html>; both accessed 25 July 2025.

foundations or floating constructions. Moreover, construction and maintenance are much more complicated. Therefore, despite turbine size advantages and stronger and more frequent winds on the open sea, the costs per kilowatt-hour generated offshore are higher than onshore.

However, despite all mechanical improvements, a key problem remained: wind blows with variable speed, whereas traditional electricity generators needed to turn at a constant speed matching the frequency of the grid. Even the most elaborate gearboxes could not fully utilize the power of varying winds. Therefore, perhaps the most decisive enhancement in the efficiency and routine functionality of wind power plants, enabling the breakthrough of modern wind power, materialized on the electrical side. Since the late 1990s, advancements in power electronics have enabled the complete decoupling of generator speed from the frequency of the power delivered to the grid. Furthermore, digital controls facilitate the continuous optimization of the blade pitch, thereby ensuring maximum rotor efficiency in variable wind conditions.

Considering this background, wind energy's cost decline has been understandably slower than in photovoltaics but still impressive. Moreover, further cost reductions seem difficult without a radically different mechanical design, which is not in sight. However, the cost per kilowatt-hour is not the only criterion for success. As shown in the next section, wind energy has important systemic advantages: the wind tends to blow stronger when the sun's rays are weaker.

Meanwhile, new ideas are emerging in wave energy, a neighboring field which also aims to transform macroscopic natural mechanical energy into electric power. Here too, modern power electronics are enabling solutions that were previously unimaginable. Some nascent, still not industrialized technologies are claiming astonishing advantages compared to wind power.¹⁶⁵⁰

The Electric Motor Becomes Flexible

The emerging energy system, increasingly based on solar and wind power, not only relies on new technologies for generating and storing electric power, but also on the massive electrification of energy use. Coupling transport and heat supply with the electricity system can lead to a strong increase in electricity demand and open up large new opportunities for energy efficiency gains and flexibility in the use of electricity. Heat accounts for almost half of global final energy consumption.¹⁶⁵¹ Transport consumes about one third.¹⁶⁵² New and improved technologies for converting electricity into heat and mechanical energy must therefore be considered an integral part of the set of technologies enabling renewable energy supply.

Traditional grid-connected electric motors operate at a constant speed since their functioning is linked to alternating current with grid frequency. Only with advanced power electronics has it become possible to regulate the speed and force of alternating-current electric motors

¹⁶⁵⁰ - Ben Boyd, "FEATURE: 5 Wave Energy Converter Designs – And Why Wind Power Could Be the Key to their Success", Patent Attorney, Mewburn Ellis, as published by Institution of Mechanical Engineers, 16 August 2023, see <https://www.imeche.org/news/news-article/feature-5-wave-energy-converter-designs-and-why-wind-power-could-be-the-key-to-their-success>; and Ocean Harvesting, "Technology", Undated, see <https://oceanharvesting.com/our-technology/>; both accessed 20 May 2025.

¹⁶⁵¹ - IEA, "Renewables 2024—Analysis and Forecast to 2030—Global Overview", October 2024, see <https://www.iea.org/reports/renewables-2024/global-overview>, accessed 25 May 2025.

¹⁶⁵² - Eurostat, "Statistics Explained—Final Energy Consumption in Transport - Detailed Statistics", Updated September 2024, see https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Final_energy_consumption_in_transport_-_detailed_statistics, accessed 26 May 2025; and IEA, "World Energy Outlook 2024", October 2024, op. cit.

by varying the frequency of the power supply. In many applications, using so-called Variable Frequency Drives (VFD, also called Adjustable Speed Drives or ASD) not only results in large energy savings, but also allows for much smoother operation and more flexibility in electricity consumption.¹⁶⁵³ This is especially true for the half of electricity that drives pumps and fans, because many applications often require less flow than the maximum possible, and their energy use varies as the cube of flow, so (for example) halving the flow can save nearly seven-eighths of the energy.

The savings potential is impressive. In 2021, electric motors represented 46 percent of the E.U.'s electricity consumption. Power savings potentials for single units range 10–75 percent. However, as a VFD does not make sense for every application, the overall potential is estimated at 12 percent, of which only a quarter has already been implemented.¹⁶⁵⁴ Secondary savings due to a more continuous operation, such as in Heating, Ventilation, and Air Conditioning (HVAC) systems, are not yet included in these figures. A fuller analysis, counting 35 improvements rather than just a few, found potential savings upwards of 50 percent.¹⁶⁵⁵

Electric Heat Pumps Revolutionize Heat Supply Across All Sectors

Heat pumps are not new. Electromechanical chillers have been built since the mid-nineteenth century. The first ones for heating purposes appeared in Europe in the 1930s.¹⁶⁵⁶ But as long as electricity was mainly generated with fossil fuels, they did not bring a real advantage. Today, heat pumps are becoming the key technology for electrifying heat use. They transport heat energy from one temperature level to another. The additional energy input necessary for this transfer depends on the temperature difference to be overcome and is much less than the heat energy transferred. Present technology heat pumps for smaller buildings in central Europe, sourcing ambient heat from the outside air, deliver on average three to four times more heat energy than the electric energy input they consume. For industrial purposes, large heat pumps today can deliver up to 300°C.¹⁶⁵⁷ As for all plants using mechanical and thermal energy, the efficiency of compression heat pumps increases with size.

The recent boom in heat pump deployment in homes and industry, coupled with the continuous growth of the air conditioning and chilling markets, has led to a surge in research and development. Despite decades of experience with refrigeration, there is still much room for improvement. Efforts have mainly focused on substituting refrigerants that are harmful to the climate if released into the atmosphere and on reaching higher temperatures for industrial uses. Only recently have major heat pump manufacturers introduced VFDs for more efficient and flexible operation of home heating systems (“inverter heat pumps”).

¹⁶⁵³ - E.g., Alex Harvey, “Energy Savings with Variable Frequency Drives in Pump Applications”, Pumps & Systems, 17 December 2011, see <https://www.pumpsandsystems.com/energy-savings-variable-frequency-drives-pump-applications>, accessed 20 May 2025.

¹⁶⁵⁴ - Alexander Schröder and Johannes Liebertseder, “Study on the Energy-Saving Potential of Electric Motors with Variable-Speed Drives in the European Union—Final Report”, Fraunhofer Institute for Chemical Technology, December 2023, see https://www.zvei.org/fileadmin/user_upload/Verband/Fachverbaende/Automation/Elektrische_Antriebe/Cemep_Studie/Cemep_Fraunhofer_study-motor-saving-potential-with-VSD-20231215.pdf, accessed 27 May 2025.

¹⁶⁵⁵ - Bill Howe, William R. Howe et al, “Drivepower Technology Atlas”, E Source, 1996.

¹⁶⁵⁶ - Irene Pallua, “The Materiality of Space Heating: Heat Pumps and Heating Transitions in Twentieth-Century Switzerland”, *History and Technology*, 2 October 2021, see <https://www.tandfonline.com/doi/full/10.1080/07341512.2022.2033385>, accessed 20 May 2025.

¹⁶⁵⁷ - Everllence, “Industrial Heat Pumps for Emission-Free Solutions”, Undated, see <https://www.everllence.com/our-focus/future-technologies/heat-pumps>, accessed 20 August 2025.

However, more radical, partly nanoscience-based innovations are emerging. They avoid problematic refrigerants, achieve much higher efficiencies, produce heat of up to 400°C, or show a high dynamic flexibility in input and output temperature levels. One approach uses sound waves for high-frequency gas compression.¹⁶⁵⁸ Another uses high-speed centrifuges in a condensation-less process.¹⁶⁵⁹ Products using the latter approach are already available, and the market introduction of thermoacoustic heat pumps is imminent. The most fascinating approach, however, will still require some years of R&D to reach market maturity: electrocaloric solid-state heat pumps, in which a substance's heat content varies with the applied electric voltage and heat pipes enable rapid one-way heat removal.¹⁶⁶⁰ Even before the completion of a hypothetical nuclear power plant decided upon today, it can be expected that heat pumps will have 70 percent better efficiency, need much less space, be very flexible concerning temperatures, and need no refrigerants.¹⁶⁶¹

The availability of flexible heat pumps of various sizes for a wide range of temperatures enables the efficient exploitation of previously inaccessible heat sources. Waste heat from industrial plants, wastewater conduits in urban areas, rivers, and geothermal sources of all kinds can now be harnessed at varying temperatures at all levels. Traditional district heating systems needed to operate at temperatures above the final use temperature, resulting in significant heat losses despite extensive insulation. Today, heat pumps on the user side allow for fifth generation district heating and cooling, which operates at much lower temperatures. This enables district heating to avoid heat losses, deliver heat at varying temperatures, and even provide cold in the summer.¹⁶⁶² However, highly efficient buildings require so little heating and cooling that district heating systems may not compete with small, distributed, highly efficient heat pumps or even passive designs that do not need any active heating/cooling source at all.

Heat Storage May Solve the Winter Problem

The existing heat capacity of industrial plants, heating systems, and buildings already provides a welcome buffer and flexibility when connected to the electricity system. Every hot water tank is a heat storage device. In France, for example, even household-level tanks are mostly connected to the grid and thus adjustable. Various conventional storage systems have been developed for storage times of several days at different temperature levels. Furthermore, as the section devoted to systemic aspects demonstrates, heat storage over extended periods becomes crucial for compensating the fluctuations in solar power generation—at least for the inefficient, current majority of the building stock. Even before the widespread availability of heat pumps,

¹⁶⁵⁸ - BlueHeart Energy, “Out Technology”, Undated, see <https://www.blueheartenergy.com/ourtechnology>, and TNO, “Using Acoustic Waves to Generate Heat and Cold (and Help Speed Up the Energy Transition)”, 21 June 2022, see <https://www.tno.nl/en/newsroom/insights/2022/06/speeding-up-energy-transition-using/>; and Equium, “Homepage—Solution”, Undated, see <https://www.equium.fr/home#solution>; all accessed 24 May 2025.

¹⁶⁵⁹ - E.g., ecop, “Product—Heat Recycling for Industry”, Undated, see <https://www.ecop.at/en/product/>, accessed 24 May 2025.

¹⁶⁶⁰ - Fraunhofer Institute, “Heat Pumps Without Compressors: Fraunhofer Advances Electrocalorics”, Press Release, as published on *Informationsdienst Wissenschaft*, 2 March 2025, see <https://nachrichten.idw-online.de/2025/02/03/heat-pumps-without-compressors-fraunhofer-advances-electrocalorics>, accessed 20 May 2025.

¹⁶⁶¹ - Electrocaloric heat pumps will reach 85% of Carnot efficiency; see Stefan Mönch et al., “How Highly Efficient Power Electronics Transfers High Electrocaloric Material Performance to Heat Pump Systems”, Fraunhofer Institute, *MRS Advances*, 31 October 2023. While present heat pumps reach around 50%; see OpenEnergyMonitor, “% of Ideal Carnot COP”, 2023, see https://docs.openenergymonitor.org/heatpumpmonitor/prc_carnot.html, accessed 23 June 2025.

¹⁶⁶² - Simone Buffa et al., “5th Generation District Heating and Cooling Systems: A Review of Existing Cases in Europe”, *Renewable and Sustainable Energy Reviews*, 1 April 2019.

so-called water Pit Thermal Energy Storage systems (PTES), i.e., very large, insulated water tanks, could deliver competitive heating energy during the winter when charged with heat from thermal solar collectors, generating most heat during the summer.¹⁶⁶³

Eventually, these systems need to be much larger (for a better surface/volume relation) than the small systems needed for a single building's heat requirements. Other technologies, not based on sensible heat (raising the temperature of a substance), can reach much higher densities and smaller heat losses, and thereby are interesting for installation in single buildings. As will become evident below, they may play a central role in balancing seasons in a fully renewable energy system. Phase-change storage systems operate at the melting point of substances (such as paraffin, ice, or salts) and store the melting heat required for the phase change from solid to liquid without changing temperature. Sorption heat storage (thermochemical storage) uses reversible processes where, in discharging, one substance (e.g., water vapor) brought in contact with another substance (e.g., porous ceramics, caustic soda) establishes weak chemical bonds while releasing heat, and in charging, heat input results in the separation of the two substances (by evaporation). Non-sensible heat storage usually comes at a higher cost if only considering the storage device itself—including the system costs of district heating grids required for large sensible heat storage, can change the picture. New developments in sorption technologies may offer disruptive opportunities for competitive seasonal heat storage at the building level within a few years.¹⁶⁶⁴

Membranes for Industrial Substance Separation

There are also lesser-known recent technologies that strongly impact the energy system. In industry, flexibility and efficiency can be greatly enhanced by using innovative membrane technologies for separation processes, which today are accomplished with heat-based drying and distillation. According to estimates for the U.S., such technologies could save a quarter of industrial energy consumption. The special membranes required for this are not yet available for all processes. However, with currently known technologies, energy consumption in the chemical and food industry can be reduced by more than half.¹⁶⁶⁵ In essence, macro-scale heating and cooling processes, as well as very large distillation columns that necessitate continuous operation in highly stable conditions, are being replaced with nano-scale physico-chemical selection processes in the membrane, driven by mechanical pressure. This substitution, therefore, not only results in higher energy efficiency, but also in considerably

¹⁶⁶³ - Michel Haller and Florian Ruesch, "Saisonale Wärmespeicher – Stand der Technik und Ausblick—Fokusstudie", Eastern Switzerland University of Applied Sciences, commissioned by Energiespeicher Schweiz, February 2019, see https://speicher.aeesuisse.ch/wp-content/uploads/sites/15/2021/09/FESS_Fokusstudie_Saisonale_Waermespeicher.pdf, accessed 1 January 2025; and Ioannis Sifnaios, Geoffroy Gauthier et al., "Dronninglund Water Pit Thermal Energy Storage Dataset", Technical University of Denmark, University of Chinese Academy of Sciences, and PlanEnergy, in *Solar Energy*, 1 February 2023, see <https://www.sciencedirect.com/science/article/pii/S0038092X22009252>, accessed 31 March 2025.

¹⁶⁶⁴ - Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology, "Thermal Storage for the Energy Transition", 1 October 2021, see <https://www.fraunhofer.de/en/press/research-news/2021/october-2021/thermal-storage-for-the-energy-transition.html>, accessed 25 May 2025; and Benjamin Fumey, Mirko Kleingries et al., "Wärmespeicher: Was steckt in der Lauge?", *Nachrichten aus der Chemie*, April 2022, see <https://onlinelibrary.wiley.com/doi/10.1002/nadc.20224126002>, accessed 20 January 2025.

¹⁶⁶⁵ - David S. Sholl and Ryan P. Lively, "Seven chemical separations to change the world", *Nature*, April 2016, see <https://www.nature.com/articles/532435a>, accessed 3 August 2024; and Fraunhofer Institute for Ceramic Technologies and Systems, "Position Paper: Membranes for Separation Technology – Application Potential for Germany", 12 April 2022, see https://www.ikts.fraunhofer.de/en/press_media/press_releases/2022_4_12_n_position_paper_membranes_separation_technology.html; also Via Separations, "Homepage—01. Technology", see <https://viaseparations.com/technology/>; both accessed 25 May 2025.

enhanced flexibility. Applied pressure can be varied in a certain range, pressure buffers with compressed air are cheap storage devices, and the units can be much smaller and shut off selectively. As industrial separation processes make up for around one-fifth of the world's final energy consumption, membrane technologies can save up to 18 percent of global energy consumption and deeply flexibilize another two percent.¹⁶⁶⁶

Hydrogen Technologies Suffer from Intrinsic Inefficiencies

Roots of the two key hydrogen technologies go back to the nineteenth century: electrolysis for hydrogen production with electricity and fuel cells for converting hydrogen back into electricity. These electrochemical technologies rely on the same family of principles as battery technologies. Therefore, the efficiencies of the core mechanisms do not depend on the scale. However, as material flows are involved, this is not true for an entire plant. In particular, electrolysis is more economical in larger units because additional parts like compressors, pumps, pipes, water treatment equipment, and sophisticated controls make up a significant portion of the overall costs.¹⁶⁶⁷

The concept of employing electrically generated hydrogen as a substitute for fossil fuels was first proposed in the early 1970s. Important development efforts in hydrogen began in Japan. There were several waves of interest in hydrogen as an energy carrier, as it could be more easily stored than electricity.¹⁶⁶⁸

While today's lithium-ion batteries offer round-trip efficiencies (electricity to electricity) of more than 90 percent, electricity storage with hydrogen, even under optimal conditions, does not reach 35 percent, as losses in the individual steps accumulate: Electrolysis efficiency remains below 70 percent, and fuel cells or gas turbines can only achieve less than 60 percent efficiency.¹⁶⁶⁹ Transport and storage losses, which strongly depend on distance and the overall system configuration, further reduce overall efficiency.¹⁶⁷⁰ However, if heat use is also considered, in a combined heat and power setting, or simply by burning hydrogen, overall energy efficiency may reach 60 percent.

A particularly controversial topic is hydrogen transport costs. While the energy content of a kilogram of hydrogen is relatively high, the volumetric energy density (the energy contained in

¹⁶⁶⁶ - The share of industry in the world final energy consumption was 39 percent in 2023; see Tables A.23 and A.24 in IEA, "World Energy Outlook 2024", October 2024, op. cit. Half of this is consumed by separation processes that could use 90% less energy with membranes; see David S. Sholl and Ryan P. Lively, "Seven Chemical Separations to Change the World", School of Chemical & Biomolecular Engineering, Georgia Institute of Technology, in *Nature*, 28 April 2016.

¹⁶⁶⁷ - Marius Holst, Stefan Aschbrenner et al., "Cost Forecast for Low-Temperature Electrolysis - Technology Driven Bottom-Up Prognosis for PEM and Alkaline Water Electrolysis Systems", Fraunhofer Institute for Solar Energy Systems, on behalf of Clean Air Task Force, October 2021, p. 9, see <https://www.ise.fraunhofer.de/de/veroeffentlichungen/studien/catf.html>, accessed 26 May 2025.

¹⁶⁶⁸ - Michael Liebreich, "Liebreich: Separating Hype from Hydrogen – Part One: The Supply Side", BloombergNEF, 8 October 2020, see <https://about.bnef.com/blog/liebreich-separating-hype-from-hydrogen-part-one-the-supply-side/>, accessed 26 August 2025.

¹⁶⁶⁹ - Electrolysis: Fraunhofer Institute for Solar Energy Systems, "Cost Forecast for Low-Temperature Electrolysis - Technology Driven Bottom-Up Prognosis for PEM and Alkaline Water Electrolysis Systems", October 2021, op. cit, p 47; in 2030: 49 kWh/kgH₂, corresponds to an efficiency of 67%. Fuel Cells: SFC Energy, "Fuel Cell Efficiency", Undated, see <https://www.sfc.com/glossary/fuel-cell-efficiency/>, accessed 26 May 2025.

¹⁶⁷⁰ - Tansu Galimova, Mahdi Fasihi et al., "Impact of International Transportation Chains on Cost of Green E-Hydrogen: Global Cost of Hydrogen and Consequences for Germany and Finland", LUT University, *Applied Energy*, June 2023, see <https://linkinghub.elsevier.com/retrieve/pii/S0306261923000733X>, accessed 15 December 2023; and Marieke Graf, "Costs and Energy Efficiency of Long-Distance Hydrogen Transport Options", Master Thesis, University of Natural Resources, 2021, see https://abstracts.boku.ac.at/download.php%3Fdataset_id%3D20961%26property_id%3D107&ved=2ahUKEwjowMjy9I-FAxVogPoHHcGHct8QFnoECBMQAQ&usg=AOvVawoP7cIDoaCwf97XTvvSKYn, accessed 26 June 2025.

a certain volume at a certain pressure) is 3.3 times lower than that of natural gas.¹⁶⁷¹ Transport in pipelines, therefore, requires larger pipe diameters and much stronger pumps. Moreover, many materials used in traditional gas pipeline technology become brittle when exposed to hydrogen. The extent to which existing gas pipelines can be repurposed for hydrogen transport and the associated costs remain controversial. In comparison, transporting hydrogen on ships for long distances, necessitates liquefying it by cooling it down to -253°C (20 Kelvin). At these temperatures, evaporation (boiling off) of a certain share of the cargo is inevitable. Liquefaction and regasification of hydrogen are energy- and capital-intensive processes.¹⁶⁷² Mostly underestimated are the negative climate effects of hydrogen losses.¹⁶⁷³ Many ambitious hydrogen strategies, such as those promoted by Germany, the E.U., or Japan, have included plans for extensive international trade with green hydrogen, taking advantage of low electricity generation costs in countries with abundant sunshine. Because of the losses and costs involved, the idea of converting green hydrogen into ammonia or more sophisticated e-fuels before transporting them over long distances is gaining traction as a more realistic solution.

The attraction of hydrogen for politics and incumbent industries lies in the hope of having found a clean drop-in substitute for fossil fuels requiring little technical modifications. However, expectations have dwindled over the past two years. Cost projections have proven to be too optimistic, demand for green or pink hydrogen (electrolysis with renewable or nuclear energy) has not developed as forecasted, and huge investments into public infrastructure, including import facilities and distribution networks, are increasingly being questioned. Nevertheless, using clean hydrogen as an energy carrier in the overall energy system is not its only possible application. With the decarbonization of the chemical industry, demand for hydrogen as a material non-energy feedstock will increase.¹⁶⁷⁴

¹⁶⁷¹ - POWER Engineers, “6 Differences Between Hydrogen and Natural Gas”, 25 February 2025, see <https://www.powereng.com/library/6-things-to-remember-about-hydrogen-vs-natural-gas>, accessed 25 June 2025.

¹⁶⁷² - Tongtong Zhang, Joao Uratani et al., “Hydrogen Liquefaction and Storage: Recent Progress and Perspectives”, Birmingham Centre for Energy Storage & School of Chemical Engineering, University of Birmingham, Khalifa University of Science and Technology, and Kelvin Thermotech Ltd, in *Renewable and Sustainable Energy Reviews*, February 2023, see <https://www.sciencedirect.com/science/article/pii/S1364032123000606>, accessed 25 June 2025.

¹⁶⁷³ - Davide Trapani, Paolo Marocco et al., “Hydrogen Leakages Across the Supply Chain: Current Estimates and Future Scenarios”, Department of Energy, Politecnico di Torino, in *International Journal of Hydrogen Energy*, July 2025, see <https://linkinghub.elsevier.com/retrieve/pii/S0360319925028824>, accessed 10 July 2025; and Michael Barnard, “Hydrogen Isn’t The Answer: 0.7-1.5 Billion Tons CO₂e Would Make It A Climate Liability”, *CleanTechnica*, 3 July 2025, see <https://cleantechnica.com/2025/07/03/hydrogen-isnt-the-answer-0-7-1-5-billion-tons-co2e-would-make-it-a-climate-liability/>, accessed 30 July 2025.

¹⁶⁷⁴ - Gabriel Lopez, Dominik Keiner et al., “From Fossil to Green Chemicals: Sustainable Pathways and New Carbon Feedstocks for the Global Chemical Industry”, LUT University, in *Energy & Environmental Science*, 2023, see <http://xlink.rsc.org/?DOI=D3EE00478C>, accessed 17 December 2023; and Fraunhofer Institute for Systems and Innovation Research, “New Study Reveals Key Strategies for Decarbonizing Industry”, Press Release, 13 January 2022, see <https://www.isi.fraunhofer.de/en/presse/2022/presseinfo-01-langfristszenarien-industrie.html>; also The Royal Society, “Catalysing Change: Defossilising the Chemical Industry”, Policy Briefing, May 2024, see <https://royalsociety.org/-/media/policy/projects/defossilising-chemicals/defossilising-chemical-industry-report.pdf>; both accessed 26 June 2025.

Conclusions

Table 17 gives an overview of the main characteristics of relevant energy technologies discussed in this section.

Table 17 · Key Characteristics of Main Energy Technologies Promoted for Decarbonization

	Energies involved	Scale of basic mechanism / forces involved	Continuity	Flexibility	Further Innovation potential	Economies of scale (manu-facturing)	Safety & security problems	Economies of scale (unit size)	Planning & Construction time	Long-term liabilities	External costs	Cost trend
Generation												
Nuclear	Nuclear → Heat → Mechanic → Electric	Nano (nucleus) / nuclear										↗
SMRs ???	Nuclear → Heat → Mechanic → Electric	Nano (nucleus) / nuclear										↗
Hydro dams	Mechanic → Mechanic → Electric	Macro / mechanical										→
PV	Radiation → Electric	Nano (shell) / electrical										↘
PV + Battery	Radiation → Electric	Nano (shell) / electrical										↘
Wind energy	Mechanic → Mechanic → Electric	Macro / mechanical										↘
Heat pump	Heat + El. → Heat	Macro / thermodynamic										↘
Transformation												
Power electronics	Electric	Nano (shell) / electrical										↘
Electric motor	Electric → Mechanic	Macro / electromagnetic										→
Storage												
New batteries	Electric ↔ Chemical	Nano (shell) / electrical										↘
Sensible heat storage	Heat	Macro / thermodynamic										→
Sorption heat storage	Heat ↔ Chemical	Nano (shell) / electrical										↘
Hydrogen	Electric ↔ Chemical	Nano (shell) / electrical										?

Scale of basic mechanism/ forces involved:

Nano (nucleus): at the level of the atomic nucleus - **Nano** (shell): at the level of the atomic electron shell - **Macro**: at the level of our everyday experience.

Positive Negative

None / Weak High / Strong

Cost Development



Upwards



Stable



Downwards



Strongly
Downwards

Key conclusions from this comparative analysis can be summarized as follows:

- ➔ Atomic energy is the only technology exploiting nuclear forces. It therefore has safety and security problems, as well as long-term liabilities, that competing technologies do not have. The consequences are rising costs and wastes to be safely stored for millennia.
- ➔ Technologies that exploit nano-level mechanisms in the electron shell of atoms, aided by quantum-mechanical insights, exhibit the most rapid innovation and cost decline.
- ➔ For generating electricity, photovoltaics has the most attractive properties in nearly all categories and the lowest electricity generation costs. However, it is not a drop-in solution for substituting conventional power plants; it needs a set of complementary technologies providing flexibility.
- ➔ Such complementary technologies have developed over the past decades with increasing speed. The most important ones are power electronics, batteries, and wind energy. Not only do they complement solar power in the electricity sector—they have started to deeply transform and decarbonize the whole energy system.
- ➔ Material sciences, powered by a combination of quantum mechanics and increasing computer performance, including AI, enable dramatic improvements in the performance of new and more conventional technologies. Highly efficient conversion, storage, and control technologies enable energy flows that previously have not been economical. This allows for more complexity and flexibility in the system.
- ➔ Solar power, therefore, or in a larger sense, renewable energy, is not about simply substituting one energy source for another. It fundamentally changes the way of conceiving energy systems. A new paradigm is already in the course of implementation.

NEW ROLES FOR ENERGY TECHNOLOGIES IN A FUNDAMENTALLY CHANGING ENERGY SYSTEM

Powerful Drivers of Change

The previous section on [Radical Changes in the Context of the Commercial Use of Nuclear Power](#) has provided an overview of the changing landscape conditioning the development of nuclear power. This section will analyze in more detail how the technology developments outlined in the last section are changing the electricity system, in particular in the following areas:

- ➔ generating electricity from renewable sources
- ➔ converting between different forms of energy
- ➔ controlling energy flows
- ➔ storing electricity and heat

The two main drivers of this change are the need for decarbonization and technological progress, which are intrinsically intertwined. The perceived necessity to stop human-made climate change by ending the use of fossil fuels has triggered a wide range of political and

industrial initiatives. These initiatives have started or accelerated technological developments and changed markets and cost structures. The result is a set of powerful, albeit complex, economic dynamics.

New technologies are profoundly changing not only electricity generation and electricity distribution, but also the role of electricity in the overall energy system. Slightly reframed, the main drivers of this role change are important and rapid improvements in performance and cost in the specific functions of digital flows control and complex interactions.

The enhanced opportunities for converting between different forms of energy, together with the need for decarbonization, are strongly encouraging the coupling of various sectors of the energy system that previously operated rather independently. In the emerging, more complex system, electricity is acquiring a central role. It is the most universally convertible form of energy.¹⁶⁷⁵

Power Generation: Renewable Electricity Unbeatably Cheap

Basic physico-technical considerations and the development of deployment statistics both show very clearly that, in spite of headwinds in some countries, photovoltaics and wind will almost certainly dominate power generation in the next decades.

As the analysis in the last section has shown, photovoltaics stand out as the most cost-effective, least harmful, and least disturbing new clean energy source with the highest innovation and deployment potential. Roof surfaces alone would be sufficient for covering 1.8 times the present electricity consumption.¹⁶⁷⁶ Moreover, it presents an attractive investment opportunity at all scales that can be deployed easily and rapidly, including on small buildings behind the meter. This latter characteristic significantly expands the pool of potential investors and operators, and, as will become more evident below, changes the role of the public grid. However, photovoltaics does have an important weakness: its fluctuating nature necessitates flexible complementary technologies.

At the level of power generation, wind is the most important complement. The global potential of wind energy is theoretically more than sufficient for covering all energy needs. However, near settlements and in beautiful landscapes, wind energy is a disturbance and often meets local opposition. Offshore wind energy is more expensive and needs longer connections.

The potential of other renewable power generation sources is limited. Large hydro energy (dams and rivers), which has its own environmental and sustainability issues but should nevertheless be mentioned as an alternative, requires appropriate geographical structures. In most OECD

¹⁶⁷⁵ - In theory, electricity can be fully converted into mechanical work. From a thermodynamic perspective, it possesses the highest quality of energy, with its exergy reaching 100 percent of its energy capacity. In practice, electricity has the most developed range of technical devices that allow it to be transformed into other forms of energy with the highest energy and exergy efficiencies. Power electronics, heat pumps, and batteries have significantly contributed to this technical versatility in recent years. Stephen R. Allen, Geoffrey P. Hammond and Russell C. McKenna, "The Thermodynamic Implications of Electricity End-Use for Heat and Power", University of Bath, Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, Vol. 231, Issue 6, September 2017, see <https://doi.org/10.1177/0957650917693483>, accessed 26 June 2025.

¹⁶⁷⁶ - Siddharth Joshi et al. calculated 55,000 TWh for a module efficiency of 20%. 2024 electricity consumption was 31,000 TWh. See supplementary data of: Siddharth Joshi, Shivika Mittal et al., "High Resolution Global Spatiotemporal Assessment of Rooftop Solar Photovoltaics Potential for Renewable Electricity Generation", Centre for Energy Climate and Marine, University College Cork, Imperial College London, Ahmedabad University, and Columbia University, in *Nature Communications*, 5 October 2021, see <https://www.nature.com/articles/s41467-021-25720-2>, accessed 25 July 2025.

countries, the potential has largely been exhausted. Moreover, hydrological regimes are becoming unreliable due to climate change.¹⁶⁷⁷ Bioenergy use has been strongly extended in the past decades. However, its overall efficiency is low,¹⁶⁷⁸ and bioenergy can pose additional problems like displacing natural habitats, competing with food production for surfaces and irrigation, being exposed to climate change affected agricultural yields, and, last but not least, it will be needed for the substitution of fossil resources in the chemical industry.¹⁶⁷⁹ Both hydro energy and biomass, as well as waste, have the advantage of being, to a large extent, dispatchable electricity sources, i.e., their output can be actively adjusted according to needs. Geothermal power production requires high temperatures and usually deep drilling. Areas where these can be accessed with reasonable effort are restricted. Capital costs are high and require rather continuous operation. Shallow geothermal energy, on the contrary, as a lower temperature heat source or as a storage medium, is accessible nearly everywhere and can become important for heat supply, especially in conjunction with heat pumps.¹⁶⁸⁰

The most recent estimates of the Levelized Costs of Energy (LCOE), i.e., the full costs per kilowatt-hour over the lifetime of a facility, not including distribution costs and not considering the temporal availability, show a clear advantage for PV (see **Figure 58**).

In a detailed study for Germany, Fraunhofer ISE concluded that in 2024, utility-scale PV plants in southern Germany could produce at €c4.1/kWh (US\$c4.5/kWh), whereas small rooftop installations, delivering at the retail level, at €c6.3/kWh (US\$c6.8/kWh). Compared at the retail level, PV rooftop electricity costs were lower than the costs of PV utility scale plus distribution. Onshore wind power came at €c4.3/kWh (US\$c4.7/kWh) for good locations. Using moderate assumptions for learning rates (PV 15 percent, wind 5 percent), Fraunhofer estimates that PV in 2045 will decrease to €c1.9/kWh (US\$c2/kWh) (ground-mounted) and €c4.9/kWh (US\$c5.3/kWh) (rooftop), while good wind locations would reach €c3.7/kWh (US\$c4/kWh).¹⁶⁸¹ For the MENA region, ISE estimated best values of €c5.3/kWh (US\$c4.7/kWh) for small rooftop and €c3.5/kWh (US\$c3.8/kWh) for ground-mounted systems in 2024. All amounts expressed in US\$₂₀₂₄.

¹⁶⁷⁷ - Jenna Travers, “Global Review Assesses Hydropower’s Vulnerability to Climate Change”, State of the Planet, Columbia Climate School, 28 July 2022, see <https://news.climate.columbia.edu/2022/07/28/global-review-assesses-hydropowers-vulnerability-to-climate-change/>, accessed 26 June 2025.

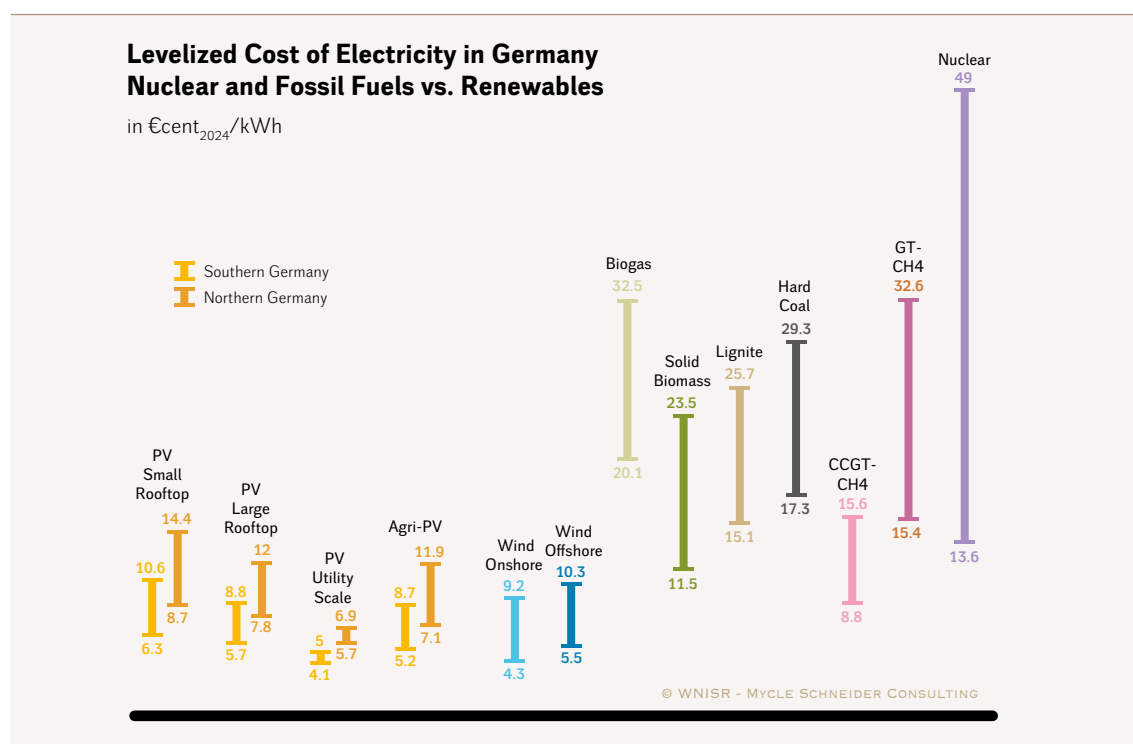
¹⁶⁷⁸ - Ruggero Schleicher-Tappeser, “Photovoltaic Power Plants on Farmland? Much Better Than Energy Crops for Cars!”, *Sustainable Strategies*, 11 December 2023, see <https://sustainablestrategies.substack.com/p/photovoltaic-power-plants-on-farmland>, accessed 26 June 2025.

¹⁶⁷⁹ - Gabriel Lopez, Dominik Keiner et al., “From Fossil to Green Chemicals: Sustainable Pathways and New Carbon Feedstocks for the Global Chemical Industry”, *Energy & Environmental Science*, 2023, op. cit.

¹⁶⁸⁰ - All kinds of geothermal energy have made strong progress due to new drilling and fracking technologies from the oil and gas industry. Joel Jaeger, Katrine McLaughlin et al., “Next-Generation Geothermal Can Help Unlock 100% Clean Power”, World Resources Institute, 10 December 2024, see <https://www.wri.org/insights/next-generation-geothermal-energy-explained>; and Rolf Bracke and Ernst Huenges, “Roadmap for Deep Geothermal Energy for Germany”, Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems, Fraunhofer Institute for Environmental, Safety, and Energy Technology, Fraunhofer for Building Physics, and Helmholtz Centre Potsdam German Research Centre for Geosciences, Karlsruhe Institute of Technology, and Helmholtz Centre for Environmental Research, October 2022, see <https://publica.fraunhofer.de/handle/publica/419996>; both accessed 26 July 2025.

¹⁶⁸¹ - Christoph Kost, Paul Müller et al., “Levelized Cost of Electricity- Renewable Energy Technologies”, Fraunhofer Institute for Solar Energy Systems, July 2024, see https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/EN2024_ISE_Study_Levelized_Cost_of_Electricity_Renewable_Energy_Technologies.pdf, accessed 30 May 2025.

Figure 58 · Levelized Cost of Energy for Various Energy Technologies at Different Locations in Germany

Source: Fraunhofer ISE, 2024¹⁶⁸²

Notes: **CCGT-CH4**: methane combined-cycle gas turbine; **GT-CH4**: methane gas turbine.

The Figure represents LCOEs of renewable energy technologies and conventional power plants at various locations in Germany in 2024. Obviously, nuclear power plants are not in operation in Germany anymore. Specific system costs are considered with a minimum and a maximum value per technology.

International studies need to estimate multi-country averages. The samples can be constructed in different ways, resulting in slightly differing averages as well. Moreover, LCOE formulas used may not be exactly the same. According to the 2025 edition of Lazard's widely referenced report, the estimated lower values for wind onshore are US\$3.7/kWh, for PV utility US\$3.8/kWh, for wind offshore US\$7/kWh, and for PV community & CI US\$8.1/kWh. For U.S. nuclear, the lower LCOE is US\$14.1/kWh (3.7 times as much as utility solar), and for gas peakers US\$14.9/kWh. With US\$3.4/kWh, purely operational costs for nuclear power plants are in the range of wind onshore and PV utility.¹⁶⁸³ Saudi Arabia, for comparison, reported an LCOE of US\$1/kWh for utility solar in June 2024.¹⁶⁸⁴

In addition to LCOE calculations based on the technologies themselves, there are different approaches to quantify the integration costs into a specific (present or future) energy system, such as the Value Adjusted LCOE (VALCOE) of the IEA and the firmed renewable energy LCOEs of Lazard. As they depend on the specifics of the energy system considered, they may

¹⁶⁸² - Ibidem.

¹⁶⁸³ - Lazard, "LCOE+—Levelized Cost of Energy+", June 2025, see <https://www.lazard.com/media/uounhon4/lazards-lcoeplus-june-2025.pdf>, accessed 22 June 2025.

¹⁶⁸⁴ - MESO, "Saudi Arabia Achieves Record Low Solar Electricity Costs", LinkedIn, 6 June 2024, see <https://www.linkedin.com/pulse/saudi-arabia-achieves-record-low-solar-electricity-costs-coihf/>, accessed 29 July 2025.

strongly differ between contexts.¹⁶⁸⁵ Moreover, the values depend on the method chosen. The extra cost of firming can range from high for 100 percent battery backup to less than zero for battery-free demand-side grid-stabilizing resources. Not to forget, thermal power plants with their large, sharp, and often unpredictable outages also have firming costs.¹⁶⁸⁶

The fluctuations of solar radiation due to astronomy (daily and seasonal variations) are regular and fully predictable. As demonstrated below, the 24-hour day/night cycle can be fully compensated by today's batteries at a reasonable cost. For the 12-month seasonal cycle, which is more pronounced in latitudes farther from the equator, this is not a viable option. These regular cycles are superimposed by weather effects that can last for several days and are governed by stochastic processes. Wind has no daily or seasonal astronomic cycles; moreover, for periods between one and 24 hours, forecasting errors for wind are larger than for PV.¹⁶⁸⁷ It tends to blow stronger when solar radiance is less intense.

However, depending on geography, wind power may even fully compensate for the seasonal variations of solar power. Elia Group, the transmission grid operator in Belgium and eastern Germany, writes in its 2021 vision for a climate-neutral European energy system: “Long-term fluctuations can be minimised with a good balance between wind (generating more energy in winter) and solar energy (generating more energy in summer), avoiding a seasonal mismatch between power supply and demand.”¹⁶⁸⁸

The distinction between utility-scale and rooftop photovoltaics is essential. Rooftop installations are usually owned by the building owner or a community of building users. They are connected behind the meter, they are not part of the public electricity system as long as the electricity is consumed in the building itself, and grid fees and (in most countries) taxes do not apply to them. This fundamentally changes the economics. Worldwide, in 2023, according to the IEA, 44 percent of the cumulative installed PV capacity was of this type; in Germany, it reached 78 percent.¹⁶⁸⁹ In most countries, privately installed PV panels behind the meter and/or electricity produced for self-consumption are not properly accounted for in public commercial energy statistics.

¹⁶⁸⁵ - See p. 15 in Lazard, “Levelized Cost of Energy+—LCOE+”, June 2024, op. cit.

LCOE figures for continents can be found p. 333 in IEA, “World Energy Outlook 2024”, October 2024, op. cit.

The IEA also calculates the VALCOE for specific countries; see IEA, “LCOE and Value-Adjusted LCOE for Solar PV Plus Battery Storage, Coal and Natural Gas in Selected Regions in the Stated Policies Scenario, 2022-2030”, 19 April 2024, see <https://www.iea.org/data-and-statistics/charts/lcoe-and-value-adjusted-lcoe-for-solar-pv-plus-battery-storage-coal-and-natural-gas-in-selected-regions-in-the-stated-policies-scenario-2022-2030>, accessed 27 June 2025. See also Elisa Veronese, Giampaolo Manzolini and David Moser, “Improving the Traditional Levelized Cost of Electricity Approach by Including the Integration Costs in the Techno-Economic Evaluation of Future Photovoltaic Plants”, Institute for Renewable Energy, EURAC Research, and Politecnico di Milano, in *International Journal of Energy Research*, February 2021, see <https://onlinelibrary.wiley.com/doi/abs/10.1002/er.6456>, accessed 27 June 2025.

¹⁶⁸⁶ - Amory B. Lovins, “Reliably Integrating Variable Renewables: Moving Grid Flexibility Resources from Models to Results”, *The Electricity Journal*, Vol. 30, Issue 10, December 2017, see <http://www.sciencedirect.com/science/article/pii/S1040619017302889>, accessed 6 July 2018.

¹⁶⁸⁷ - This statement is a summary of the answers obtained with Scholar GPT using two consecutive questions (“How precise are wind forecasts for different time horizons” and “Compare these data with PV forecasting”) drawing on a wide range of sources. There was no literature with direct comparisons. The statement corresponds with colloquial opinion in the industry.

¹⁶⁸⁸ - Elia Group, “Roadmap to Net Zero—Elia Group’s Vision on Building a Climate-Neutral European Energy System by 2050”, November 2021, see <https://www.sohertz.com/en/News/FullarticleNewssof50Hertz/11597/elia-group-publishes-roadmap-to-net-zero-our-vision-on-building-a-climate-neutral-european-energy-system-by-2050>, accessed 29 July 2025.

¹⁶⁸⁹ - Gaëtan Masson, Melodie de l’Epine and Izumi Kaizuka, “Trends in Photovoltaic Applications 2024”, International Energy Agency Photovoltaic Power Systems Programme, 2024, Table 2.6, p. 34, see <https://iea-pvps.org/wp-content/uploads/2024/10/IEA-PVPS-Task-1-Trends-Report-2024.pdf>, accessed 25 October 2024.

As behind-the-meter installations continue to scale, their capacity is becoming increasingly important. This was recently illustrated in Pakistan: The 10-percent decline in power demand in the public grid between 2022 and 2023, while the economy grew, can be partly explained by examining the import statistics for PV panels. In 2024 alone, the imported solar generation capacity amounted to 22 GW (compared to 46 GW of mostly conventional capacity operating in the public grid in 2023), primarily adding to private installations behind the meter.¹⁶⁹⁰ The chaotic development, intensified by sharply rising public electricity prices and unsatisfactory reliability of the grid, is creating new opportunities but also causing social problems. It highlights new challenges in managing the transition in emerging economies with intense sunshine.¹⁶⁹¹ In the case of Pakistan, it appears that a combination of key cost trends has reached a systemic tipping point.

Electricity Use: Electrification Brings Efficiency and Flexibility

Sector Coupling Expands and Stabilizes the Electric System

Electrification of the heat and transport sectors is a key strategy for decarbonization and an official policy goal in most countries. While this means more electricity will be needed, it also opens up opportunities for greater temporal flexibility in power demand due to the inclusion of more use cases.

Often, there is confusion between the installed generation capacity (measured in megawatts or gigawatts) needed to cover consumption peaks on one hand, and the overall electricity demand over a day or a year (measured in megawatt-hours, i.e., a megawatt power for the duration of an hour) on the other hand. As flexibility can reduce peak demand, increased flexibility can reduce the need for peak generation capacity. However, because solar and wind power only produce when the sun shines or the wind blows, they usually need more generation capacity than nuclear power to produce the same amount of electricity.

Considering the energy (MWh) needed, it is important to understand that the electrified overall energy system requires more electricity, but overall much less energy than the old system. As we have seen in the previous section, electrification offers many opportunities for higher efficiency. Energy units presently consumed in the form of fossil fuels for heat and transport purposes will therefore translate into far fewer energy units in the form of electricity. Two main factors contribute to this reduction: the electrification of propulsion (substitution of combustion engines with electric motors) and the electrification of heat production (substitution of combustion with heat pumps). While combustion engines lose about two-thirds of the energy input as heat, electric motors have efficiencies of over 90 percent. Heat

¹⁶⁹⁰ - Azeem Azhar and Nathan Warren, “The Rooftop Energy Revolution No One Knew About”, Exponential View, 14 August 2024, see <https://www.exponentialview.co/p/the-rooftop-revolution>; and Christoph S. Sprung and Mujtaba Khan, “Pakistan Is Experiencing a Solar Power Boom. Here’s What We Can Learn From It”, Engro Corporation, and Reon Energy Limited, World Economic Forum, 25 November 2024, see <https://www.weforum.org/stories/2024/11/pakistan-solar-power-energy-transition/>; also Michael Barnard, “Pakistan’s 22 GW Solar Shock: How a Fragile State Went Full Clean Energy”, *CleanTechnica*, 5 April 2025, see <https://cleantechnica.com/2025/04/04/pakistans-22-gw-solar-shock-how-a-fragile-state-went-full-clean-energy/>; all accessed 30 May 2025.

¹⁶⁹¹ - Ariba Shahid, Sudarshan Varadhan, and Charlotte Greenfield, “Pakistan’s Solar Revolution Leaves Its Middle Class Behind”, *Reuters*, 29 April 2025, see <https://www.reuters.com/business/energy/pakistans-solar-revolution-leaves-its-middle-class-behind-2025-04-29/>; and Azeem Azhar and Nathan Warren, “Is Distributed Solar Energy a Game-Changer for Emerging Economies?”, Exponential View, as published by World Economic Forum, 9 October 2024, see <https://www.weforum.org/stories/2024/10/distributed-solar-energy-emerging-economies/>; both accessed 30 May 2025.

pumps, on the other hand, can harness about two-thirds of their heat output from ambient heat. As a result, the system reduces its energy losses in propulsion and gains additional energy in heating.

Flexibility: Untapped Potential on Multiple Levels

While estimating overall efficiency improvements can be challenging, the concept of efficiency is relatively straightforward. Efficiency is defined as the ratio of output to input energy. For a specific service or product, historical data allows for comparisons.

The concept of flexibility, on the other hand, refers to the potential for changes in operational modes. It must at least include speed, frequency, and duration of possible changes compared to a standard. This multitude of dimensions makes it difficult to compare costs across technologies. Historical data are usually not available because the technical limitations, consequences, or costs of such changes have mostly never been tested, as nobody has requested it. In most domains, market designs did not incentivize flexibility, and control options were missing.¹⁶⁹²

There is a wide array of opportunities for flexibility in the electricity system. It ranges from reserve generation capacity provided by gas peaker plants to excess solar generation capacities curtailed during maximum sunshine, from batteries in homes to intermediate heat storage in industrial plants, and from changes in consumer habits or cost-neutral power use patterns to changes in industrial production rhythm enabled by additional intermediate product storage.

For the short-term management of electricity grids, a series of flexibility “products” have been defined that already trade on specific markets. These products include balancing power with different reaction times as well as other ancillary services linked to the specificities of three-phase alternating current. However, access to these markets has historically been limited to large operators, and their spatial reach is a subject of debate. (See also [Figure 68 in WNISR2024](#)).

An important compensation mechanism for up to ten seconds is provided for free by the inertia of the large rotating masses of the turbines in large thermal or hydro power plants. Some are still arguing that this is a reason for maintaining such power plants. However, the technology of inverters that in solar or wind power plants convert direct current (DC) into alternating current (AC) with grid frequency has evolved considerably. In addition to “grid following” inverters that adapt to grid conditions, there are now “grid forming” inverters that can take over the role of rotating masses. In order to stabilize the grid in critical situations, however, there needs to be a sufficient share of grid forming inverters, and they require coordination. “Virtual inertia” can be faster, more precise, and more effective than the mechanical inertia of classical rotating machines. The much-discussed blackout on the Iberian Peninsula in April 2025, which immediately triggered calls for not giving up thermal power plants with rotating masses, was caused by an insufficient adaptation of the grid to renewable energy sources and a lack of balance in the deployment of these new technologies, as well as failure of

¹⁶⁹² - Hans Ulrich Buhl, Alexander Sauer et al., “Industrial Flexibility Options and their Applications in a Future Energy System”, White Paper, University of Stuttgart, Research Center Finance & Information Management and Project Group Business & Information Systems Engineering, Mannheim University of Applied Sciences, and Fraunhofer Institute for Manufacturing Engineering and Automation, 2021, see <https://publica.fraunhofer.de/handle/publica/301167>, accessed 30 May 2025.

thermal plants to deliver the voltage control they had agreed and were being paid to provide.¹⁶⁹³ How to precisely define the requirements for inverters is an ongoing learning process.

In the medium- and long-term, however, there will be a much easier way to guarantee a very stable functioning of electricity networks with millions of active participants: the transition of ever larger parts of the grid from three-phase alternating current, with its complicated phase-shift parameters, to direct current, where voltage, and not frequency, is the main coordinating reference. With the development of power electronics, more and more AC-based traditional transformers and ancillary equipment can be replaced by more flexible semiconductor-based devices that can convert direct current across all voltage levels and switch it safely.¹⁶⁹⁴ In a conservative and safety-oriented business, however, where important investments are based on well-established standards, such a transition takes time and meets resistance.¹⁶⁹⁵

While the flexibility of electricity *generation* has always been a key issue, the flexibility of energy *demand* has gained much more interest only recently. Timid experiments with opening access to traditional flexibility markets, with additional flexibility products such as grid capacities, and with more differentiated spatial reach of these markets (zonal or nodal pricing) have shown that flexibility margins are larger than previously estimated and that they have grown over time as appropriate investments were made.¹⁶⁹⁶ Only real-world experience can show the potential under specific conditions. Available literature, therefore, often refers to monetization options in specific market designs, which, however, will undoubtedly change, making general statements and comparisons difficult.

¹⁶⁹³ - An interesting comparison between Dutch and the Spanish grid upgrading efforts is to be found in: Pablo Ruiz, Coen Hutters, and Sanne de Boer, “Facts and Lessons Learned from the Iberian Blackout”, Rabobank, 22 May 2025, see <https://www.rabobank.com/knowledge/d011479255-facts-and-lessons-learned-from-the-iberian-blackout>, accessed 24 June 2025.

A more comprehensive analysis shows the challenges of grid transformation in detail; see Agora Energiewende, “Power System Stability in the Age of Renewable Energy—Recommendations in the Context of the Iberian Blackout.”, June 2025, see https://www.agora-energiewende.org/fileadmin/Projekte/2023/2023-32_EU_System_stability/A-EW_The_Iberian_Blackout_recommendations.pdf; accessed 25 June 2025. See also the annexes in Agora Energiewende, “Power System Stability in the Age of Renewable Energy”, 19 June 2025, see <https://www.agora-energiewende.org/publications/power-system-stability-in-the-age-of-renewable-energy>, accessed 25 June 2025.

The official report is much less interesting; see Ministry for the Ecological Transition and the Demographic Challenge, “The Report of the Committee for the Analysis of the Electricity Crisis of April 28 Is Presented”, Press Release, Government of Spain, 18 June 2025, see <https://www.azonadigital.com/wp-content/uploads/2025/06/cause-of-spain-blackout-media-release.pdf>, accessed 18 June 2025. ENTSOE has not yet concluded its analysis: ENTSO-E, “28 April Blackout in Spain and Portugal: Expert Panel Releases New Information”, 16 July 2025, see <https://www.entsoe.eu/news/2025/07/16/28-april-blackout-in-spain-and-portugal-expert-panel-releases-new-information/>, accessed 27 July 2025.

¹⁶⁹⁴ - Ruggero Schleicher-Tappeser, “Power Electronics Turns Electricity into a Flexible Universal Energy”, *Sustainable Strategies*, 15 September 2023, see <https://sustainablestrategies.substack.com/p/power-electronics-turns-electricity>, accessed 17 May 2025.

¹⁶⁹⁵ - There are more than 60,000 km of HVDC lines, 60% of them in China; see Michael Barnard, “How Much HVDC Transmission Is There Now, Coming, & Where?”, *CleanTechnica*, 3 October 2023, see <https://cleantechnica.com/2023/10/03/how-much-hvdc-transmission-is-there-now-coming-where/>, accessed 27 July 2025.

Medium-Voltage DC grids are less developed, but research and pilot projects are ongoing in many countries; see CIGRE, “Medium Voltage DC Technical Brochure”, 2022, see <https://www.spenergynetworks.co.uk/userfiles/file/Medium%20Voltage%20DC%20Technical%20Brochure%20CIGRE.pdf>, accessed 27 July 2025. China is most advanced. Siemens offers a growing portfolio for MVDC grids; see Siemens Energy, “Medium-Voltage Direct Current (MVDC PLUS®)”, 2025, see <https://www.siemens-energy.com/global/en/home/products-services/product-offerings/medium-voltage-direct-current.html>; and Siemens Energy, “MVDC PLUS. Medium Voltage Direct Current. Managing the future grid”, 2021, see <https://www.siemens-energy.com/global/en/home/products-services/product-offerings/medium-voltage-direct-current.html>; both accessed 27 July 2025.

¹⁶⁹⁶ - Francesco D’Ettorre, Mohsen Banaei et al., “Exploiting Demand-Side Flexibility: State-of-the-Art, Open Issues and Social Perspective”, Technical University of Denmark, University of Adelaide, National Information Processing Institute, and University of Warsaw, in *Renewable and Sustainable Energy Reviews*, May 2022, see <https://linkinghub.elsevier.com/retrieve/pii/S1364032122005007>, accessed 30 June 2023; and Energy Transitions Commission, “Demand Side Flexibility: Unleashing Untapped Potential Alongside Electricity Grids and Storage”, Undated, see <https://www.energy-transitions.org/bitesize/demand-side-flexibility-an-important-route-alongside-electricity-grids-and-storage/>, accessed 30 May 2025.

In the early 2000s, it was widely believed among experts and often repeated by utility representatives that the electricity system could not manage to have more than 10 to 20 percent of variable generation from wind and solar.¹⁶⁹⁷ Meanwhile, confronted with the pressure to integrate fluctuating renewables, much more flexibility has been mobilized. Today, in many systems, variable renewable sources make up more than 50 percent of total generation for periods of at least several days. Several European countries with modest or no hydropower get more than half their *annual* electricity from renewables, while the GW-scale grid of South Australia, with zero “baseload” capacity, was 74 percent powered by variable renewables in 2024, with its grid operator forecasting 100 percent by 2027.¹⁶⁹⁸ The wide and confusing variety of flexibility options raises the question of why they have not been discovered and utilized earlier.

Various flexibility mechanisms have long been employed, either as ingrained practices or when circumstances required them. In Italy, for instance, standard household grid connections have traditionally been capped at 3 kW. It was widely understood that using too many appliances simultaneously would trip the automatic circuit breaker. In the early 2000s, international observers were surprised by how quickly Italy’s national electricity provider deployed electronic meters in nearly every household—an undertaking that proceeded much more slowly in other countries. The utility’s motivation was clear: replacing conventional fuses with electronic switches significantly reduced the margin of error in power control. This, in turn, curbed peak electricity demand, eliminating the need to build several new power plants. The savings generated from avoiding those investments were used to fund the full-scale rollout of digital metering instead. Additionally, the new meters paved the way for introducing multiple time-of-use pricing structures.¹⁶⁹⁹

In France, the need for demand-side flexibility emerged earlier than elsewhere because the share of rather inflexible nuclear power was higher than anywhere else.¹⁷⁰⁰ Initially, compensating for the inflexibility of nuclear power was easy, since the building up of the electricity system in France was to a very high extent based on hydro power, which is highly flexible and easy to regulate. Since EDF owns both nuclear and hydro power plants, costs for this flexibility were not made explicit. Promoting the use of electricity for heating and hot water supply with special tariffs was then an easy way for early forms of demand-side flexibility. In 2020, 37 percent of homes had electric space heating, of which 5 percent used heat pumps. As a result, the difference between day and night consumption in France is lower than in other

¹⁶⁹⁷ - Benjamin K. Sovacool, “The Intermittency of Wind, Solar, and Renewable Electricity Generators: Technical Barrier or Rhetorical Excuse?”, *Utilities Policy*, September 2009.

¹⁶⁹⁸ - The Department for Energy and Mining, “Leading the Green Economy”, Government of South Australia, Undated, see <https://www.energymining.sa.gov.au/industry/hydrogen-and-renewable-energy/leading-the-green-economy>, accessed 13 July 2025.

¹⁶⁹⁹ - Ruggero Schleicher-Tappeser, “Stromverteilnetze für die Energiewende. Empfehlungen des Stakeholder-Diologs Verteilnetze für die Bundesrepublik - Schlussbericht”, Agora Energiewende, January 2014, see https://www.agora-energiewende.de/fileadmin/Projekte/2013/Stromverteilnetze-fuer-die-zukunft/Agora_Stromverteilnetze_fuer_die_Energiewende_Stakeholder-Dialog_web.pdf, accessed 7 June 2025; and Ferruccio Villa, “Italy: The Case of Smart Meters”, Head of Electricity Quality of Supply, and Head of Electricity and Gas Smart Metering, Quality and Consumer Affairs Department, Autorità per l’energia elettrica e il gas, as presented at IEA Workshop: Transforming Innovation into Realistic Market Implementation Programmes, 28 April 2010, see <https://iea.blob.core.windows.net/assets/imports/events/320/villa.pdf>, accessed 7 June 2025.

¹⁷⁰⁰ - According to the Energy Institute, in 2024 the highest percentages were: France 67.8%, Slovakia 61.5%, Ukraine 52.4% and Hungary 42.8%.

countries. However, increasing differences between winter and summer consumption limited the use of this approach.¹⁷⁰¹

In many countries, however, utilities were reluctant to pave the way for solar power, and changing traditional habits and expectations of households or industrial users is a long-term task. An important reason for using only a small selection of the above-mentioned flexibility options is the difficulty of coordinating them. Yet this becomes possible with modern power electronics and appropriate market designs. A more detailed discussion of this aspect follows below.

The expansion of the electricity system into the heat and transport sectors, which widens the range of usage patterns involved, considerably enhances the opportunities for flexibility. Moreover, the section on the physical principles has shown how new technologies have widened flexibility options in many regards. Additional storage is not always the most economical option. However, spectacular advances in electrical storage and the new role of heat in the overall system make it worthwhile to analyze their impact in more detail.

Electricity Storage: Battery Costs Reach a Tipping Point for the System

In 2024, the price of lithium-ion battery packs declined by 20 percent, reaching US\$115/kWh towards the end of the year. The corresponding cell price was US\$78/kWh.¹⁷⁰² This was not simply due to dumping prices: according to the Volta Foundation, the leading international battery expert organization, the average LFP battery cell production cost in China by Tier 1 producers in 2024 was US\$60/kWh. BYD, the second largest producer, achieved a cost of US\$43/kWh. Volta estimates that an average of only US\$25/kWh is on the horizon.¹⁷⁰³

This has worldwide consequences. Retail prices for ready-to-use home storage kits range from US\$200 to over US\$1,000/kWh. A simple rule-of-thumb calculation based on actual offers for two popular brands, BYD and GLCE, yields levelized costs of storage of US\$8.9/kWh and US\$3.4/kWh, respectively.¹⁷⁰⁴ Assuming that 100 percent of the electricity generated by rooftop PV is being stored to be delivered at any time during the following 24 hours (just for setting an upper boundary), taking Fraunhofer's lower values for rooftop PV in southern Germany quoted earlier and applying the two indicated levelized cost estimates leads to an

¹⁷⁰¹ - Arthur de Lassus and Cédric Philibert, "La dimension stratégique de la flexibilité des systèmes électriques—Opportunités en Europe", French Institute of International Relations, May 2025, p. 16, see https://www.ifri.org/sites/default/files/2025-05/ifri_lassus_philibert_flexibilite_electrique_europe_ifri_2025.pdf, accessed 9 June 2025; and Institut de l'entreprise, "Trente ans de chauffage électrique : histoire d'une innovation mouvementée", Undated, see <https://www.melchior.fr/synthese/trente-ans-de-chauffage-electrique-histoire-d-une-innovation-mouvementee>, accessed 9 June 2025.

¹⁷⁰² - BloombergNEF, "Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to \$115 per Kilowatt-Hour: BloombergNEF", Press Release, 10 December 2024, see <https://about.bnef.com/blog/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/>, accessed 17 May 2025.

¹⁷⁰³ - Volta Foundation, "Battery Report 2024", January 2025, see https://report.volta.foundation/annual-battery-report/public/Battery_Report_2024.pdf, accessed 1 March 2025.

¹⁷⁰⁴ - BYD for €370/kWh (US\$420/kWh) yielding 6,000 cycles, efficiency 96%, and GLCE for €240/kWh (US\$272/kWh) yielding 10,000 cycles, same efficiency assumed. See TroniX, "BYD Premium HVM 0% VAT \$12 III UstG 22.1 Battery Box 22.08 kWh Solar Storage", on Amazon, 30 May 2025, see https://www.amazon.de/Premium-HVM-22-1-Battery-Solarspeicher/dp/B0DDKXH85W/ref=sr_1_8; and GLCE Energy, "48 V 400 Ah Lifepo4 Battery (4 Pack 48 V 100 Ah), GLCE Energy 20.48 kWh All-in-One LiFePO4 Lithium with Home Battery Inverter for Solar Storage System/Motorhome/Energy Storage System for Home", on Amazon, 30 May 2025, see https://www.amazon.de/Stackable-LiFePO4-Battery-Inverter-Off-Grid/dp/B0D3TV8DHL/ref=sr_1_4_ssapa; both accessed 30 May 2025. Assuming additional financing costs of 10% and 80% discharge per cycle results in LCOSs of €0.089/kWh and €0.034/kWh respectively.

overall cost for solar power delivered around the clock of US\$c15.2/kWh (or even US\$c9.7/kWh)—about half of the present utility power retail price in southern Germany.¹⁷⁰⁵ In reality, for households and small businesses, the percentage of own electricity produced and consumed that needs storage will be much lower. This means that the incentive for installing storage systems that level out 24 hours is even higher.

The effect of this rapid development is also being felt on the other side of the scale. In China, the market price for large grid-connected storage systems (completion in 2025 or 2026) is now US\$66 per kWh of capacity.¹⁷⁰⁶ The price, which was set in an auction that ended in December 2024, included maintenance services for 20 years. This means the cost of storing energy at this scale in China is about US\$c1/kWh.

The price decline has led to a surge in installations over the past three years. In Europe, the cumulative storage capacity has grown by an impressive 58 percent annually (see [Figure 59](#)). Two-thirds of these European installations are behind the meter, demonstrating the influence of private economic considerations.¹⁷⁰⁷ Utility-scale BESS (Battery Energy Storage Systems) have been hindered by (technical or bureaucratic) connection problems to the grid—in many countries, waiting queues for connection are long.¹⁷⁰⁸

At the global level, the average *annual* growth of cumulative capacity over the same period has even amounted to 80 percent. Countries leading this deployment were China and the United States. In 2024, Europe accounted for only 17 percent of global capacities (61 GWh of 352 GWh).¹⁷⁰⁹ Volta Foundation's estimation of a mere 20 percent of installations behind the meter globally appears to be an underestimation when considering the proportions in Europe and the poor accounting of behind-the-meter solar installations in many countries.

¹⁷⁰⁵ - Obviously, these figures are higher than the VALCOE given by the IEA for utility scale PV in Europe (US\$c6/kWh). This is a maximum guess for rooftop-generated power around the clock in a single building, it shows to which extent extreme 24 h storage is economically interesting for prosumers. In this calculation the size of the battery has not been considered. The storage cost was based on the overall energy the battery can charge and discharge over its lifetime calculated in cycles. Assuming 365 full cycles per year, 6,000 cycles correspond to 16.4 years, calculating with only 250, the battery should last more than 24 years.

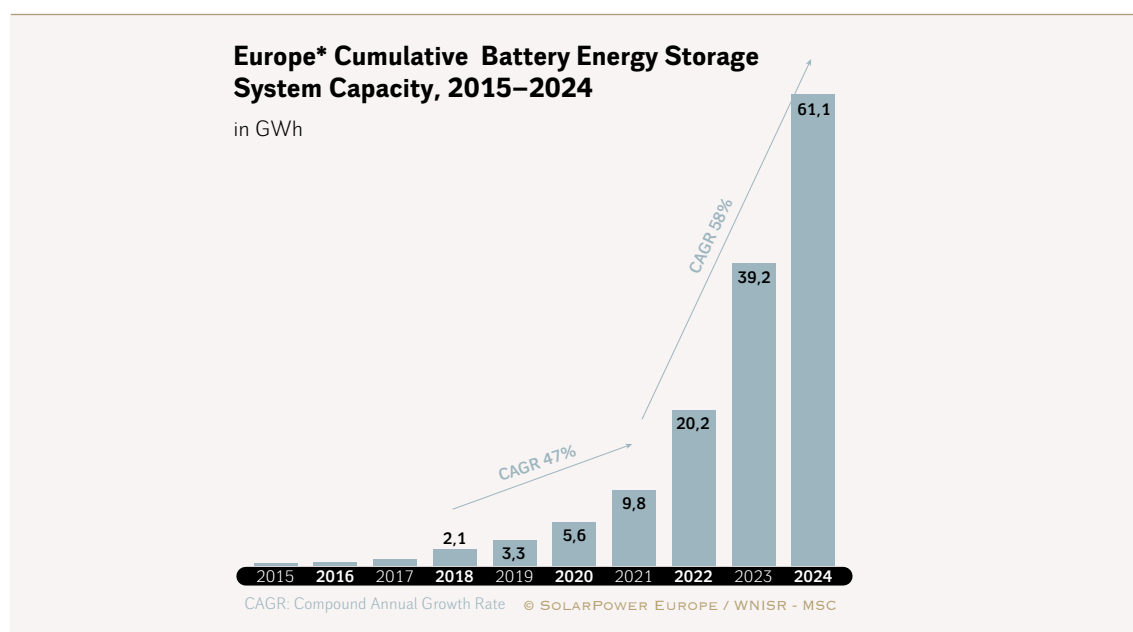
¹⁷⁰⁶ - Giles Parkinson and Joshua S Hill, “Mind Blowing: Battery Cell Prices Plunge in China’s Biggest Energy Storage Auction”, *RenewEconomy*, 17 December 2024, see <https://reneweconomy.com.au/mind-blowing-battery-cell-prices-plunge-in-chinas-biggest-energy-storage-auction/>, accessed 1 June 2025.

¹⁷⁰⁷ - SolarPower Europe, “European Market Outlook for Battery Storage 2025-2029”, May 2025, see https://api.solarpowereurope.org/uploads/SPE_European_Battery_Outlook_2025_62b89db476.pdf, accessed 30 May 2025.

¹⁷⁰⁸ - Especially in Germany, grid operators claim that they do not have enough connection points available. A “battery tsunami” has led to a queue of several hundred gigawatts of applications that will need years to resolve. The capacity of actually connected storage is far smaller than in Britain. Pairing storage with existing renewable power plants is much easier than connecting stand-alone storage. A significant problem in allowing larger storage operations is the lack of transparency concerning the actual status of the grid, due to insufficient digitalization.

¹⁷⁰⁹ - Volta Foundation, “Battery Report 2024”, January 2025, op. cit.

Figure 59 · Grid-Size Battery Fleet in the EU27, U.K., and Switzerland, 2015–2024

Source: SolarPower Europe, 2025¹⁷¹⁰

Note: *EU27, U.K., Switzerland.

While the share of overall battery production being used for BESS has increased from 7 percent in 2020 to 15 percent in 2024, the vast majority of batteries are still being used in electric cars.¹⁷¹¹ The success of policy-driven strategies for pushing e-mobility adoption has fallen short of expectations. Battery development, mainly driven by the Chinese government and Chinese companies, however, has pushed cost and performance to such a point that cost arguments in favor of electric cars are becoming increasingly compelling. Within ten years, electrification in the transport sector will therefore have a massive implications for the energy system.

Private cars are sitting idle on average for about 90–96 percent of the time. From an energy system perspective, their batteries are underutilized and could be an extremely valuable asset if connected to the grid when not in use for driving (bidirectional charging). In all scenarios, the charging of large numbers of electric cars must be distributed over the day by some coordinating mechanism in order to avoid a problematic and expensive surge in peak demand. If all present cars in Germany were electrified according to current standards, their combined capacity would equal two days of the country's current electricity consumption.¹⁷¹² A loss in service comfort and a shortening of battery lifetime through bidirectional charging is not to

¹⁷¹⁰ - SolarPower Europe, "European Market Outlook for Battery Storage 2025-2029", May 2025, op. cit.

¹⁷¹¹ - Ibidem, p. 140.

¹⁷¹² - 2023 statistics for Germany count 47.98 million passenger cars running 591,132 million kilometers i.e., on average 12,320 km/a; see Federal Office for Motor Traffic, "Inländerfahrleistung", June 2024, see https://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/vk_inlaenderfahrleistung/2023/2023_vk_kurzbericht.html, accessed 23 June 2025.

Corresponding EU data are not available. In the U.S., travelled distances are larger. Assumptions for an average passenger BEV: consumption 16 kWh/100km; usable battery capacity 60 kWh. This results in an average daily consumption of 5.4 kWh/day, a full charge lasting for 11.1 days, and a usable car battery capacity of 2.88 TWh.

In 2023, net electricity consumption in Germany amounted to 466 TWh or 1.28 TWh per day. The usable BEV battery capacity would therefore correspond to 2.25 days; see AGEb, "Energieverbrauch in Deutschland im Jahr 2023", Arbeitsgemeinschaft Energiebilanzen, 2024, see https://ag-energiebilanzen.de/wp-content/uploads/2024/04/AGEB_Jahresbericht2023_20240403_dt.pdf, accessed 23 June 2025.

be feared: In Germany, a fully charged standard car battery lasts for eleven days of average driving, the possible number of charging cycles is far from being exhausted over the lifetime of an average car.¹⁷¹³

A fully charged standard car battery lasts for eleven days of average driving, the possible number of charging cycles is far from being exhausted over the lifetime of an average car.

The costs and performance of stationary battery storage systems have reached a tipping point, making their widespread use in the electricity system a compelling prospect. They have achieved a level of proficiency that enables them to balance the fluctuations in renewable power generation over a 24-hour period, both from a technical and economic standpoint. This has profound consequences for the economic viability of renewable power generation, especially solar. Moreover, equalizing electricity flows over 24 hours, significantly reduces the need for grid expansion, as discussed below.

While these calculations referred to 24-hour cycles, the economics of storage look totally different for long periods of low renewable power production, especially seasonal variations of sunshine. If used for only one or two cycles per year, the investment cost of lithium-ion batteries with a limited lifetime of 20, perhaps 30 years, would lead to very high costs per kWh actually stored¹⁷¹⁴—for strong seasonal cycles of fluctuating renewable power, other storage technologies are definitely welcome. Heat storage and hydrogen are two main options.

Heat Storage: The Ideal Buffer for a Large Part of Electricity Consumption

While the electrification of the transport sector causes increasing electricity demand, it can add flexibility to a significant extent, as shown above.

The electrification of heat production has more complex consequences. Implemented straightforwardly, it would exacerbate seasonal differences: In regions far from the equator, heat demand is higher in the winter, but solar power generation is stronger in the summer. In other regions, power demand peaks in the summer because of cooling needs and thus constitutes a better match for solar PV.

¹⁷¹³ - Battery lifetime is determined by time, temperature, charging dynamics, and the number of charging cycles. Too little use over time can increase degradation. While average German mileage over a car lifetime of 20 years corresponds to only 670 cycles, the cycle life of modern batteries reaches up to 7,000 cycles or more. Jiangyun Zhang, Hongni Huang et al., “Cycle Life Studies of Lithium-Ion Power Batteries for Electric Vehicles: A Review”, *Journal of Energy Storage*, 15 July 2024, see <https://www.sciencedirect.com/science/article/pii/S2352152X24018176>; and EV Connect, “How Long Does an Electric Car Battery Last?”, 8 November 2024, see <https://www.evconnect.com/blog/how-long-does-an-electric-car-battery-last>; also Mark Golden, “Existing EV Batteries May Last up to 40% Longer Than Expected”, *Stanford Report*, 9 December 2024, see <https://news.stanford.edu/stories/2024/12/existing-ev-batteries-may-last-up-to-40-longer-than-expected>; and Charlotte Argue, “EV Battery Health Insights: Data From 10,000 Cars”, Geotab, 20 January 2025, see <https://www.geotab.com/blog/ev-battery-health/>; all accessed 23 June 2025.

¹⁷¹⁴ - Over-the-thumb calculation: assuming costs of US\$80/kWh for BESS, 20 years lifetime and 2 cycles per year results in US\$2/kWh not including financing costs. Comparisons with gas peakers depend very much on utilization times which are determined by seasonal load curves. Cost structures are very different. At present BESS costs, in most cases, building gas peakers—which traditionally have an average utilization rate of 10%, i.e., much higher than the extreme case considered here—is not economical anymore. How far BESS with the new price levels can replace gas/hydrogen peakers still needs to be analyzed for most markets. Thunder Said Energy, “Gas Peaker Plants: The Economics?”, Undated, see <https://thundersaidenergy.com/downloads/gas-peaker-plants-the-economics/>; and Sergio Dueñas, Aliasid Animas et al., “Battery Storage for Fossil-Fueled Peaker Plant Replacement. A Maine Case Study”, Clean Energy State Alliance, and Strategen Consulting, April 2024, see <https://www.cesa.org/wp-content/uploads/Battery-Storage-for-Fossil-Fueled-Peaker-Plant-Replacement-A-Maine-Case-Study.pdf>; both accessed 28 July 2025.

An interesting solution to cover the winter needs could be long-term heat storage. This would allow for the generation of heat with high heat-pump efficiencies and abundant solar electricity in the summer for use in the winter. This would increase efficiency by shifting considerable amounts of electricity demand from the winter to the summer and add considerable flexibility to electricity consumption since producing heat for storage would not be time-sensitive.

Existing competitive seasonal heat-storage technologies require large plants feeding local heating networks. Their centralized heat generation adds flexibility to the public electricity grid.

In June 2025, the largest sand battery in the world started operating. It can deliver 1 MWh of thermal power and store up to 100 MWh of excess energy from variable renewables. It can feed the local urban heating system or provide 400–500°C hot process heat for the industry.¹⁷¹⁵

Advanced sorption heat storage, on the other hand, is not yet competitive, but it will likely be on the market before new nuclear power plants can provide power. This technology could be installed in a single building and fed with heat produced by solar power generated behind the meter. It would considerably enhance the competitiveness of integrated energy generation and energy use by private prosumers (system participants that are both *producers* and *consumers* of energy and can balance production and consumption behind the meter for much of the time). The technology's ease of installation, permitting, and financing suggests a potential for rapid growth, similar to the current trend in home electricity storage.¹⁷¹⁶

Hydrogen and E-Fuels: Costly Workarounds for the Transition

Many scenarios for the future energy system include the use of gas peaker plants fueled with green hydrogen. As hydrogen can be stored in caverns for many months, this seems to be an obvious solution for seasonal storage. Countries such as Japan and Germany, as well as the E.U., have developed ambitious plans for a hydrogen economy. However, as round-trip efficiencies (electricity–hydrogen–electricity) will not exceed 35 percent, this will remain a rather expensive solution requiring high investments in complex infrastructures.¹⁷¹⁷ As the expansion of renewable electricity production is a bottleneck in the overall system transformation, green hydrogen production may not only be a waste of capital, but also lead to a diversion of badly needed green electricity and thereby slow down the transformation (see [previous WNISR editions](#)). From a system efficiency perspective, a combination of distributed long-term heat storage and other flexibility options is a more elegant and cost-effective way of balancing medium- to long-term electricity shortages. However, they require more advanced market designs and bottom-up control concepts than those in place today. If gas peakers are considered to be inevitable in a transition phase, the use of green ammonia as a storage medium and fuel may be preferable to green hydrogen. While green ammonia's production requires green hydrogen in the first place, and is therefore more expensive at the source, its handling, transport, and storage are much easier and necessitate much smaller infrastructure

¹⁷¹⁵ - *The Helsinki Times*, “Finland Activates World’s Largest Sand Battery to Store Renewable Heat”, 19 June 2025, see <https://www.helsinkitimes.fi/finland/finland-news/domestic/27194-finland-activates-world-s-largest-sand-battery-to-store-renewable-heat.html>, accessed 14 August 2025.

¹⁷¹⁶ - See *Heat Storage May Solve the Winter Problem*.

¹⁷¹⁷ - See *Hydrogen Technologies Suffer from Intrinsic Inefficiencies*.

investments.¹⁷¹⁸ Ammonia is a traded commodity on the global market because it is an essential chemical industry feedstock, particularly for the production of fertilizers.

Ammonia is but one example of e-fuels, which are fuels produced with carbon-neutral electricity. They are being discussed not only for electricity generation at demand peaks, but also as fuels for other hard-to-abate purposes, mainly maritime transport and aviation. There is a wide variety of scenarios analyzing different e-fuels, different local production and import strategies, and different uses.¹⁷¹⁹ None of them, however, can deny the fact that at least 40 percent of the energy input in the form of electricity is lost in the process of producing the e-fuel, and—except for heat uses—another 45 to 65 percent is lost in the engine transforming fuel into motion or electricity. Transport and handling losses come on top. When direct use of electricity or more efficient storage alternatives are conceivable in the medium term, infrastructure costs and lock-in effects have to be considered. Even for aviation, one of the hardest-to-abate sectors, electrification is extremely desirable as battery-driven airplanes would need around one quarter of the electricity of those powered by e-fuels.¹⁷²⁰

In any case, hydrogen and e-fuels will be crucial material feedstocks for decarbonizing the chemical industry.¹⁷²¹ Therefore, using surplus electricity, when not needed elsewhere, to produce hydrogen as a byproduct of the energy system makes perfect sense. However, using hydrogen and e-fuels as energy carriers will remain a costly exception. It may be inevitable in transitory phases, but it does not make sense in the long term.

System Integration: Enhanced Interlinkages Change the Control Paradigm

The increasingly central role of electricity in the energy system and the tighter coupling of different sectors call for more attention to the character of the growing number of interlinkages and their consequences.

Power Electronics (PE) enable bidirectional flows and nearly lossless conversion (AC/DC, frequency, voltage, phase shift etc.). Combined with Information and Communication

¹⁷¹⁸ - Ammonia Energy Association, “Ammonia-Fueled Gas Turbines: A Technology and Deployment Update”, 11 December 2024, see <https://ammoniaenergy.org/articles/ammonia-fueled-gas-turbines-a-technology-and-deployment-update/>; and IRENA, “Global Hydrogen Trade to Meet the 1.5°C Climate Goal—Part II: Technology Review of Hydrogen Carriers”, International Renewable Energy Agency, 2022, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_Global_Trade_Hydrogen_2022.pdf; both accessed 24 June 2025; also Rong Lan, John T.S. Irvine and Shanwen Tao, “Ammonia and Related Chemicals as Potential Indirect Hydrogen Storage Materials”, University of Strathclyde, and University of St Andrews, in *International Journal of Hydrogen Energy*, January 2012, see <https://linkinghub.elsevier.com/retrieve/pii/S0360319911022968>, accessed 12 January 2023; and Sarb Giddey, Sukhvinder P. S. Badwal et al., “Ammonia as a Renewable Energy Transportation Media”, *ACS Sustainable Chemistry & Engineering*, 6 November 2017, see <https://pubs.acs.org/doi/10.1021/acssuschemeng.7b02219>, accessed 10 January 2023.

¹⁷¹⁹ - Sonia Dell'Aversano, Carlo Villante et al., “E-Fuels: A Comprehensive Review of the Most Promising Technological Alternatives towards an Energy Transition”, *Energies*, 12 August 2024, see <https://www.mdpi.com/1996-1073/17/16/3995>, accessed 16 January 2025; and Fabian Neumann, Johannes Hampp and Tom Brown, “Energy Imports and Infrastructure in a Carbon-Neutral European Energy System”, Berlin University of Technology, and Potsdam Institute for Climate Impact Research, 5 April 2024, see <http://arxiv.org/abs/2404.03927>, accessed 12 April 2024; also Tansu Galimova, Manish Ram et al., “Global Trading of Renewable Electricity-Based Fuels and Chemicals to Enhance the Energy Transition Across All Sectors Towards Sustainability”, LUT University, in *Renewable and Sustainable Energy Reviews*, Vol. 182, September 2023, see <https://linkinghub.elsevier.com/retrieve/pii/S1364032123002770>, accessed 15 December 2023.

¹⁷²⁰ - Roughly, half of the original electricity input is lost providing e-fuels at the point of use, and half of the energy content of the e-fuel is lost in the engine.

¹⁷²¹ - Gabriel Lopez, Dominik Keiner et al., “From Fossil to Green Chemicals: Sustainable Pathways and New Carbon Feedstocks for the Global Chemical Industry”, *Energy & Environmental Science*, 2023, op. cit.

Technologies (ICT), PE is increasingly allowing for full digital control of electricity grids. More generally, power electronics, ICT, and artificial intelligence together enable fully digitalized and automated control of generation, consumption, and flows from the top level of the system down to the household level. This opens a wide range of scenarios involving interactions between millions of subsystems and actors.¹⁷²²

Traditional electricity systems were controlled by adapting the power generation of a limited number of large power plants to electricity demand. Load imbalances were indicated by deviations of the grid frequency. Generous safety margins for the tricky parameters of three-phase current enabled the safe operation of essentially “dumb” grids.

When combined with decentralized storage at various grid levels, optimization of power parameters at each grid node can significantly increase the capacity of existing grids, especially in the distribution network. Electricity flows can be distributed over time, and traditional security margins in electrical parameters can be reduced.

Furthermore, the surge in photovoltaic and storage installations behind the meter means that a growing share of overall electricity production is consumed onsite rather than flowing through the public grid. Sophisticated energy management systems in homes, buildings, and industries can optimize energy flows behind the meter according to a wide range of criteria and can control the exchange of energy with the grid.¹⁷²³

But with the need for more flexibility to accommodate variable renewable power generation, the number of assets that generate, consume, or store electricity and need to be coordinated in some way is exploding. Millions of owners and decision-makers are involved, some delegating short-term decisions to automated management systems while occasionally changing preferences, such as the time they need a fully charged car. Meanwhile, incumbent utilities’ attempts to maintain central control by directly controlling major appliances behind the meter are failing due to complexity, social acceptance, or falling short of realizing even a small share of the potential. Increasingly, market mechanisms are being explored or used for coordinating individual decisions. In Germany, where wind and solar power accounted for 47 percent of electricity consumption in the public grid in 2024, discussions on market design have intensified. Detailed expert papers from a diverse range of specialized think tanks are contributing to this debate.¹⁷²⁴ Sophisticated energy management systems can

¹⁷²² - *Renewable Energy Magazine*, “How Digitalization is Transforming the Energy Landscape: An Interview With Gerhard Salge of Hitachi Energy”, Interview with Gerhard Salge, Senior Vice President and Global CTO, Hitachi Energy, 19 December 2024, see <https://www.renewableenergymagazine.com/interviews/20241219>; and Compass Lexecon, “Prospects for Innovative Power Grid Technologies—Final Report”, 17 June 2024, see <https://www.currenteurope.eu/wp-content/uploads/2024/06/CL-CurrENT-BE-Prospects-for-Innovative-Grid-Technologies-final-report-20240617-2.pdf>; also Aneesh Manocha, Gabriel Mantegna et al., “Reducing Transmission Expansion by Co-Optimizing Sizing of Wind, Solar, Storage and Grid Connection Capacity”, University of California, Princeton University, and State University of New York at Binghamton University, 23 September 2024, see <http://arxiv.org/abs/2409.12971>; all accessed 24 June 2025.

¹⁷²³ - Eero Vartiainen, Christian Breyer et al., “Attractiveness of Photovoltaic Prosumerism in the European Electricity Market”, *Solar RRL*, Vol. 8, Issue 1, January 2024, see <https://onlinelibrary.wiley.com/doi/abs/10.1002/solr.202300576>, accessed 27 June 2025.

¹⁷²⁴ - The discussion encompasses many aspects. Local pricing is increasingly discussed as a market-based instrument for improving previously central or bureaucratic decision-making; see Agora Energiewende and Fraunhofer IEE, “Lokale Strompreise—Wie die Integration der Netzrealität in den Strommarkt gelingt und Kosten senkt”, April 2025, see https://www.agora-energiewende.de/fileadmin/Projekte/2023/2023-15_DE_Nodal_Agorameter/A-EW_355_Lokale_Strompreise_WEB.pdf, accessed 25 June 2025. The structure of grid fees is about to be revised. An alliance of innovative electricity companies has issued a joint statement emphasizing the need of incentivizing flexibility; see Elli, ENPAL et al., “Flexibel ist das neue Solidarisch: Wie ein effizientes Netzentgeltsystem für alle aussehen sollte.”, 19 May 2025, see https://cdn.prod.website-files.com/6543e4f90c4a38faf3ca5c8a/6835af94723880d5088c4bea_positionspapier-netzentgelte-reform.pdf, accessed 25 June 2025.

optimize energy exchange across the meter in reaction to price signals, weather forecasts, and behavior patterns.¹⁷²⁵ Similarly, transactions between grid operators, power plant operators, storage operators, system integrators (“virtual power plants”), and prosumers are increasingly coordinated through appropriately constructed markets for power products, grid capacities, or specific ancillary services.¹⁷²⁶

Special agencies in countries or trading zones are busy designing new markets according to perceived new necessities following changes in the technology mix. Often demands and interests of old and new participants in the energy system are diverging and clashing, but the overall tendency is clear: There is a consistent shift in the control philosophy of the system—from centralized control in a hierarchical system with tendentially monopolistic structures to bottom-up control in a complex network that needs carefully designed markets to set the right incentives. The intrinsically monopolistic infrastructure of the physical public grid must be kept open, functioning, and optimally utilized by a wide variety of private actors.

All these trends, including the transitions from

- fossil fuels to electricity,
- centralized to distributed power generation,
- dispatchable to independently fluctuating power sources,
- careless energy consumption to price-sensitive flexibility,
- public supply to autonomous prosumers,
- monopolies to complex networks of millions of actors,
- central planning to complex market interactions,
- top-down to bottom-up control,

constitute a profound paradigm shift that necessitates intensive learning and adaptation on all levels.

¹⁷²⁵ - The market for energy management systems is booming. Inter Solar, “Energy Management Systems: Centerpieces of Integrated Components”, 7 February 2025, see <https://www.intersolar.de/market-trends/energy-management-systems>, accessed 25 June 2025. Even without storage, the impact of home energy management systems (HEMS) is impressive; see Philipp Mascherbauer, Lukas Kranzl et al., “Investigating the Impact of Smart Energy Management System on the Residential Electricity Consumption in Austria”, *Energy*, Vol. 249, 15 June 2022, see <https://linkinghub.elsevier.com/retrieve/pii/S0360544222005680>, accessed 25 June 2025.

¹⁷²⁶ - Giuliano Rancilio, A. Rossi et al., “Ancillary Services Markets in Europe: Evolution and Regulatory Trade-Offs”, Politecnico di Milano, and Autorità di Regolazione per Energia, Reti e Ambiente, in *Renewable and Sustainable Energy Reviews*, Vol. 154, February 2022, see <https://www.sciencedirect.com/science/article/pii/S1364032121011175>; and Blockchain4Prosumers, “Pilot Eupen: Local Energy Market (RE Electricity and Heating)”, European Regional Development Fund, 25 June 2025, see <https://www.blockchain4prosumers.eu/pilot-cases/pilot-eupen-local-energy-market-re-electricity-and-heating/>; also CTRM, “VPP Market Study”, CTRM, 2024, see <https://www.ettcenter.net/publications/reports/vpp-market-study/>; and Kreutzer Consulting, “Energiedienstleistungen für Prosumer-Haushalte: Die nächste Stufe hat begonnen”, 19 July 2023, see <http://www.kreutzer-consulting.de/energy-services/energy-news/energy-blog/energy-blog-beitrag/energiedienstleistungen-fuer-prosumer-haushalte-die-naechste-stufe-hat-begonnen.html>; all accessed 25 June 2025.

Consequences of Long-Term Trends: Key Characteristics of the Coming Energy System

In many countries, the trends described here are not yet dominant. However, by 2035, when a hypothetical new nuclear power plant currently under consideration could potentially become operational, and halfway to the political goal in most countries to fully decarbonize by 2050, these trends will have profoundly transformed our energy systems.¹⁷²⁷

The emerging energy system can be characterized as follows:

- ➔ PV and wind will dominate power production.
- ➔ Electricity will play a central role in the energy system as the main energy source (generated with sunlight and wind) and as a universally convertible energy carrier.
- ➔ Flexibility will be a highly appreciated characteristic of all assets in the energy system.
- ➔ Market mechanisms, mediated by digital controls and power electronics, will play a key role in coordinating millions of actors.
- ➔ A consistent part of the energy used will be generated behind the meter and not pass through the public grid.
- ➔ Residential and service buildings will deliver power to the grid in the summer and withdraw power from it in the winter, while being able to react to market prices in the short term.
- ➔ Consumption flexibility, battery storage, and heat storage may be complemented with combustion of green hydrogen. E-fuel use for aviation will be difficult to avoid in the short term.
- ➔ Carbon-neutral hydrogen production with excess power will be essential for non-energy uses in a decarbonized chemical industry.
- ➔ Low-income countries with high solar radiation and low seasonal variations will likely leapfrog the development of conventional “dumb” grids with central power stations.¹⁷²⁸

INTEGRATING NUCLEAR POWER INTO THE ENERGY SYSTEM: INCREASING DIFFICULTIES

In the above analysis of the energy system’s ongoing transformation, it has already become clear where and how nuclear power has a different logic and faces growing difficulties in integrating into the increasingly dominant system. Nevertheless, supporters claim that there are new opportunities for nuclear energy. The following pages will take a closer look at these arguments while summarizing the challenges. As a starting point for analyzing possible future roles of nuclear energy, it is useful to briefly look at the role for which it was originally conceived.

¹⁷²⁷ - Omri Wallach, “Race to Net Zero: Carbon Neutral Goals by Country”, *Decarbonization Channel*, 6 November 2022, see <https://decarbonization.visualcapitalist.com/race-to-net-zero-carbon-neutral-goals-by-country/>, accessed 26 June 2025.

¹⁷²⁸ - See the example of Pakistan. Global Energy Alliance for People and Planet, “Leapfrogging in Asia Can Drive Clean Energy Transitions”, 6 September 2024, see <https://energyalliance.org/leapfrogging-in-asia/>, accessed 26 June 2025; and IRENA, “Innovation Outlook: Renewable: Mini-Grids”, International Renewable Energy Agency, 2016.

Nuclear Power in Conventional Energy Systems

The commercial or civil use of nuclear power was born as a more likable version of a radically new technology developed for military purposes.¹⁷²⁹

In the 1960s and 1970s, the heyday of atomic energy, nuclear power plants were meant to simply complement or substitute large thermal power plants. In 1980, at the apex of reactor constructions, the global electricity generation mix was dominated by coal (38 percent), oil (20 percent), natural gas (12 percent), hydropower (21 percent), and nuclear energy (9 percent), with non-hydro renewables accounting for less than 1 percent.¹⁷³⁰

In the year 2000, nearly two decades after the early wave of nuclear power plant construction, only the following countries generated more than 50 percent of their electricity with nuclear: France (76 percent), Lithuania (74 percent), Belgium (57 percent), and Slovakia (53 percent).¹⁷³¹ All of these were integrated into larger interconnected regional networks, which allowed them to comfortably run their nuclear plants at maximum capacity, as fossil fuel plants with lower fixed costs would buffer demand fluctuations. Fossil fuel plants would also compensate for planned and unplanned outages of nuclear reactors. Among the other countries on the list with a high reliance on nuclear energy, only South Korea (41 percent of electricity provided by 16 commercial reactors) was operating an insular grid with no international connections.

Worldwide, utilities were monopolies with little cost transparency. State authorities promoted nuclear energy by offering incentives. It has been demonstrated that not a single nuclear power plant has been built as a fully commercial project.¹⁷³² As of mid-2025, 60 units (or 95 percent) of the 63 reactors under construction in the world are being either built in nuclear weapon states or implemented by nuclear weapon state-controlled companies in other countries.¹⁷³³ An important motivation for bearing the costs was to share efforts with military developments or to build up nuclear expertise that might be useful for military purposes (see *Interdependencies Between Civil and Military Nuclear Infrastructures* in WNISR2018 and *Civil-Military Cross-Financing in the U.K. Nuclear Sector* in WNISR2024).

Civil nuclear power was developed in the old paradigm of energy systems, and it has not substantially developed further since. Can it, nevertheless, provide answers to new energy problems?

Help in Solving the Climate Emergency?

A central argument in favor of the admittedly costly nuclear power is the ever-increasing urgency for decarbonization. As discussed in the opening section on the evolution of the overall context of nuclear power development, the speed at which fossil fuels need to be substituted

¹⁷²⁹ - E.g., see Gabrielle Hecht, “The Radiance of France: Nuclear Power and National Identity After World War II”, MIT Press, 2009.

¹⁷³⁰ - AGEB, “Energieverbrauch in Deutschland im Jahr 2023”, AGEB, Arbeitsgemeinschaft Energiebilanzen, 2024, see https://ageb-energiebilanzen.de/wp-content/uploads/2024/04/AGEB_Jahresbericht2023_20240403_dt.pdf accessed 23 June 2025.

¹⁷³¹ - IAEA, “IAEA Releases Nuclear Power Statistics for 2000”, Press Release 2001/07, 3 May 2001, see <https://www.iaea.org/newscenter/pressreleases/iaea-releases-nuclear-power-statistics-2000>, accessed 29 May 2025.

¹⁷³² - Ben Wealer, Simon Bauer et al., “Nuclear Power Reactors Worldwide – Technology Developments, Diffusion Patterns, and Country-by-Country Analysis of Implementation (1951–2017)”, DIW, TUB, 2018, op. cit.

¹⁷³³ - Only the 3 reactors under construction in South Korea do not fall under the definition, with Mochovce-4 in Slovakia started by Russian companies but completed by a Czech-led consortium.

is far beyond nuclear power's achievable growth rate (see also *Climate Change and Nuclear Power* in WNISR2019). Growth rates are not only limited by the costs involved, but more so by the lead times necessary for building a single plant and for building up the necessary industrial capacities, workforce skills, as well as oversight and enforcement capacities that can ensure a level of quality, safety, and security throughout the entire fuel chain that is not required in other industries. Most scenarios aiming for decarbonization foresee a declining share of nuclear in the overall energy supply.¹⁷³⁴

Nuclear power's much longer lead times and far higher costs per MWh, compared to modern renewables, mean new nuclear plants will save less emissions per dollar as well as per year (see *Climate Change and Nuclear Power* in WNISR2019).

The argument that nuclear power would have a positive economic impact because of its need for a highly skilled workforce is not as straightforward as it seems. The nuclear industry requires highly specialized nuclear experts who need long training periods; highly skilled manual workers who can reliably execute tasks at changing, large, and remote construction sites and follow stringent safety standards in specialized industries; as well as specialists who can build unusually large constructions onsite. Such a workforce is much more difficult to build up and to coordinate than the equally skilled workforce needed for conceiving, building, and operating solar panel, battery, or electronics factories.¹⁷³⁵

Bearable Nuclear Costs with Serial Production and New Designs?

The WNISR has extensively discussed the rising costs of nuclear power over the years. Earlier in this chapter, they have been explained from the perspective of fundamental scientific principles. There is no reason to think that the cost situation could substantially improve. New concepts cannot eliminate the basic cost drivers: safety and security issues linked to the elementary nuclear forces involved and the inherent drive for size in thermal power plants, whatever primary energy they operate on.

With some success, advocates of nuclear energy have spread the impression that decarbonization is expensive anyway and that alternatives to nuclear are no better. However, the widespread perception that the energy transition is an economic burden and that renewable energies are expensive has proven to be wrong. A series of simulations has consistently shown that 100-percent renewable energy systems are not more expensive than the conventional fossil-fuel-based approach.¹⁷³⁶ More importantly, 100-percent renewables-based systems are less costly than those that include nuclear power. New technological and manufacturing advances presented in this chapter even indicate a larger cost difference.

¹⁷³⁴ - IEA, "World Energy Outlook 2024", International Energy Agency, October 2024, p. 311; and IPCC, "Climate Change 2022—Mitigation of Climate Change—Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change" Intergovernmental Panel on Climate Change, 2022, p. 353.

¹⁷³⁵ - Jack Thomas, "The Shortfall in Nuclear Engineers: Why We Need More Talent Now", *Innovation News Network*, 7 June 2024, see <https://www.innovationnewsnetwork.com/the-shortfall-in-nuclear-engineers-why-we-need-more-talent-now/51419/>, accessed 25 June 2025.

¹⁷³⁶ - See Christian Breyer, Siavash Khalili et al., "On the History and Future of 100% Renewable Energy Systems Research", *IEEE Access*, July 2022, see <https://ieeexplore.ieee.org/document/9837910/>, accessed 9 June 2023; as well as a number of older and newer country-specific studies of Breyer et al.

Moreover, nuclear power plants with investment costs of some US\$15–20 billion and a ten-year construction time represent a considerable cluster risk even for larger economies. In an increasingly dynamic environment, the importance of this risk is growing. Competing technologies today evolve rapidly; their unit size is much smaller, and their lead time is much shorter. Shorter product cycles mean faster innovation: Wind turbines built twenty or thirty years ago are often being “repowered”—substituted with much more efficient technologies—which frequently doubles or triples their output. In contrast, “uprating” nuclear power plants on the occasion of a lifetime extension can only increase yields by little more than 20 percent at the most. Repowering to double their output becomes attractive for solar power plants as well.¹⁷³⁷ Most private companies remain reluctant to take the additional risk of nuclear power plant investments. Increasingly, as upfront subsidies and state responsibility for accident risks and long-term waste management were not sufficient to convince reluctant private operators, guaranteed offtake prices were introduced to also cover commercial risks at least during much of the lifetime of the plants.¹⁷³⁸

A real problem for fast decarbonization with renewables is the cost structure involving high upfront investments. However, nuclear has no advantage in this regard either. The upfront capital costs of nuclear power plants far exceed those of renewable energies, leaving wide margins for storage and other flexibility investments. The capacity-factor-corrected CAPEX for nuclear power plants is about 3.5 times higher than for large PV plants.¹⁷³⁹ And even marginal costs from old reactors are higher than the LCOE of solar.

The cost problem that led to a sharp decline in nuclear power deployment more than forty years ago has not disappeared; it has worsened.

Nuclear as Reliable Source for “Firm Power”?

Advocates of nuclear power often propose this energy source as an ideal complement for renewable energy that would be able to reduce the need for flexibility.¹⁷⁴⁰ They promote nuclear power as an essential component to provide “firm power”, often keeping this concept rather

¹⁷³⁷ - Wind: Statkraft, “Repowering Wind Farms: Generating More Power from Existing Sites”, Press Release, 17 September 2024, see https://www.statkraft.com/newsroom/explained/Repowering-for-wind-farms_17-more-power-from-existing-turbines/, accessed 26 June 2025.

Nuclear: IAEA, “Power Uprate in Nuclear Power Plants: Guidelines and Experience—Prepared Within the Framework of the Technical Working Group on Life Management of Nuclear Power Plants”, 2011.

Solar: Justin Gerdes, “Is It Time to Repower the First Wave of Large Solar Projects?”, *Quitting Carbon*, 8 May 2025, see <https://www.quittingcarbonmedia.com/is-it-time-to-repower-the-first-wave-of-large-solar-projects/>; and SolarPower Europe, “Operation & Maintenance Best Practice Guidelines—07-Revamping and Repowering”, December 2021, see <https://solarbestpractices.com/guidelines/detail/revamping-and-repowering>, both accessed 26 June 2025.

¹⁷³⁸ - For example, for Hinkley Point C, the guaranteed offtake price under the Contract for Difference will amount to at least US\$0.15/kWh. IWR Online, “New Hinkley Point C Nuclear Power Plant - Electricity Costs Over 15 Cents per Kilowatt Hour at Launch”, as published by Renewable Energy Industry, 27 December 2023, see <https://www.renewable-energy-industry.com/news/world/article-6502-new-hinkley-point-c-nuclear-power-plant-electricity-costs-over-15-cents-per-kilowatt-hour-at-launch>, accessed 25 June 2025.

¹⁷³⁹ - Taking the average of the CAPEX ranges for nuclear and for large PV given by Fraunhofer ISE yields a relation of 13.75 nuclear/PV. This must be corrected with the capacity factors for both technologies (average US: 92.3% nuclear, 23.4% PV). See Fraunhofer Institute for Solar Energy Systems, “Levelized Cost of Electricity- Renewable Energy Technologies”, July 2024, op. cit., p. 11; and Statista, “Capacity Factor by Energy Source 2024 US”, 9 May 2025, see <https://www.statista.com/statistics/183680/us-average-capacity-factors-by-selected-energy-source-since-1998/>, accessed 26 June 2025.

¹⁷⁴⁰ - Leslie Abrahams, “We Need Clean Firm Electricity for a Decarbonized Energy System”, Clean Air Task Force, 19 May 2025, see <https://www.catf.us/2023/05/we-need-clean-firm-electricity-decarbonized-energy-system/>; and EPRI, “Powering Decarbonization: Strategies for Net-Zero CO₂ Emissions”, Electric Power Research Institute, February 2021, see <https://www.epri.com/research/products/3002020700>; both accessed 10 June 2025.

diffuse, suggesting that nuclear power can provide electricity around the clock and throughout the whole year.

The concept of firm power has only emerged recently. Often, it is confounded with the concept of baseload. More precisely, it may be defined as follows:

Firm power generation represents the capability for a resource or an ensemble of resources to meet electrical demand 24x365, i.e., embodying both baseload and dispatchable generation capabilities.¹⁷⁴¹

Essentially, it mirrors the old paradigm that generation-plus-storage must be able to meet variable demand by providing a combination of baseload (nuclear, lignite, run-of-river hydro) and dispatchable (coal, gas, reservoir-based hydro) power generation. A slightly different interpretation of firm power is included in the effort to calculate integration costs of renewable energy (as discussed earlier).¹⁷⁴²

Taking into account new decentralized storage technology, which can be deployed on the generation as well as on the demand side, this concept can be widened to describe a hybrid combination of generation and storage—similar to the concept of “virtual power plants”—able to optimize the meeting ground between flexible demand and flexible supply in such a way that energy flows are as continuous as possible for enabling maximum use of grid capacity.

Proposing nuclear power as a component in a firm power energy mix with strongly fluctuating renewable power, however, neglects its weak points. For technical and economic reasons, nuclear plants do not provide the type of flexible, dispatchable power that can fill the gaps between solar power peaks. They need flexibility from other sources for bridging considerable planned and unplanned outages and for buffering between changing demand and their inflexible full-load operation. The cost of their baseload electricity is more expensive than the ultra-flexible combination of renewables-plus-storage-plus-flexible demand.

The latest driver for nuclear power plants is the assumed rapidly increasing demand for energy supply in vast quantities for large AI data centers (“firm power for AI”).¹⁷⁴³ It may be interesting for data-center operators to secure the large output of existing nuclear power plants for the large consumption of their facilities that changes within seconds, minutes, and hours, but not over weeks or months. However, they require guaranteed complementary grid power during the reactor downtime (around one month per year or more, plus any unplanned outages) and storage for managing the rapidly changing power demand in daily operations. Where utilities are eager to attract a new large customer, they may be willing to sign corresponding

¹⁷⁴¹ - Photovoltaic Power Systems Programme, “Firm Power Generation 2023”, International Energy Agency, January 2023, see <https://iea-pvps.org/key-topics/firm-power-generation/>, accessed 10 June 2025.

¹⁷⁴² - It would be interesting to estimate the integration costs of nuclear in the same way as Lazard has done it for renewables; see p. 30 in Lazard, “LCOE+—Levelized Cost of Energy+”, 2025, op. cit. The VALCOE numbers for nuclear calculated by the IEA in 2022 for whole continents would surely be higher for markets with high shares of renewables; see p.57 in IEA, “Nuclear Power and Secure Energy Transitions - From Today’s Challenges to Tomorrow’s Clean Energy Systems—Executive Summary”, June 2022, see <https://www.iea.org/reports/nuclear-power-and-secure-energy-transitions/executive-summary>, accessed 1 July 2022.

¹⁷⁴³ - IEA, “Energy and AI – Analysis”, April 2025, see <https://www.iea.org/reports/energy-and-ai>, accessed 10 April 2025; and Michael Liebreich, “Liebreich: Generative AI – The Power and the Glory”, BloombergNEF, 24 December 2024, see <https://about.bnef.com/blog/liebreich-generative-ai-the-power-and-the-glory/>, accessed 15 April 2025; also Amory B Lovins, “Artificial Intelligence Meets Natural Stupidity: Managing the Risks”, Stanford Energy, 30 June 2025, see https://integrative-design-for-radical-energy-efficiency.stanford.edu/sites/extreme_energy_efficiency/files/media/file/data-centersaiel-corrd-dr-17_30june2025_o.pdf, accessed 28 July 2025.

contracts.¹⁷⁴⁴ These agreements, often incentivized by production tax credits in the U.S., de facto divert low-emission power from other customers and indirectly subsidize electricity supply to Big Tech companies (see [United States Focus](#)).

Building new nuclear plants for AI data centers, however, appears incoherent. Time horizons do not match: while data centers need power quickly, nuclear power plants need many years to build; competing solar power plants can be set up within months.

In several years, needs and priorities may completely shift: On the one hand, power needs may dwindle—conventional data centers have become much more efficient over short periods, so may specialized AI data centers, due to both software and hardware innovations. On the other hand, location preferences may change—data can be transmitted easily, and new centers may emerge where energy is cheapest.

The idea of building power plants especially for large industrial complexes with a high need for a rather continuous supply of power is failing for the same reasons. Nuclear plants need flexibility from the grid and powerful grid connections to compensate for their inflexibility and outages. There is no “firm power” advantage compared to the alternative set of technologies; cost, safety, security, and time horizon disadvantages remain. In other words, since nuclear electricity is uncompetitive, changing its use does not make it competitive, because cheaper carbon-free sources (or savings) can still beat its price.

In larger markets, other flexibility sources may compensate for the rigidity of a smaller share of nuclear power, but this comes at a cost. In smaller electricity markets though, such as in many low-income countries, substantial shares of nuclear power from a few plants can become a serious problem in the long term because they block other developments, but even in the short term in the case of unplanned outages of what would be a substantial share of capacity in the grid.

Remaining Drivers for Nuclear Energy Expansion

Against the background of all the facts and considerations in this chapter, one may wonder why nuclear power still has influential advocates. The initial enthusiasm for nuclear power and the surge of new nuclear projects ebbed more than forty years ago. Since then, with the exception of few countries, the traditional community of nuclear professionals has considerably shrunk. A handful of large incumbent international nuclear builders—only about a handful in the world have built abroad in recent years—have restarted hiring, hoping for a “nuclear revival”. Moreover, there is a new wave of heavily subsidized startups, especially around the development of SMRs, that attract increasing amounts of private capital. However, overall private investments in nuclear, both into innovation and into deployment, are marginal compared to those flowing into competitors of nuclear energy.¹⁷⁴⁵

¹⁷⁴⁴ - Stephen Lacey, Jigar Shah, and Katherine Hamilton, “Who’s Really Paying AI’s Power Bill?”, Podcast, with Ari Peskoe, Director, Electricity Law Initiative, Harvard Law School, *Open Circuit*, 25 April 2025, see <https://podcasts.apple.com/de/podcast/whos-really-paying-ais-power-bill/id1794164180?i=1000704882389>, accessed 10 June 2025.

¹⁷⁴⁵ - In 2024, investments into renewable energy were 21 times higher than those into nuclear energy. See [Nuclear Power vs. Renewable Energy Deployment](#).

Under the pressure of the urgency of decarbonization, hard choices have to be made. New renewable and associated technologies have the potential to address the decarbonization issue. However, they also present major challenges to the established energy system paradigm, which has persisted for decades despite the decline of nuclear power. Western industries were reluctant to embrace these new technology developments, which are now dominated by Chinese industries. Those who are still attached to the old paradigm, whether due to vested interests, ideological reasons, or deep identification with past activities and declining structures, prefer to strive to renew the past glory of nuclear power than to embrace this strange new mix of technologies, which involves all levels of stakeholders including citizens who were never interested in electricity issues. Changing paradigms is a tedious and slow process. “Science advances one funeral at a time,” wrote Max Planck, who was at the center of the paradigm shift in physics a century ago.¹⁷⁴⁶ But the time left for complete decarbonization of the energy system is short—not even a generation.

One of the reasons for the ongoing and even growing interest in nuclear energy points back to its origins. “Without civil nuclear, no military nuclear; without military nuclear, no civil nuclear,” said French President Macron in his historic speech on nuclear power in 2020.¹⁷⁴⁷ Military considerations can override economic ones, and mostly, they are not explicitly stated as Macron did. When analyzing national nuclear power programs, the interdependencies with military interests are often obvious—the WNISR has shown this repeatedly. Maintaining a workforce with nuclear expertise, developing small reactors for submarines and aircraft carriers or simply showing the ability to carry out nuclear projects are essential to incumbent military nuclear establishments (see *Civil-Military Cross-Financing in the U.K. Nuclear Sector* in WNISR2024).

There are other powerful drivers like geopolitical interests and strategies. A nuclear power plant project has a fabulous lock-in effect that binds two or more countries together over decades. The discussion of these issues would far exceed the scope of this chapter.

¹⁷⁴⁶ - Pierre Azoulay, Christian Fons-Rosen and Joshua S. Graff Zivin, “Does Science Advance One Funeral at a Time?”, *American Economic Review*, Vol. 109, No. 8, August 2019, see <https://pubs.aeaweb.org/doi/10.1257/aer.20161574>, accessed 25 June 2025.

¹⁷⁴⁷ - Presidency of France, “Notre avenir énergétique et écologique passe par le nucléaire. Déplacement du Président Emmanuel Macron sur le site industriel de Framatome.”, L’Elysée, 8 December 2020, see <https://www.elysee.fr/emmanuel-macron/2020/12/08/deplacement-du-president-emmanuel-macron-sur-le-site-industriel-de-framatome>, accessed 9 December 2020.

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

INTRODUCTION: GLOBAL TRENDS

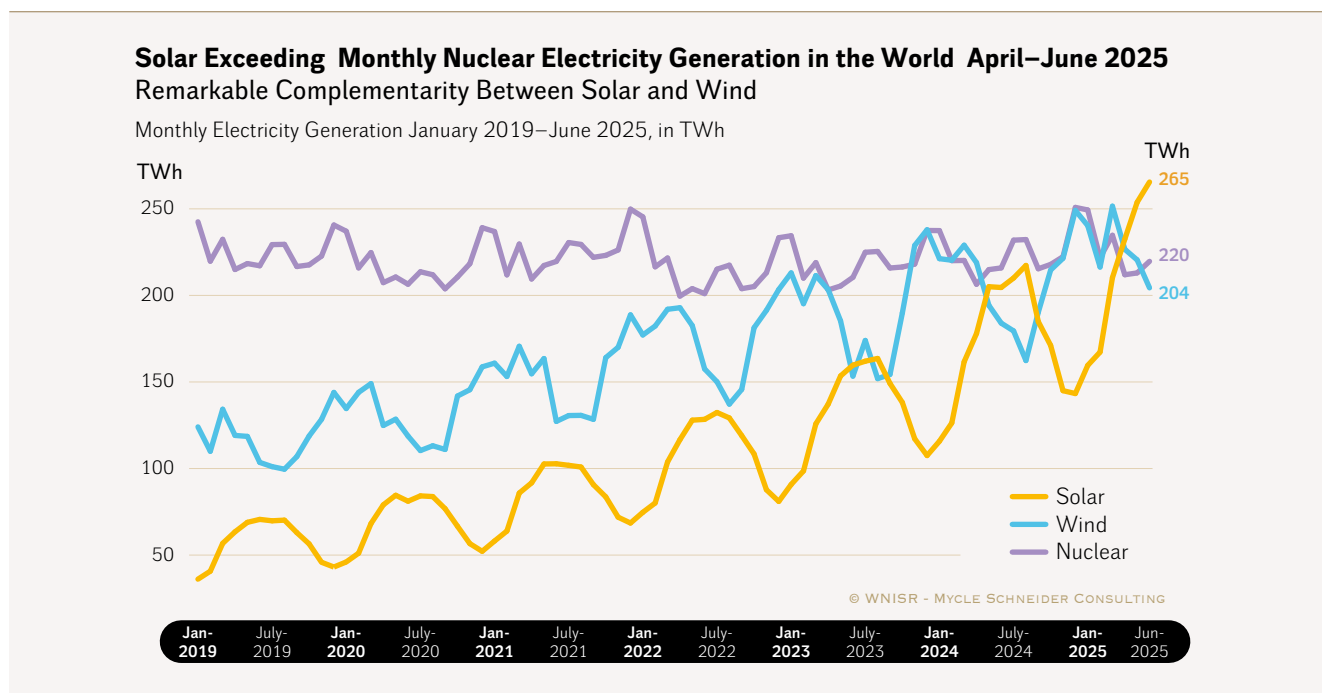
A mix of contradictory trends has marked the year 2024. On the one hand, in most regions, inflation, rising interest rates, growing political uncertainties, regulatory stagnation, and declining investor confidence provided a more difficult environment for the energy transition than the year before. On the other hand, declining prices and advancements in key technologies have been encouraging and have opened new perspectives. In the first months of 2025, these trends became even more pronounced. The energy transition is entering a new phase, and this is reflected in the structure of this part of the report.

The complexity of the energy system's transformation, driven by the need for decarbonization and new technological opportunities, poses a challenge to traditional comparisons. As the share of renewable electric power generation in the system increases, nuclear power can no longer be simply compared with wind and solar power, which have quite distinct characteristics and behave differently within the system. Looking at the overall energy system—including the electrification of the heat and transport sectors, as well as the evolving needs and self-generation capabilities of electricity consumers—considerable changes to the potential systemic roles of renewable energies and nuclear power need to be examined. Therefore, this year, the WNISR includes a special focus chapter on the systemic aspects of the power sector (see [Challenges of Integrating Nuclear Power into the Energy System](#)). And the present chapter, in the tradition of past editions, examines the dimensions of deploying new energy technologies and includes new considerations, foremost among them the impact of more-affordable batteries. In this way, the aspects discussed in the short chapter on Power Firming and Competitive Pressure on Nuclear in [WNISR2024](#) are integrated into larger contexts.

Batteries are becoming increasingly important. In an increasing number of electricity markets, the growing share of wind and solar-photovoltaic power, whose output depends on fluctuating natural phenomena, requires much more flexibility in the system—flexible consumption, storage, or complementary flexible generation. The cost of this flexibility may be challenging to calculate since it may be associated with changes in consumer habits, industrial procedures, or more sophisticated management of upgraded grids, and it may take time to implement such flexibility. More straightforward to calculate is the cost of electricity storage in batteries, and this has declined considerably in the course of 2024 alone (see [Challenges of Integrating Nuclear Power into the Energy System](#)). Think tank EMBER titled a report released in June 2025: “Solar

electricity every hour of every day is here and it changes everything” and further stated “the LCOE of near 24/365 solar generation are falling fast – 22% in the last year alone.”¹⁷⁴⁸

Figure 60 · Solar Power Overtakes Nuclear Power



Source: EMBER, Monthly Electricity Data, July 2025

The full consequences of this will take some time to develop and to be understood. Key quantitative data in 2024 underline the growing importance of photovoltaics (PV):

- ➔ Compared to 2023, PV capacity additions in 2024 have grown by 33 percent (increasing the cumulative global capacity by 36 percent), according to SolarPower Europe. That is impressive, but still a smaller market growth rate than the “exceptional 85 percent surge” in 2023. Not only has a more difficult overall economic environment and a shifting political focus from climate concerns to security issues contributed to this outcome, but also declining electricity prices following the energy crisis in 2022/23.¹⁷⁴⁹ Solar electricity generation has increased by about 28 percent.¹⁷⁵⁰ In April 2025, global solar electricity generation exceeded nuclear power generation for the first time and kept doing so in May and June 2025 (see Figure 60).
- ➔ Wind energy deployment has been hindered by the general economic and political environment more than PV deployment, as technological and cost developments were less favorable. While investments declined more significantly, so did costs, so capacity

¹⁷⁴⁸ - Kostantsa Rangelova and Dave Jones, “Solar Electricity Every Hour of Every Day Is Here and It Changes Everything”, EMBER, 21 June 2025, see <https://ember-energy.org/app/uploads/2025/06/Ember-24-Hour-Solar-Electricity-June-2025-6.pdf>, accessed 3 July 2025.

¹⁷⁴⁹ - SolarPower Europe, “Global Market Outlook for Solar Power 2025-2029”, 6 May 2025, see <https://www.solarpowereurope.org/insights/outlooks/global-market-outlook-for-solar-power-2025-2029/detail>, accessed 9 May 2025.

¹⁷⁵⁰ - Energy Institute, “Statistical Review of World Energy 2025”, 2025, op. cit.

additions were only one percent lower than in the previous year. Wind power electricity generation in 2024 still increased by close to 8 percent.¹⁷⁵¹

- ➔ Battery Energy Storage Systems (BESS) are characterized by two metrics: power capacity (kW or GW) and energy capacity (kWh or GWh). Globally, grid-scale BESS power grew by 113 percent in 2024 (reaching 126 GW). The average annual growth rate during 2014–2024 was 75 percent.¹⁷⁵² BESS energy capacity (expressed in GWh) has grown even more, as more and more batteries with longer storage time are installed.¹⁷⁵³
- ➔ Between nuclear reactor startups and closures in 2024, nuclear added 5.3 GW net. Taking into account the balance of reactors entering and leaving LTO (see Figure 67) operating capacity increased by 2 percent (+6.9 GW) and electricity output by 2.9 percent.¹⁷⁵⁴

Including hydro, gross electricity generation of all renewables grew by 862 TWh or 9.6 percent in 2024—not enough to keep pace with the rising global electricity demand (up by 1,293 TWh), driven by higher temperatures, industrial expansion, electrification, and unambitious demand-side management and efficiency policies.¹⁷⁵⁵

In national and international politics, climate and energy policies are losing priority. Several countries are scaling back policies supporting the energy transition. This trend has increased globally since the Trump administration took office in the U.S. in early 2025. At the same time, renewable energies are becoming increasingly competitive, and their deployment dynamics are showing remarkable resilience considering the headwinds. The 2002–2024 constancy of exponential growth in global renewable generation suggested that market forces tend to beat political fluctuations, and early signs in 2025 suggest this may continue to be true.

This leads to the question of whether we have reached a point where the energy transition driven by economic considerations alone, without significant policy support, could halt global warming. In April 2025, Bloomberg New Energy Finance (BloombergNEF or BNEF) published a new, updated base-case scenario, which explores “how far and how fast the low-carbon transition can proceed based purely on competitive economics and existing short-term policy settings.” BloombergNEF concludes that under these assumptions, global warming would amount to 2.6°C in 2100, and that “deploying only economically competitive climate solutions

¹⁷⁵¹ - Ibidem.

¹⁷⁵² - Ibidem, p. 54.

For short-term balancing, power (GW) is more important. For bridging hours and days, capacity (GWh) is the key metric. Unfortunately, many statistics give only the power rating. Linked to these concepts are the often-used terms 2-hour-battery, 4-hour-battery etc., which indicate the relation of power and capacity. More and more, batteries with a higher capacity/power ratio are being installed as longer storage duration gets interesting.

¹⁷⁵³ - Volta Foundation, “Battery Report 2024”, January 2025, see https://report.volta.foundation/annual-battery-report/public/Battery_Report_2024.pdf, accessed 1 March 2025.

Volta Foundation numbers are higher than Energy Institute numbers as they also include small-scale installations. See also Paul Denholm, Wesley Cole and Nate Blair, “Moving Beyond 4-Hour Li-Ion Batteries: Challenges and Opportunities for Long(er)-Duration Energy Storage”, National Renewable Energy Laboratory, 2023, see <https://www.osti.gov/servlets/purl/2000002/>, accessed 31 July 2025.

¹⁷⁵⁴ - Energy Institute, “Statistical Review of World Energy 2025—Consolidated Dataset”, op. cit.

¹⁷⁵⁵ - Energy Institute, “Statistical Review of World Energy 2025—Consolidated Dataset”, 2025, op. cit.; and REN21, “Renewables Global Status Report 2025—Global Overview”, June 2025, see https://www.ren21.net/wp-content/uploads/2019/05/25-1395_GO_2025_Full_Report_120pt.pdf, accessed 24 June 2025, also IEA, “Growth in Global Energy Demand Surged in 2024 to Almost Twice its Recent Average”, International Energy Agency, 24 March 2025, see <https://www.iea.org/news/growth-in-global-energy-demand-surged-in-2024-to-almost-twice-its-recent-average>, accessed 30 March 2025.

will not be enough to avert climate disaster.”¹⁷⁵⁶ Nuclear power generation, in this scenario, would increase around 20 percent between 2023 and 2035—certainly unrealistic considering nuclear’s long lead-times—while PV growth would amount to 450 percent.

Other voices are more optimistic concerning the economic push for renewables.¹⁷⁵⁷ And this chapter will unveil some signs of a more fundamental shift.

China’s control of around four-fifths of every step in the global supply chain for batteries and photovoltaic modules has been met with increasing concern, primarily in the U.S. and Europe. However, the effects of the Biden administration’s efforts to establish a strong renewable energy industry in the U.S., which began to become visible in the investment statistics in 2023, have slightly receded in 2024. The Trump administration has rolled back many of the incentives for renewables and strongly expanded those for nuclear power and fossil fuels. The difficulties of substituting fossil and nuclear fuel imports from Russia, following the invasion of Ukraine, have continued to draw attention to the significance of energy independence and energy supply security on a global scale, but on these important issues too the advantage goes to renewable supplies and efficient use. Even if one buys solar modules from China, once they are bought, they require no further material inputs to keep working for decades.

INVESTMENT

Statistics describing the development of electricity generation include three consecutive types of indicators, each representing a distinct step on the path to the goal. Each of these indicators—investment sums (US\$ per year), generation capacities (GW added per year), and electricity generated (TWh per year)—comes with its own interpretation difficulties. Investments are an early indicator of the system’s evolution. They translate into building generation capacities. Investing in the right technology is crucial—relative costs, technological and political risks, construction times, and cost development trends can make a big difference in the selection. Investment decisions can determine infrastructure structures for many decades, depending on the technology. Generation capacities, then, reflect past investment decisions and determine future electricity generation. Gigawatt indications per technology are not directly comparable as are dollars and euros, since full-load hours differ between technologies, technology generations, and locations. Terawatt-hours measuring the electricity generated, finally, are easier to compare, but, as we will see later, their value depends on the regularity or rhythm with which they are produced.

For two decades, investments in renewable power generation globally have exceeded those in nuclear energy—which hardly changed over the past decade—and are now 21 times higher (see Figure 61).

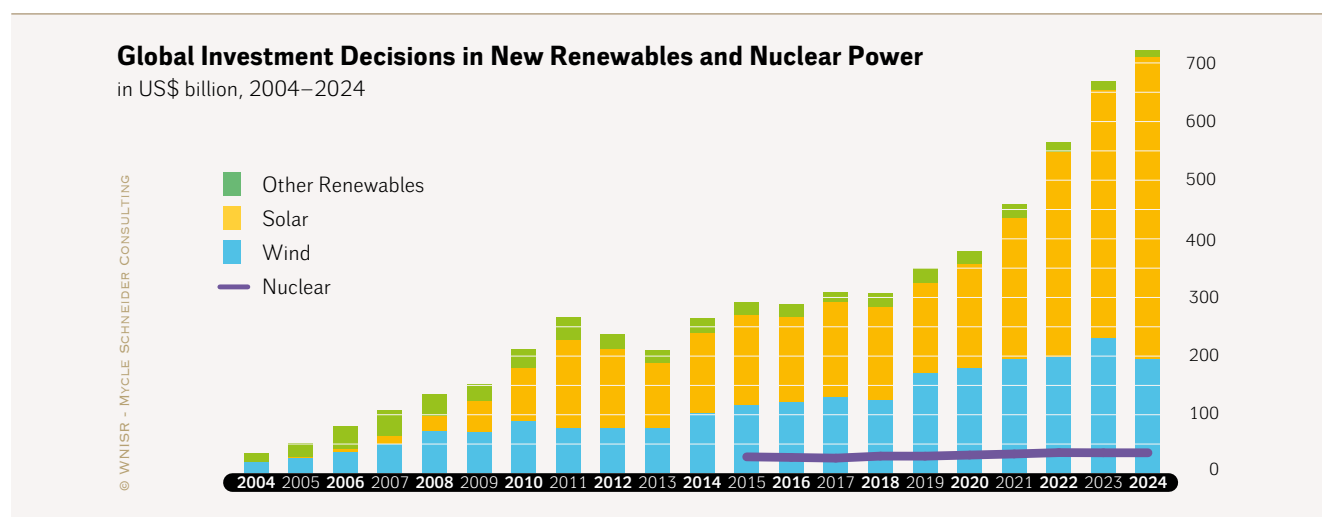
¹⁷⁵⁶ - BloombergNEF, “New Energy Outlook 2025”, April 2025, see <https://about.bnef.com/insights/clean-energy/new-energy-outlook/#download-report-summary>, accessed 3 May 2025.

¹⁷⁵⁷ - Hadi Vatankhah Ghadim, Jannik Haas et al., “Are We Too Pessimistic? Cost Projections for Solar Photovoltaics, Wind Power, and Batteries Are Over-Estimating Actual Costs Globally”, University of Canterbury, LUT University, Institute of Networked Energy Systems, and International Renewable Energy Agency, in *Applied Energy*, 15 July 2025, see <https://www.sciencedirect.com/science/article/pii/S0306261925005860>, accessed 21 July 2025; and Christian Breyer, Siavash Khalili et al., “On the History and Future of 100% Renewable Energy Systems Research”, *IEEE Access*, 25 July 2022, see <https://ieeexplore.ieee.org/document/9837910/>, accessed 9 June 2023.

According to BloombergNEF data, investments in PV saw the strongest growth (22 percent) in 2024 compared to 2023. That is a rather good result, considering the growth rate of about 20 percent one year earlier, the growing inflation, and the shift in public attention from climate concerns to security issues (though those would support the same investments).¹⁷⁵⁸ As a consequence, with some delay, taking into account the ongoing decline in PV system prices¹⁷⁵⁹ (see next section), one can expect the corresponding PV generation capacities to continue to grow strongly.

Investments in wind power, on the other hand, have declined by 16 percent in 2024. The Global Wind Energy Council notes: “It might be fair to say that many people in the wind industry will not look back on 2024 too fondly. It was a year in which the impact of interest rate increases, inflation, supply chain pressures, investor confidence, regulatory inertia and political uncertainty all had a relevant impact across many key markets.”¹⁷⁶⁰

Figure 61 · Global Investment in Renewables and Nuclear Power, 2004–2024



Notes:

As of the 2025 edition, WNISR is using BloombergNEF data as source for nuclear as well as renewables investments and is thus abandoning its own calculations. The BloombergNEF nuclear investment data series is only available from 2015 onwards.

BloombergNEF notes: “Nuclear power investment data covers reactors under construction or major refurbishment. It excludes funding for research and development and capex investment during refueling outages. We also exclude spending to bring back retired reactors to operation, such as in Japan, and at Palisades and Three Mile Island in the US.” Whereas WNISR’s nuclear investment numbers were based on the total estimated investment sum and allocated to the construction-start year, BNEF has opted “to spread the investment cost of each project equally over the construction period”. As shown in WNISR2024, when cumulated over several years, BloombergNEF and WNISR analyses were in the same order of magnitude.

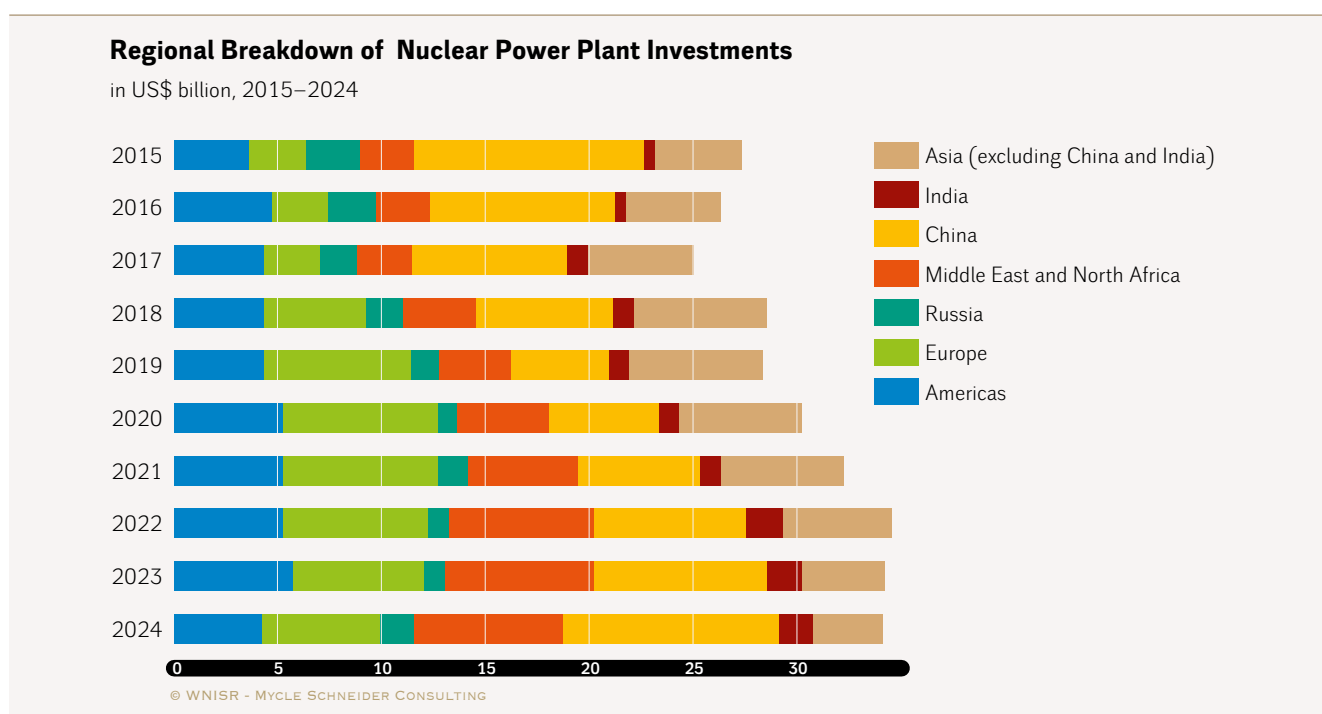
¹⁷⁵⁸ - All data based on BloombergNEF 2025, as REN21 also uses BloombergNEF data. IEA data may differ. See BloombergNEF, “Energy Transition Investment Trends 2025 - Abridged Report”, 30 January 2025, see https://assets.bbhub.io/professional/sites/24/951623_BNEF-Energy-Transition-Trends-2025-Abridged.pdf, accessed 9 July 2025; and REN21, “Renewables Global Status Report 2025—Global Overview”, June 2025, op. cit.

¹⁷⁵⁹ - According to the IRENA analysis, price declines of PV installations in 2024 were: China: 14%, U.S.: 7%, India: 27%, Brazil: 3%, Germany: 21%. Using the (rather average) China value, 122% investments correspond to 122%*114%=139% capacity. See Figure 6; and IRENA, “Renewable Power Generation Costs in 2024”, International Renewable Energy Agency, 2025, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jul/IRENA_TEC_RPGC_in_2024_2025.pdf, accessed 23 July 2025.

¹⁷⁶⁰ - GWEC, “Global Wind Report 2025”, Global Wind Energy Council, 23 April 2025, see [https://26973329.fs1.hubspotusercontent-eu1.net/hubfs/26973329/2.Reports/Global Wind Report/GWEC Global Wind Report 2025.pdf](https://26973329.fs1.hubspotusercontent-eu1.net/hubfs/26973329/2.Reports/Global%20Wind%20Report/GWEC%20Global%20Wind%20Report%202025.pdf), accessed 30 June 2025.

Global investment into nuclear power projects remains small—below US\$35 billion per year (including major refurbishment), in the 5-percent range of renewable energy investment. It has not seen any significant growth rate over the past decade, and only the Middle East and North Africa (MENA) region has seen a rather consistent growth. On the contrary, total nuclear investment has been shrinking slightly over the past two years. A closer regional breakdown of nuclear investments (see [Figure 62](#)) reveals ups and downs in investment patterns. The year 2024 shows a remarkable decline in the Americas (–26 percent) compensated by an expansion in China (+25 percent), and a decline in Europe (–10 percent) compensated by an increase in Russia (+60 percent).

Figure 62 · Regional Breakdown of Nuclear Power Plant Investments, 2015–2024

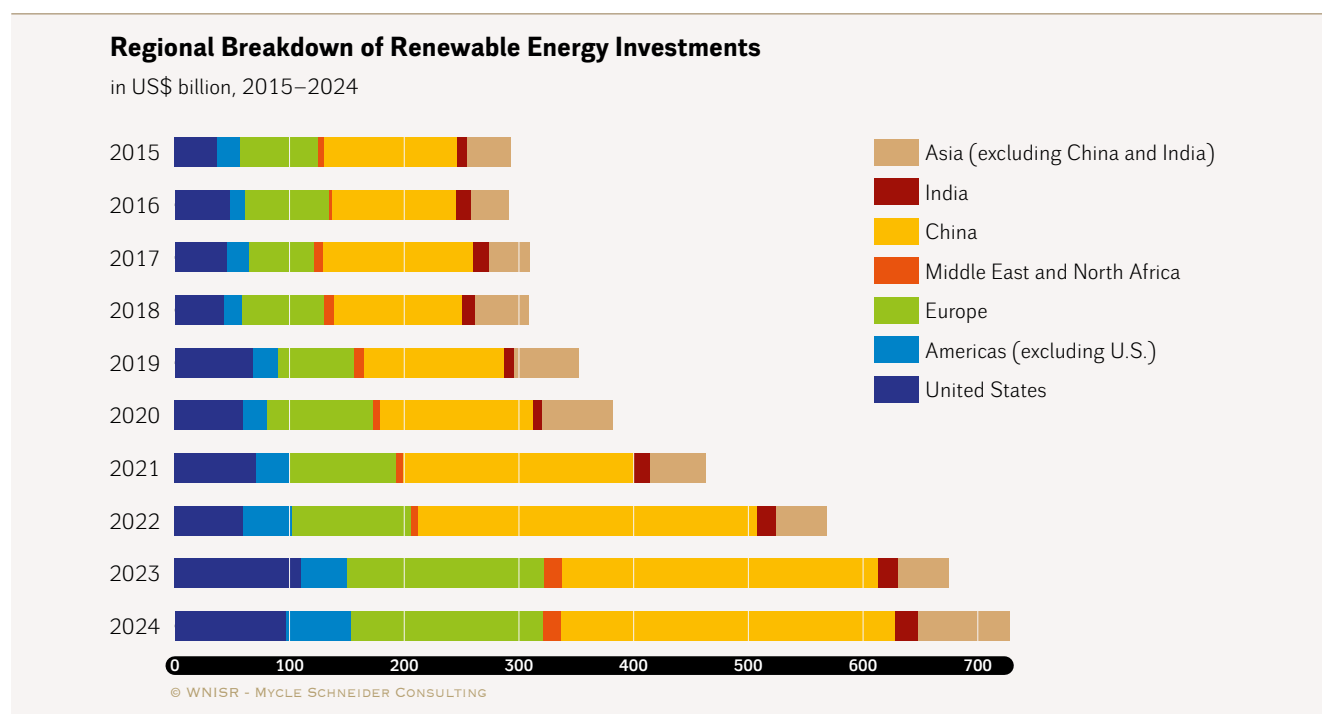


Source: BloombergNEF, 2025

Notes: see under Figure 61.

The 2024 regional breakdown of renewable energy investments reveals interesting changes in dynamics compared to 2023 (see [Figure 63](#) and [Table 18](#)). Despite the Biden administration's efforts, the U.S. has slightly scaled back, while China has increased its efforts but has not yet reached its 2022 numbers, following the setback in 2023.

Figure 63 · Regional Breakdown of Renewable Investments, 2015–2024



Source: BloombergNEF, 2025

Notes: Europe includes the EU27, the U.K., and the rest of EMEA (Europe, Middle East, Africa) as presented in Table 18.

Most remarkable, however, is the 2024-surge in minor markets: Asia-Pacific, excluding China and India, +81 percent; Central and Southern Africa, plus Europe excluding the E.U. and U.K., +85 percent; and the Americas excluding the U.S. and Brazil, +167 percent. Together, in 2024, they have seen an average 95-percent increase, while investments in the rest of the world have declined by 5 percent. Their share in global investments has increased from 13 to 23 percent (see Figure 61).¹⁷⁶¹ Persisting discrepancies between regions will be discussed below in the context of electricity generation statistics.

Table 18 · Regional Breakdown of Renewable Energy Investments (in US\$ billion) and their Growth Rates, 2022–2024

	Asia Pacific			Europe / EMEA				Americas			Total	Minor Markets		Total excluding Minor Markets
	China	India	Other	EU27	U.K.	MENA	Rest EMEA	U.S.	Brazil	Other		US\$ billion	% of total	
2022	296.0	16.1	44.7	79.7	3.2	6.4	20.0	59.3	27.4	15.5	568.4	80.2	14%	488.2
2023	274.7	18.2	44.2	117.4	25.3	16.1	28.7	110.1	26.8	13.2	674.7	86.1	13%	588.6
2024	290.4	20.9	79.9	106.0	8.2	16.0	53.0	96.7	21.5	35.2	727.7	168.1	23%	559.6
'23 vs. '22	-7%	13%	-1%	47%	691%	152%	44%	86%	-2%	-15%	19%	7%		21%
'24 vs. '23	6%	15%	81%	-10%	-68%	-1%	85%	-12%	-20%	167%	8%	95%		-5%

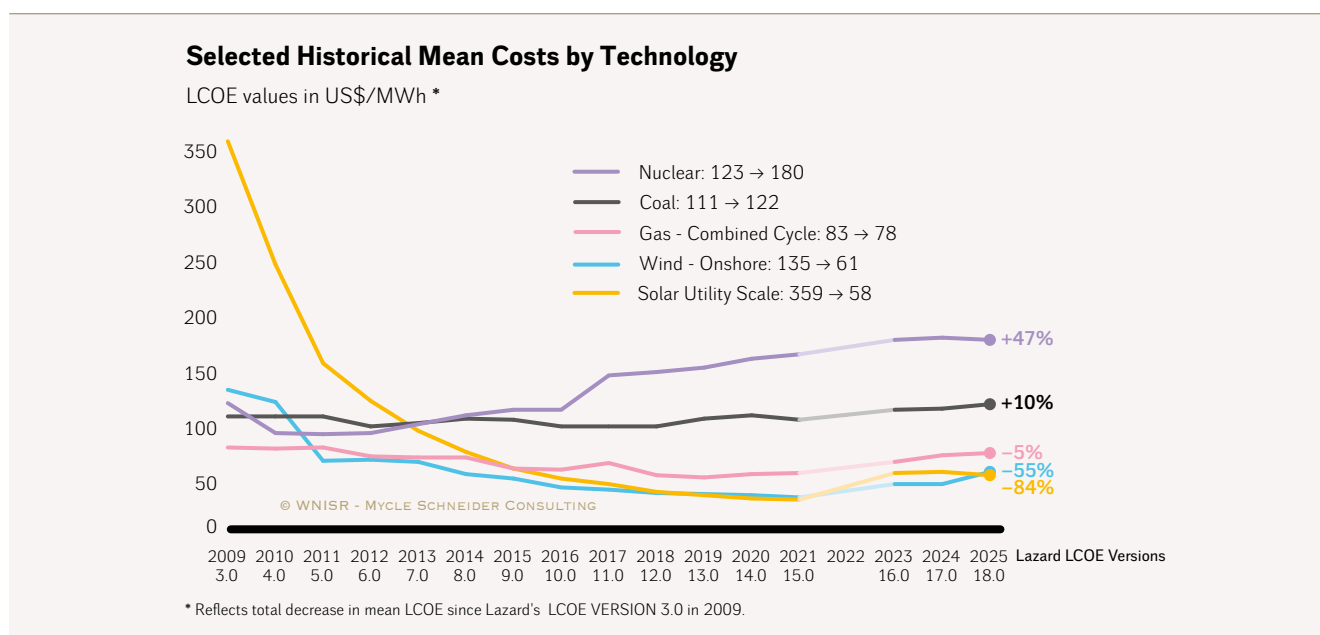
Source: BloombergNEF, 2025

Notes: **EMEA**: Europe, Middle East, Africa; **MENA**: Middle East + North Africa.¹⁷⁶¹ - Calculated on the basis of BloombergNEF 2025 data; see also note to Figure 61.

ELECTRICITY GENERATION COST DEVELOPMENT

Lazard's annual Levelized Cost of Energy (LCOE) analysis provides the most-quoted analysis of electricity costs by different technologies, although it primarily relies on U.S. data. As Figure 64 shows, solar and wind deliver far more competitive electricity than gas and coal, not to speak of nuclear, whose costs are three times higher. The newest edition, released in mid-2025, shows that electricity costs from utility solar have declined slightly (–4 percent), while onshore wind costs, though still highly competitive, have increased by around 22 percent.¹⁷⁶² Negative macroeconomic factors (interest rates, installation cost inflation etc.) had a strong influence, while the development of solar module manufacturing costs and prices, as well as wind turbine costs, proved more favorable.¹⁷⁶³

Figure 64 · The Declining Costs of Renewables vs. Traditional Power Sources



Source: Lazard Estimates, 2025

Notes: **LCOE**: Levelized Cost of Energy

*This graph reflects the average unsubsidized LCOE values in current dollars (not adjusted for inflation) for a given version of LCOE study. It primarily relates to the North American energy landscape but reflects broader, global cost developments.

While Lazard's reporting is based on U.S. markets where import tariffs for Chinese manufacturers affected local prices, other sources based on other markets report an ongoing decline in the cost of PV. The German Fraunhofer ISE (Institute for Solar Energy Studies), the largest solar research organization in Europe, states in its latest Photovoltaics Report on global developments:

¹⁷⁶² - Lazard, "LCOE+—Levelized Cost of Energy+", June 2025, see <https://www.lazard.com/media/uounhon4/lazards-lcoeplus-june-2025.pdf>, accessed 22 June 2025.

¹⁷⁶³ - NREL, "Solar Manufacturing Cost Analysis", National Renewable Energy Laboratory, 3 April 2025, see <https://www.nrel.gov/solar/market-research-analysis/solar-manufacturing-cost>, accessed 11 July 2025, and PVXchange, "Price Index | June 2025", July 2025, see <https://www.pvxchange.com/Price-Index>, accessed 11 July 2025.

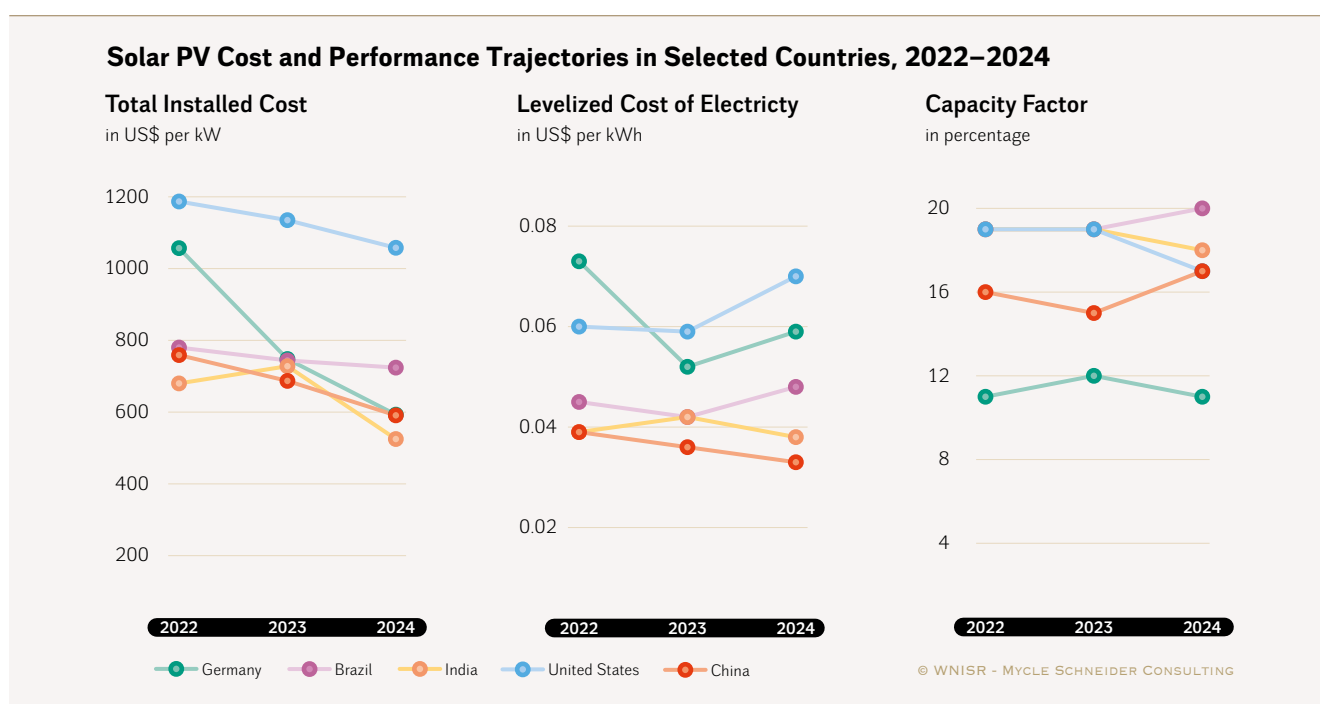
Due to the coronavirus crisis and the associated disruptions to supply and trade chains, market prices rose noticeably in 2022 and at times some products were not available in sufficient quantities. In 2023 prices fell again and have continued to fall in 2024.¹⁷⁶⁴

The International Energy Agency's Photovoltaic Power Systems Programme (IEA-PVPS) writes in its overview on global markets:

After several years of tension on material and transport costs, module prices continued to drop through 2024 in a still massively over-supplied market, putting tremendous financial pressure on all industrial actors on one hand but stimulating markets on the other.¹⁷⁶⁵

The factors influencing LCOE calculations are illustrated in the most recent analysis by the United Nations' International Renewable Energy Agency, IRENA (see Figure 65).¹⁷⁶⁶ Total Installation Costs (TIC) for PV plants have declined everywhere but to differing extents. The capacity factor has evolved differently in different countries, as it also depends on the specific weather conditions in a particular year. The LCOE depends on the two previous inputs while also reflecting interest rates and other financing conditions.

Figure 65 · Solar PV Cost and Performance Trajectories in Selected Countries, 2022–2024



Source: IRENA, 2025

These numbers, however, do not reflect the temporal availability of the electricity generated. This is particularly important for solar and wind energy, which depend on weather

¹⁷⁶⁴ - Simon Philipps and Werner Warmuth, "Photovoltaics Report", Fraunhofer ISE, and PSE Projects, 28 May 2025, see <https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf>, accessed 22 July 2025.

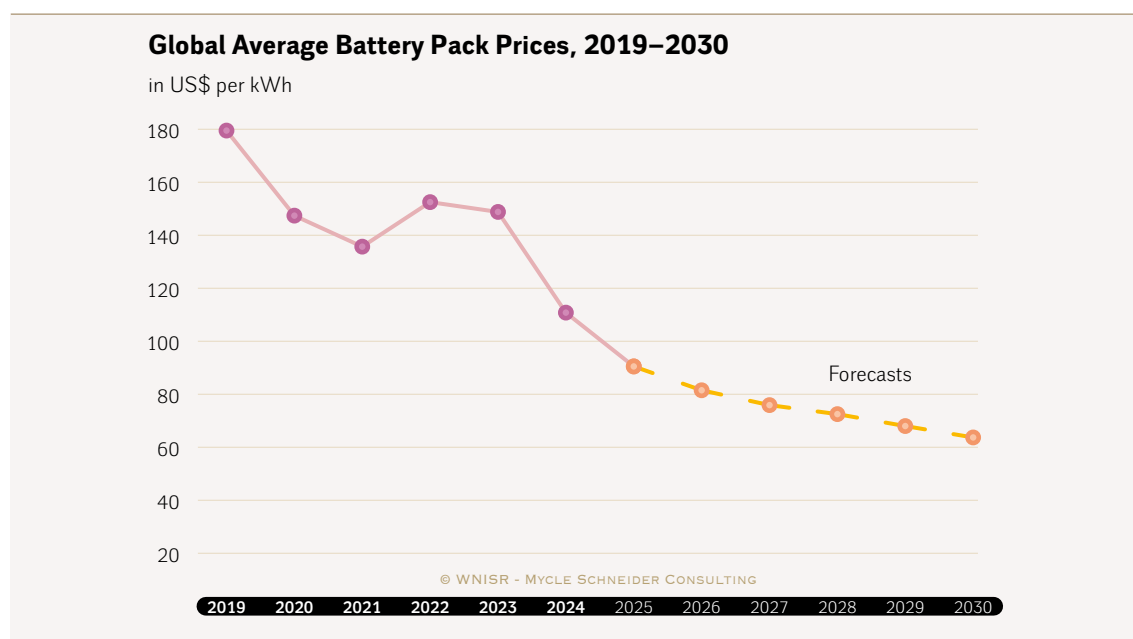
¹⁷⁶⁵ - Gaëtan Masson, Adrien Van Rechem et al., "Snapshot of Global PV Markets - 2025", Photovoltaic Power Systems Programme, International Energy Agency, April 2025, see https://iea-pvps.org/wp-content/uploads/2025/04/Snapshot-of-Global-PV-Markets_2025.pdf, accessed 31 May 2025.

¹⁷⁶⁶ - IRENA, "Renewable Power Generation Costs in 2024", International Renewable Energy Agency, 2025, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jul/IRENA_TEG_RPGC_in_2024_2025.pdf, accessed 23 July 2025.

conditions. This conditioned availability leads to much confusion in the public debate, as an optimization must consider more factors than in the past. However, nuclear energy also requires compensation from other sources, as it needs to operate relatively constantly and requires extended downtimes for inspection, maintenance, upgrading, and refueling as well as unplanned outages for technical reasons.¹⁷⁶⁷

Various authors have developed different methods to calculate “integration costs” or “firming costs” for intermittent/variable/fluctuating¹⁷⁶⁸ energy sources that are not dispatchable. They are usually not taken into account for technologies that are deemed dispatchable (e.g., nuclear power) but have their own level of intermittency. The problem is that such costs depend on the specific conditions of the grid in which these sources are to be integrated—specifically, the temporal structure of electricity demand (which can vary widely due to building characteristics, peak-shifting technologies or behaviors, etc.) and the costs of flexibility required from other sources/sinks. Moreover, the yield of a solar or wind plant depends on its specific location. Therefore, measures such as the VALCOE—where VA stands for Value Adjusted—of the IEA vary across different countries and change over time (see also [Challenges of Integrating Nuclear Power into the Energy System](#)).

Figure 66 · Sharp Decline in Battery Costs After the End of the Lithium Shortage



Source: Goldman Sachs, 2025¹⁷⁶⁹

¹⁷⁶⁷ - Energy analyst Amory Lovins noted: “At least 15.5 GW of U.S. hydro pumped storage plants... got built by the owners of nearby U.S. nuclear plants”; see Amory B. Lovins, “US Nuclear Power: Status, Prospects, and Climate Implications”, *The Electricity Journal*, Vol. 35, Issue 4, May 2022, see <https://www.sciencedirect.com/science/article/pii/S1040619022000483>, accessed 30 October 2023.

¹⁷⁶⁸ - Often the term “intermittent” suggests an on/off behavior, the term “variable” includes variation by both natural causes and operator controls, and “fluctuating” may describe best the lack of permanent control over the power generation from wind and solar radiation. That said, no source of electricity is completely constant and unvarying: everything breaks sometime. Sources differ in their fluctuations’ cause, size, duration, predictability, countermeasures, and consequences. Some analysts, such as Amory Lovins, contend that thermal power plants, with typical forced outage rates around 10–15 percent, are *more* “intermittent” than solar or wind power, because their outages are bigger, longer, more abrupt, and far less predictable than the fluctuations of wind and solar portfolios—and that the thermal plants therefore require bigger and costlier “firming” resources, widening renewables’ whole-system cost advantage.

¹⁷⁶⁹ - Goldman Sachs, “The Outlook for the Cost of Decarbonization”, 1 April 2025, see <https://www.goldmansachs.com/insights/articles/the-outlook-for-the-cost-of-decarbonization>, accessed 12 July 2025.

The storage (or equivalent flexibility) required by a specific generation profile to deliver a constant output for a defined fraction of the year is a more useful benchmark, as it does not depend on the specifics of the grid. The think tank EMBER, in its previously quoted report on the impact of declining storage prices, employs such an approach. Pragmatically, EMBER starts from a very sunny location in the U.S. (Las Vegas, Nevada) and calculates that a 1 MW constant output over 97 percent of the time can be achieved with a combination of 5 MW_p (megawatt-peak) PV and 17 MWh of storage capacity.¹⁷⁷⁰

This PV/storage combination results from a cost optimization that yields electricity costs of US\$104/MWh (US\$0.10/kWh)—22 percent less than a year earlier, primarily due to lower storage costs. The cost is also well above that of a 10-MW ultrareliable all-solar microgrid producing 24/365 power at below US\$80/MWh, built in four months in early 2025 by Redwood Energy in Sparks, near Reno, Nevada. That plant simply laid solar modules on the ground, rather than mounting them on metal racks set in concrete, then added 2–48 hours of storage by ~800 second-life electric-vehicle batteries. Redwood Energy is now engineering solar microgrids an order of magnitude larger. Their round-the-clock solar power is cheaper and more reliable than grid power in early 2025.¹⁷⁷¹

Calculations for other cities show the effect of less sunshine: Madrid can cover 88 percent of the time at US\$114/MWh, Washington and Buenos Aires 81 percent at US\$124, and Birmingham still 62 percent at US\$160/MWh.¹⁷⁷² EMBER concludes, and Redwood Energy's project confirms empirically:

The emergence of 24-hour solar generation marks a fundamental shift in how solar fits into the broader power system. With the ability to deliver electricity around-the-clock, solar can now support 24/7 clean energy contracts (PPAs) for industries which require continuous power, not just daytime supply. This is extremely valuable for emerging economies, where solar-powered industrial and economic zones can emerge in sunny areas far from existing grid infrastructure.

Essential for this result is the rapid decrease in battery costs. The disruptive decline in 2024 (40 percent) represents a return to the longer-term price curve, after the lithium supply chain finally adapted to the rapid growth in demand that had led to temporary shortages and price increases (see [Figure 66](#)).¹⁷⁷³ A particularly striking example was the case of “Mind-blowing bids in China Power’s 16 GWh tender” in late 2024. Reportedly, the “tender attracted 76 bidders with quoted prices ranging from US\$60–82 per kWh, averaging US\$66.3 per

¹⁷⁷⁰ - The ratio would be the same for a small-scale (e.g., residential) system: 1 kW constant output 97 percent of the time with a combination of 5 kW and 17 kWh storage.

¹⁷⁷¹ - Crusoe, “Crusoe and Redwood Materials Unveil World’s Largest Second-Life Battery Deployment, Powering the Future of AI, with Repurposed EV Batteries”, 26 June 2025, see <https://www.crusoe.ai/resources/newsroom/crusoe-and-redwood-materials-power-the-future-of-ai>, accessed 17 August 2025; and Amory Lovins, personal communication, 16 August 2025.

¹⁷⁷² - Realistic detailed assumptions for utility scale solar. See Kostantsa Rangelova and Dave Jones, “Solar Electricity Every Hour of Every Day Is Here and It Changes Everything”, EMBER, 21 June 2025, op. cit.

¹⁷⁷³ - Andy Colthorpe, “Behind the Numbers: BNEF Finds 40% Year-on-Year Drop in BESS Costs”, *Energy Storage News*, 5 February 2025, see <https://www.energy-storage.news/behind-the-numbers-bnef-finds-40-year-on-year-drop-in-bess-costs/>, accessed 12 July 2025; and Goldman Sachs, “Electric Vehicle Battery Prices Are Expected to Fall Almost 50% by 2026”, 7 October 2024, see <https://www.goldmansachs.com/insights/articles/electric-vehicle-battery-prices-are-expected-to-fall-almost-50-percent-by-2025>, accessed 30 May 2025.

kWh.”¹⁷⁷⁴ A staggering decline indeed if compared with Goldman Sachs’ estimate for average global storage costs in excess of US\$100/kWh for 2024 (see [Figure 66](#)). And then in early June 2025, a 25 GWh auction “viewed as a watershed moment for the marketization of China’s energy storage industry” saw four-hour storage bids in the range of US\$51–68/kWh averaging US\$59/kWh, that is 11 percent below the December 2024 auction average.¹⁷⁷⁵

With upcoming new technologies and increasing production—still mainly driven by the growth of electric vehicle markets—battery costs are expected to further decrease for many years to come. As in the past, the battery learning curve will most probably be steeper than that of photovoltaics, resulting in an accelerated cost decline of round-the-clock solar power. This will affect not only utility-scale installations but also small-scale installations behind the meter (see also [Challenges of Integrating Nuclear Power into the Energy System](#)).

INSTALLED CAPACITY AND ELECTRICITY GENERATION

The Overall Picture

In 2024, installed global electricity generation capacities increased by a slightly smaller percentage than the record increase of the year before, while nuclear power showed a 5–10 times lower growth rate than its renewable competitors:

- ➔ Solar power capacity: +32 percent (2023: +32 percent, 2014–2024: +26 percent/year);
- ➔ Wind power capacity: +11 percent (2023: +13 percent, 2014–2024: +12 percent/year) onshore +12 percent (2023: +13 percent), offshore +7 percent (2023: +20 percent);
- ➔ Operating nuclear power capacity: +2 percent (2023: +0.4 percent; 2014–2024: 1.1 percent/year);
- ➔ Grid scale battery capacity: +113 percent (2023: +121 percent, 2014–2024: +75 percent).¹⁷⁷⁶

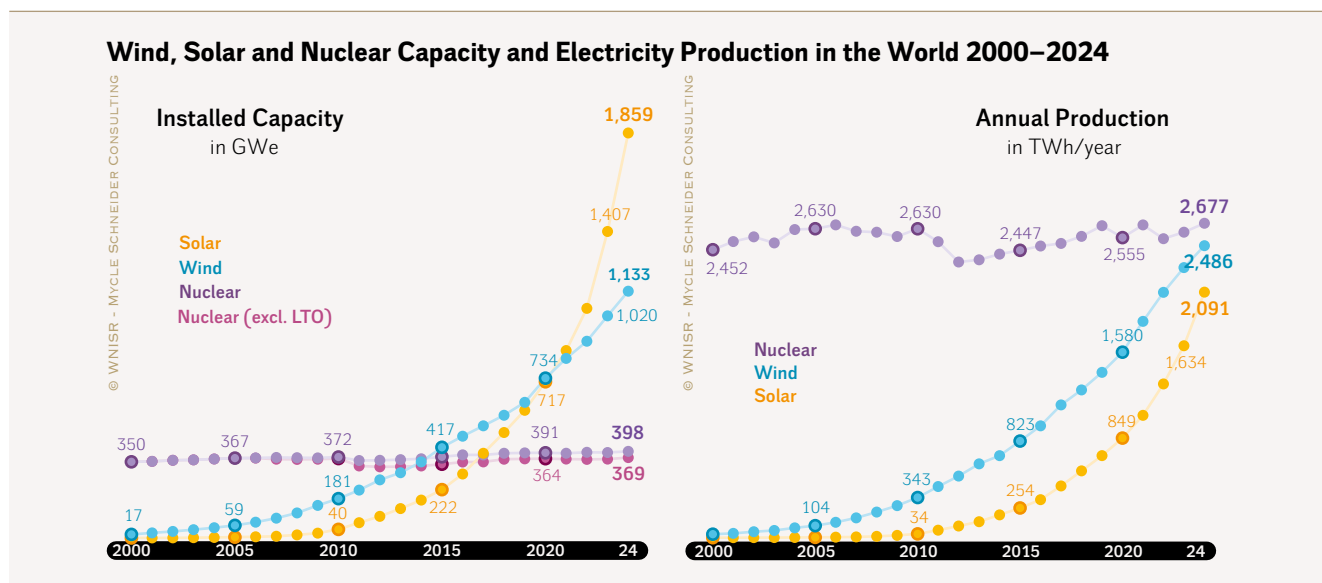
Generation capacities of these different technologies cannot be simply compared or added because their load factors (percentage of the time they are running on full capacity) are different. One must therefore look at the electricity generated for understanding the proportions (although generation lags behind capacity installation). [Figure 67](#) shows the long-term dynamics of both: the different growth curves reflect the exponential growth of wind and solar—with wind starting first and solar catching up with a higher growth rate—in contrast to nuclear, which has essentially remained constant for much more than this quarter of a century. In 2025, both wind and solar are likely to catch up with nuclear output.

¹⁷⁷⁴ - Cameron Murray, “‘Mind-Blowing’ Bids in Power China’s 16GWh BESS Tender as State-Owned Firms Squeeze Market Share”, *Energy-Storage.News*, 19 December 2024, see <https://www.energy-storage.news/mind-blowing-bids-power-chinas-16gwh-bess-tender-state-owned-firms-market-share/>, accessed 9 August 2025.

¹⁷⁷⁵ - Vincent Shaw, “China Energy Engineering Launches Record 25 GWh Storage Tender As Prices Hit Historic Low”, *Energy Storage*, 26 June 2025, see <https://www.ess-news.com/2025/06/26/china-energy-engineering-launches-record-25-gwh-storage-tender-as-prices-hit-historic-low/>, accessed 17 August 2025.

¹⁷⁷⁶ - Energy Institute, *Statistical Review of World Energy 2025—Data*, June 2025.; and Energy Institute, “Statistical Review of World Energy 2024”, June 2024, see https://www.energyinst.org/_data/assets/pdf_file/0006/1542714/EI_Stats_Review_2024.pdf, accessed 24 June 2025.

Figure 67 · Global Wind, Solar, and Nuclear Installed Capacity and Electricity Production

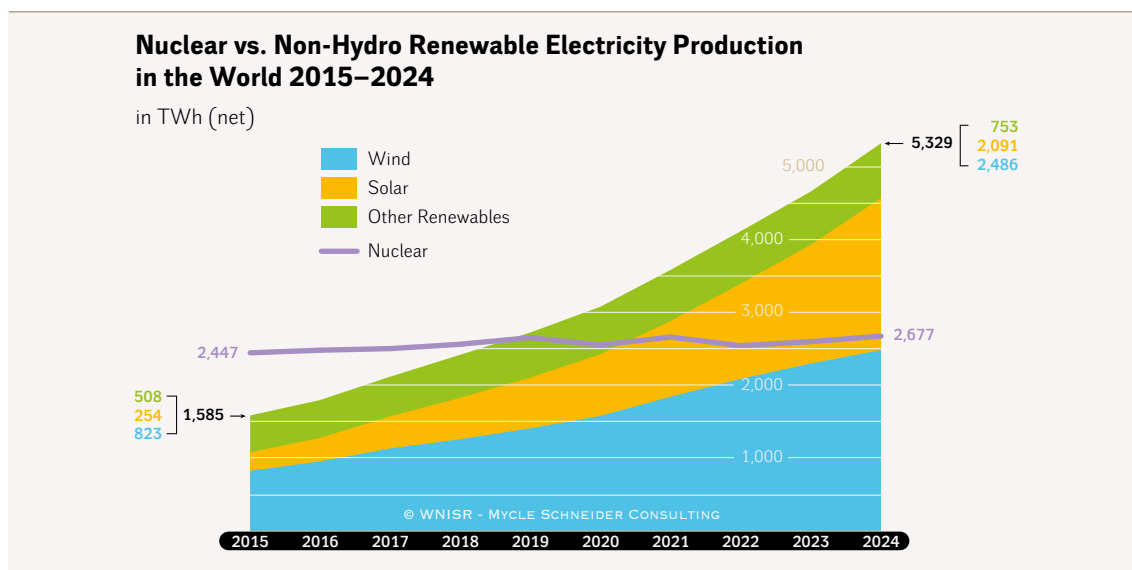


Notes pertaining to figures comparing production and capacities from various power sources. Unless otherwise indicated:

- Production data for renewables and nuclear are in net TWh, from Energy Institute “Statistical Review of World Energy 2025 – Consolidated Dataset”, June 2025;
- Gross production numbers from Energy Institute are used for comparisons with fossil fuels (for which net data is not available);
- Shares in total generation are based on gross data;
- Numbers for installed capacity for renewables are from IRENA; and
- Nuclear operating capacity (i.e., excluding reactors in LTO or Long-term Outage) and installed capacity (including reactors in LTO) are compiled by WNISR based on IAEA-PRIS.

Over the past decade, non-hydro renewables—mainly wind, solar, and biomass—have increased power generation by 236 percent while nuclear output gained just 9.4 percent (see Figure 68).

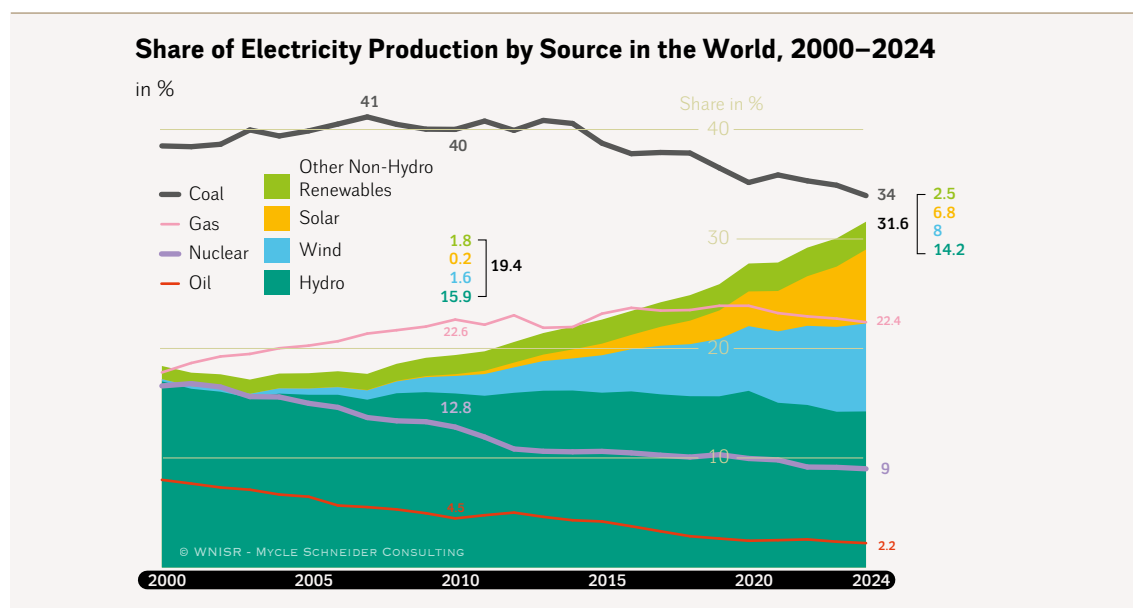
Figure 68 · Nuclear vs. Non-Hydro Renewable Electricity Production in the World



Notes: see under Figure 67.

Looking at the evolution of the various sources' relative shares in world electricity generation since 2000, shows that coal's part peaked in 2007 at 41 percent and declined to 34 percent in 2024, while the renewables' share (including hydro) increased from 19.4 percent to 31.6 percent between 2010 and 2024 alone. Over the same period, the nuclear share fell from almost 13 percent to 9 percent (see Figure 69).

Figure 69 - Electricity Generation in the World by Source, 2000–2024



Source: Energy Institute, 2025

Notes: see under Figure 67.

In 2024, global gross electricity generation evolved as follows:¹⁷⁷⁷

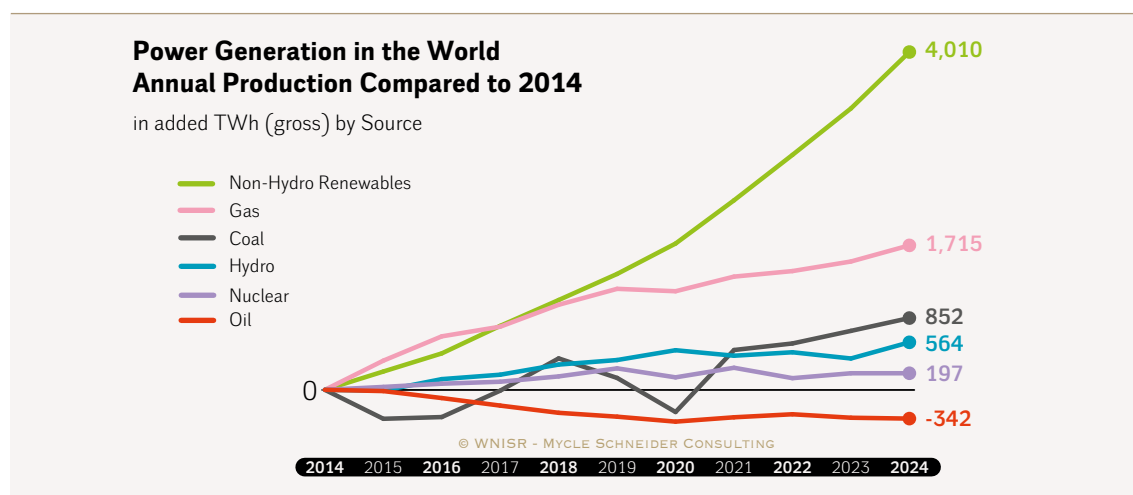
- ➔ Solar power generation: +28 percent, or + 461 TWh (reaching 2,112 TWh or 6.8 percent of total generation)
- ➔ Wind power generation: + 8 percent, or + 188 TWh
- ➔ Non-hydro renewable power: +14 percent, or + 670 TWh (reaching 5,415 TWh or 17 percent of total generation)
- ➔ Hydro power generation: + 5 percent, or + 192 TWh
- ➔ Nuclear power generation: + 3 percent, or + 80 TWh
- ➔ Fossil fuel power generation: + 2 percent, or + 334 TWh
- ➔ Total global electricity generation: + 4 percent, or +1,293 TWh (reaching 31,256 TWh)

This means that the additional non-hydro renewable electricity generation in absolute terms (670 TWh) covered only 52 percent of the overall worldwide increase in electricity production (1,293 TWh). As global electricity consumption has begun to grow more rapidly in

¹⁷⁷⁷ - Gross electricity generation from Energy Institute, "Statistical Review of World Energy 2025—Consolidated Dataset", June 2025, op. cit.

recent years, this is even less than the share of 57 percent achieved over the past decade (2014–2024) during which non-hydro renewables increased annual production by over 4,000 TWh of a total net increase of just under 7,000 TWh, reflected in Figure 70.

Figure 70 · Power Generation in the World, Annual Production Compared to 2014



Source: Energy Institute, 2025

In the rather unlikely case that the growth rates of 2024 remain constant, renewables would catch up with overall generation increase in three to four years, and solar power would cover total generation (equal to consumption, which would have nearly doubled) by 2038. However, most scenarios do not foresee such ongoing renewables growth due to political obstacles and challenges in adapting the whole energy system to large shares of fluctuating renewables. In fact, the whole system logic is undergoing a deep transformation, as the chapter on **Challenges of Integrating Nuclear Power into the Energy System** of this report describes in more detail. BNEF writes in its already quoted new baseline scenario:¹⁷⁷⁸

Our base case scenario falls short of the Paris Agreement goals, with emissions falling only 22% by 2050 – a far cry from net zero – and is consistent with 2.6°C of global warming by 2100.

IRENA and the IEA keep emphasizing that present policies are not sufficient for reaching the pledge to triple renewable energy deployment and to keep climate change within 1.5°C.¹⁷⁷⁹

Photovoltaics and Batteries—The New Dream Team

SolarPower Europe (SPE), in its Global Market Outlook published in May 2025, forecasts a decline in solar power capacity growth rates: After added capacity grew 33 percent in 2024, SPE's medium scenario envisages only 10 percent in 2025, 1.5 percent in 2026, and resumes stronger growth with 14 percent in 2027. The main reason SPE cites for this temporary drop

¹⁷⁷⁸ - BloombergNEF, “New Energy Outlook 2025”, April 2025, op. cit.

¹⁷⁷⁹ - IRENA, “World Energy Transitions Outlook 2024: 1.5°C Pathway”, 2024, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Nov/IRENA_World_energy_transitions_outlook_2024.pdf, and IEA, “Renewable Capacity Growth and the Gap to Global Tripling, 2022–2030”, 7 October 2024, see <https://www.iea.org/data-and-statistics/charts/renewable-capacity-growth-and-the-gap-to-global-tripling-2022-2030>; both accessed 13 July 2025.

is a change in Chinese deployment policies. “With China implementing major changes to its solar market design this year, a temporary dip in global growth in 2026 appears very likely.”

However, recently, there have been several indications that China is not slowing down at all. January through May 2025, China had already installed 70 percent of the capacity added in 2024.¹⁷⁸⁰ Moreover, in early July, the Chinese State Grid Energy Research Institute declared that for 2025, it expected an additional solar capacity of 380 GW, 36 percent up from last year.¹⁷⁸¹ Reported Chinese installations of 93 GW of solar and 26 GW of wind power capacity just in the month of May 2025 are equivalent to nearly four gigawatts per day.¹⁷⁸²

Predictions of a slowdown would fit the history of the systematic underestimation of photovoltaic development. Not only does the IEA have a long record of heavily lowballing photovoltaics, but even SolarPower Europe (SPE), the association of the European PV sector, systematically undervalued its own technology: Its 2020 Global Market Outlook forecasted less than 200 GW of new capacity for 2024. Every year, this figure was increased until the latest Outlook stated that, effectively, 596 GW had been installed in 2024, three times SPE’s 2020 estimate for 2024.

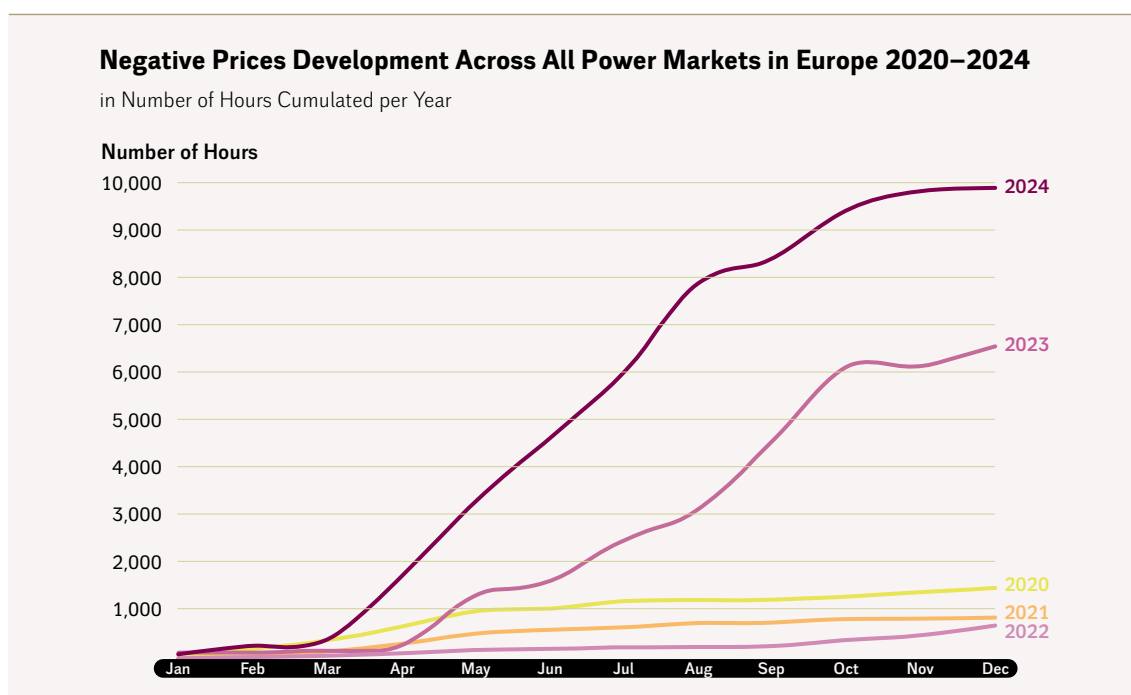
Widespread expectations that the expansion of renewables and especially solar will slow down are rooted in grids’ difficulties to provide sufficient flexibility for high shares of renewables. Figure 71 shows the increase in hours with negative power prices in Europe. Negative power prices indicate a temporary overproduction, which cannot be avoided at all times. However, if they last for too many hours, they are an indicator of the system’s difficulties in coping with fluctuating renewables, and they reduce the income of solar installations in particular. Lawmakers and grid operators in various markets have answered very differently to these challenges. Those reluctant to embrace change call for a slowdown in the growth of renewables and are slow to pave the way for additional flexibility. Others adapt market and connection rules to allow potential flexibility sources, such as storage, to participate in electricity markets and in other ways encourage grids to catch up with the fixed-price, nearly-zero-operating-cost renewable supplies that need to be matched with customers. Batteries offer lucrative opportunities to buy negative-cost or cheap renewable power, sell it on-peak at high prices, and meanwhile sell valuable ancillary services such as frequency and voltage stabilization.

¹⁷⁸⁰ - Nat Bullard, Post, on X (formerly Twitter), June 2025, see <https://x.com/NatBullard/status/1937096033286414437>, accessed 9 July 2025.

¹⁷⁸¹ - Lauri Myllyvirta, “Solar and Wind Energy in China”, Centre for Research on Energy and Clean Air, on LinkedIn, July 2025, see https://www.linkedin.com/posts/lauri-myllyvirta-3164703b_jaw-dropping-while-most-everyone-has-been-activity-7346980641902604288-6eks, accessed 10 July 2025; and China Electricity, “速递 | 预计2025年‘风光’新增装机或超5亿千瓦”, 4 July 2025, see <https://mp.weixin.qq.com/s/nENo5gH7BK4zxGqMj5F79Q>, accessed 13 July 2025.

¹⁷⁸² - Noah Bennett, “‘China Shatters Global Energy Records’: Historic Surge in Solar and Wind Power Redefines the Future of Clean Electricity”, *Sustainability Times*, 1 July 2025, see <https://www.sustainability-times.com/energy/china-shatters-global-energy-records-historic-surge-in-solar-and-wind-power-redefines-the-future-of-clean-electricity/>, accessed 17 August 2025.

Figure 71 · Growth of Hours with Negative Power Prices



Source: Rystad Energy, “Energy Storage Outlook—Energy Macro Report”, May 2025

Notes: Rystad Energy defines Europe as the EU27 + the U.K. and Ireland + the EFTA countries (Norway, Iceland, Switzerland, and Liechtenstein). The number of negative hours has been calculated based on data from all the power markets in continental Europe. Thus, the cumulated number is larger than the average 8,766 hours per year.

*With more temporal distance, it may appear that 2024 was the year
when the energy system crossed a tipping point.*

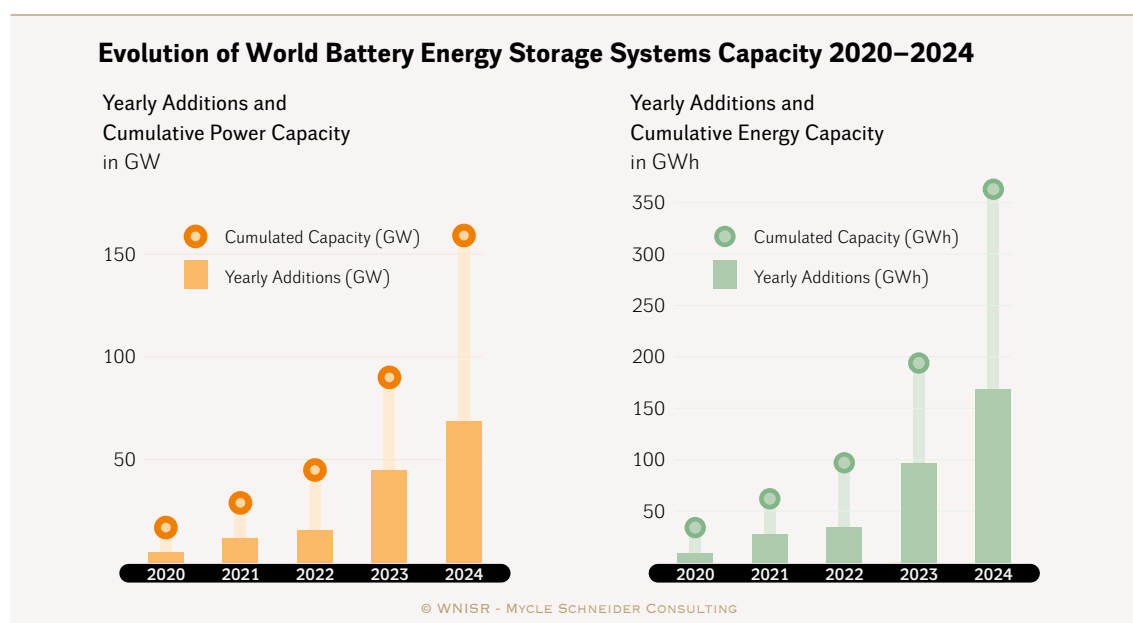
The rapid decline in battery prices (see Figure 66) may be a game changer that will remove hurdles for a sustained rapid growth of PV. While batteries are being mentioned here and there in recent scenarios and outlooks, the impact of recent price drops has not yet been integrated. With more temporal distance, it may appear that 2024 was the year when the energy system crossed a tipping point.

Starting at negligible levels five years ago, the deployment of stationary Battery Energy Storage Systems (BESS) has increased significantly since then (see Figure 72).

The acceleration of grid-scale BESS installations is impressive. Over 80 percent of the overall BESS capacity has been added in the past three years. This overall picture, however, conceals a much more complex dynamic across different markets: Large grid-scale batteries presently make up around four-fifths of the worldwide market, while small batteries behind the meter—appealing to other customers and having a different impact on the system—are one-fifth.¹⁷⁸³ Both the overall adoption of batteries and the proportion of those in front and behind the meter differ strongly between regions.

¹⁷⁸³ - Volta Foundation, “Battery Report 2024”, January 2025, op. cit., p. 149.

Figure 72 · Grid-Connected Battery Storage Additions, 2020–2024



Sources: BloombergNEF, based on Graphic by PowerSwitch/Volta Foundation, 2025

Considering only grid-scale BESS power, between 2018 and 2021, the average annual global growth rate was 52 percent and then jumped to 115 percent (2021–2024). The main driver was the Asia-Pacific region, whose growth rate jumped from 51 percent to 167 percent, resulting in a 68 percent share of global installations by 2024. In the EU27, growth only climbed from 44 percent to 59 percent annually, reaching a share of 3.8 percent. The U.K. alone accounts for more than all EU27 installations.¹⁷⁸⁴

U.S. data for 2023 show how tightly the deployment of BESS is linked to photovoltaics. Of the 19 GWh grid BESS energy capacity added in 2023 (+166 percent), 79 percent were paired with PV plants, one percent with other power plants, and 20 percent were not paired. Interestingly, 89 percent were owned by independent power producers, which can then better compete with incumbent utilities' legacy thermal power plants.¹⁷⁸⁵

While globally, the overall storage capacity of around 360 GWh¹⁷⁸⁶ at the end of 2024 makes up for only about 6 percent of the average daily solar power production, in some regions, batteries are already starting to have a considerable impact. The public grid in California, with the assistance of BESS, has successfully shifted solar electricity generated around noon into the evening hours.¹⁷⁸⁷

¹⁷⁸⁴ - Calculated from the GW capacity data in Energy Institute, "Statistical Review of World Energy 2025", June 2025, op. cit.

¹⁷⁸⁵ - Calculated on the basis of U.S. EIA, "Battery Storage in the United States: An Update on Market Trends", United States Energy Information Administration, 25 April 2025, see <https://www.eia.gov/analysis/studies/electricity/batterystorage/>, accessed 16 July 2025.

¹⁷⁸⁶ - Volta Foundation, "Battery Report 2024", January 2025, op. cit. GW specifications from Volta Foundation are higher than those of the Energy Institute which only counts "grid-level" BESS. Paul Denholm, Wesley Cole and Nate Blair, "Moving Beyond 4-Hour Li-Ion Batteries: Challenges and Opportunities for Long(er)-Duration Energy Storage", National Renewable Energy Laboratory, 2023, op. cit.

¹⁷⁸⁷ - See e.g., Rystad Energy, "Energy Storage Outlook 2025—Energy Macro Report", 26 May 2025, see <https://sf-asset-manager.s3.amazonaws.com/97637/392/6640.pdf>, accessed 15 July 2025.

To put present growth rates into perspective: extrapolating the 2024 growth rates of PV electricity generation (+28 percent) and BESS energy capacity (+87 percent), batteries would be able to store the average daily solar electricity production in 2032, a quantity that would correspond to nearly half of the present daily overall electricity consumption.¹⁷⁸⁸ This does not predict the future but it does illustrate the enormity of current growth rates.

Extrapolating the 2024 growth rates of PV electricity generation (+28 percent) and BESS energy capacity (+87 percent), batteries would be able to store the average daily solar electricity production in 2032.

These astonishing prospects may even prove conservative, because they include only stationary batteries. Yet a fifth of new cars in the U.S. and a third in the world are battery-electric, rapidly expanding what will soon be an immense resource—about 350 GWh of batteries-on-wheels in the U.S. Many new electric vehicles (cars, trucks, buses, etc.) are designed for smart power exchanges with the grid, charging when power is cheap and abundant, then selling back electricity (and other services) when that is profitable and the vehicle is parked. Many new business models and institutional structures are rapidly emerging to exploit this potential. There may soon be a flood of batteries that could reshape grid operations and economics before a new reactor could even be built. And meanwhile, similar forces are at work with stationary storage in buildings, which use half the world's and three-fourths of U.S.' electricity.¹⁷⁸⁹

First Signs of a Boom Behind the Meter

While cost-effective utility-scale storage may remove barriers for further growth of PV in many electricity markets, small-scale storage behind the meter may become even more important on a global scale.

The role of prosumers, who consume a portion if not all of the electricity they produce without passing through the public grid, has been a topic of discussions for many years.¹⁷⁹⁰ Recent massive cost reductions for batteries and energy management systems have been game-changers. They enable much higher rates of self-consumption, making prosumers more independent of public policies governing feed-in tariffs and of grid companies that are late to adapt to renewable energies. There are first signs that this could lead to a surge in PV, even where governments and incumbent utilities are reluctant to embrace new renewable technologies.

The focus of international reporting on PV has always been on utility-scale installations. However, recently, rooftop installations and their potential impacts are increasingly gaining attention. For installers and component providers, rooftop installations have simply addressed

¹⁷⁸⁸ - Volta Foundation reports for 2024 an added battery capacity of 169 GW resulting in 363 GWh energy capacity, that is an increase of 87.1%; see Volta Foundation, “Battery Report 2024”, January 2025, op. cit. p. 138. Extrapolating this growth rate to 2032 leads to 54,544 GWh at the end of the year.

According to Energy Institute, “Statistical Review of World Energy”, June 2025, op. cit; PV electricity generation in 2024 was 2,112 TWh corresponding to 5,786 GWh per day. Extrapolating that with the reported growth rate of 28% per year yields 41,695 GWh/day at the end of 2032. (At the end of 2031 the battery capacity would still be lower).

¹⁷⁸⁹ - Amory Lovins, personal communication, 16 August 2025.

¹⁷⁹⁰ - Ruggero Schleicher-Tappeser, “How Renewables Will Change Electricity Markets in the Next Five Years”, Sustainable Strategies, *Energy Policy*, Vol. 48, September 2012, see <https://www.sciencedirect.com/science/article/pii/S0301421512003473>, accessed 14 July 2025.

a different kind of customer. However, on the one hand, with a growing share in the electricity market, fluctuating renewables are becoming increasingly challenging to integrate, requiring adjustments in regulation and grid infrastructure. On the other hand, with increasingly affordable storage, electricity generation and consumption behind the meter are becoming more independent of the public grid and will thereby alter and diminish its role.¹⁷⁹¹ The significance of this change has not been fully acknowledged yet. The last IEA report on the subject was published in April 2024, specifying behind-the-meter storage prices for 2025 that amount to twice the actual market prices in July 2025.¹⁷⁹²

The last IEA report on the subject was published in April 2024, specifying behind-the-meter storage prices for 2025 that amount to twice the actual market prices in July 2025.

Over the past decade, the global market share of rooftops, as reported by SolarPower Europe, has varied annually between 28 percent (in 2016/17) and nearly 50 percent (in 2022).¹⁷⁹³ Concerning additional installations in 2024, SolarPower Europe reports a minor reduction of the global rooftop market share from 43 percent to 42 percent, due to a further drop in electricity prices following the energy crisis in 2022–2023 and a series of policy changes that reduced financial support. However, among the Top 10 markets, Brazil (place 4) with 63 percent rooftops and Türkiye (place 7) with 90 percent show the rooftop potential in sunny countries, while Germany (place 5) with 62 percent and Japan (place 9) with 68 percent deliver the proof of rooftop's attractiveness for highly industrialized, less sunny regions. Some of these figures should rise further as, for example, the Tokyo Metropolitan Government intensifies its push for ubiquitous rooftop solar for greater Tokyo's 35 million residents, e.g., through the mandatory installation of solar power systems in residential buildings starting in April 2025.¹⁷⁹⁴ China, which had pushed the rooftop market share to 58 percent in 2022, scaled back to 44 percent—still above the international average, which is suffering from a mere 17 percent rooftop market share in the U.S. and 15 percent in India.¹⁷⁹⁵

Cumulative PV installations behind the meter never seemed to be of interest, but with the prospect of massively raising the self-consumption rate with the help of batteries, they start to get more attention. In 2024, the IEA's PV observatory PVPS published a list of the rooftop share of cumulative installations for 27 countries in 2023: Globally, 44 percent of all installations were

¹⁷⁹¹ - Seyyed Ali Sadat and Joshua M. Pearce, "The Threat of Economic Grid Defection in the U.S. with Solar Photovoltaic, Battery and Generator Hybrid Systems", Western University, in *Solar Energy*, 1 November 2024, see <https://www.sciencedirect.com/science/article/pii/S0038092X24006054>, accessed 17 July 2025; and Elisa Wood, "Big Beautiful Bill Unleashes Unintended Distributed Energy Trends", *Energy Changemakers*, 5 July 2025, see <https://energychangemakers.com/big-beautiful-bill-distributed-energy-trends/>, accessed 17 July 2025.

¹⁷⁹² - IEA indicates US\$820/kWh for Europe; see IEA, "Batteries and Secure Energy Transitions", April 2024, Figure 2.26, see <https://iea.blob.core.windows.net/assets/cb39c1bf-d2b3-446d-8c35-aae6b1f3a4a0/BatteriesandSecureEnergyTransitions.pdf>, accessed 14 July 2025.

Market prices for storage systems between 15 and 25 kWh in Germany in July 2025 were between €250 and 350 (US\$293–410); see GLCE Energy, "GLCE Energy All-in-One 15.36kWh LiFePO4 Lithium with Home Battery Inverter, Built-in Smart BMS, Lithium Battery for Solar Storage System/RV/Energy Storage System for Home", on Amazon.de, as of 18 July 2025, see https://www.amazon.de/15-36kWh-LiFePO4-Lithium-Battery-Inverter/dp/B0DHVRJX2B/ref=sr_1_1_sspa; and Idealo.de, "BYD Premium HVM 22.1 Battery Box 22,08kWh", as of 18 July 2025, see https://www.ideal.de/preisvergleich/OffersOfProduct/201969425_-premium-hvm-22-1-battery-box-22-08kwh-byd-energy.html; both accessed 18 July 2025.

¹⁷⁹³ - See the editions of SolarPower Europe's Global Market Outlook from 2014 to 2025.

¹⁷⁹⁴ - Bureau of Environment "Tokyo Solar Power -TMG", Tokyo Metropolitan Government, 10 April 2025, see <https://www.english.metro.tokyo.lg.jp/w/021-101-001016>, accessed 17 August 2025.

¹⁷⁹⁵ - SolarPower Europe, "Global Market Outlook for Solar Power 2025-2029", 6 May 2025, op. cit.

“decentralized”. Outstanding high percentages were found in Türkiye (79 percent), Germany (78 percent), Italy and South Africa (both 69 percent), as well as Japan (60 percent).¹⁷⁹⁶

Combining new PV installations with storage and retrofitting existing ones could have a tangible impact on public grids. In Germany, already in 2023, 80 percent of new rooftop PV installations were equipped with batteries.¹⁷⁹⁷ A new phenomenon in Germany is “balcony power plants”. Over a million such small, self-installed PV plants make up only one percent of all PV capacity, but their ongoing boom, following a doubling in 2024, shows the attractiveness of easy electricity production behind the meter, even without compensation for electricity fed into the grid.¹⁷⁹⁸ Most of them are now coupled with batteries to increase the self-consumption rate.¹⁷⁹⁹ Many need no installer—you just plug them into the wall outlet to feed their modest amount of power back into the home’s circuits whenever available.

However, all these figures need to be taken with a grain of salt. Statistics concerning rooftop installations and, more so, concerning electricity generation and self-consumption are not equally reliable in all countries. And the statistics of international organizations sometimes differ. A recent report from IEA-PVPS provides a detailed explanation of the difficulties.¹⁸⁰⁰ A prominent example of misinterpretations is the case of Pakistan (referred to in *Challenges of Integrating Nuclear Power into the Energy System*), where a mysterious drop in power consumption despite economic growth was later explained by analyzing import statistics: private, non-registered PV installations had allowed for considerable self-consumption that did not pass through the public grid. With growing shares of photovoltaics behind the meter, statistics that reflect only what happens on the public grid increasingly reveal only one part of the story, making forecasts more difficult. This is now important in Australia, where PV production is on most homes and counts as a negative load.

Moreover, it must be acknowledged that all these markets are still in a very early stage, where huge price spreads often lead to confusion and obscure opportunities. A case in point is the cost of residential PV plus battery installations in the U.S., which are still three times higher than in Australia¹⁸⁰¹ or two times higher than in Germany. No wonder that the rooftop share in the U.S. (17 percent) is much lower than in Australia (67 percent), the country with the highest PV density in the world (1,521 W/capita). Also in northern Europe, where the cloudy

1796 - Gaëtan Masson, Melodie de l’Epine and Izumi Kaizuka, “Trends in Photovoltaic Applications 2024”, Photovoltaic Power Systems Programme, International Energy Agency, 2024, see <https://iea-pvps.org/wp-content/uploads/2024/10/IEA-PVPS-Task-1-Trends-Report-2024.pdf>, accessed 25 October 2024.

1797 - Sören Amelang, “Large-Scale Battery Storage in Germany Set to Increase Five-Fold Within 2 Years – Report”, *Clean Energy Wire*, 2 October 2024, see <https://www.cleanenergywire.org/news/large-scale-battery-storage-germany-set-increase-five-fold-within-2-years-report>, accessed 17 July 2025; and MVV Energie AG, “Die ideale Stromspeichergröße für Ihre PV-Anlage”, 28 April 2025, see <https://www.mvv.de/photovoltaik/ratgeber/stromspeicher-so-ermitteln-sie-die-ideale-groesse>, accessed 20 July 2025.

1798 - Julian Korb, “Zahl der Balkonkraftwerke verdoppelt – Millionengrenze könnte fallen”, *Zeitung für Kommunalwirtschaft*, 8 January 2025, see <https://www.zfk.de/energie/strom/zahl-der-balkonkraftwerke-verdoppelt-millionengrenze-koennte-fallen>, and *ARD Tagesschau*, “Solarboom auf Balkonien: Eine Million Balkonkraftwerke”, 11 June 2025, see <https://www.tagesschau.de/wirtschaft/energie/balkonkraftwerke-million-100.html>; both accessed 18 July 2025.

1799 - As of July, the price for market-leading storage devices, including all necessary electronics for connecting PV panels to the home grid, was down to €300–350/kWh (US\$351–410/kWh); see Anker Solix, “Products—Anker SOLIX Solarbank 3 E2700 Pro”, as of 18 July 2025, see <https://www.ankersolix.com/de/products/a17c5>, accessed 18 July 2025.

1800 - Gaëtan Masson, Adrien Van Rechtem et al., “Snapshot of Global PV Markets - 2025”, IEA-PPSP, April 2025, op. cit.

1801 - Amalyah Hart, “Rooftop Solar Three Times Cheaper to Install in Australia Than US, Canada”, *RenewEconomy*, 10 February 2025, see <https://reneweconomy.com.au/rooftop-solar-three-times-cheaper-to-install-in-australia-than-us-canada/>, accessed 15 July 2025.

Netherlands has the second-highest PV density worldwide (1,491 W/capita), residential PV is much cheaper than in the U.S.

For residential and commercial users, the question of energy supply is getting more and more complex: The first step was to complement electricity from the plug with an own PV system, which would sell most or all of the electricity to the grid and involve complicated tariffs. Then batteries appeared on the horizon, soon accompanied by Home Energy Management Systems (HEMS) for optimizing not only the long-discussed time of use of the washing machine but also those of more demanding devices such as the heat pump, the air conditioning, and the wallbox for charging the electric car. This requires a learning process not only for customers, but also for the vendors of all these devices.

The theoretical potential given by today's battery and PV costs is far from being exhausted. The main topic at trade fairs for new energy technologies, such as the Intersolar in Munich, is management systems, their interoperability and standardization, their transparency for the customer, and their rapid evolution with the support of AI.¹⁸⁰² Even large equipment suppliers are still in the early stages of their journey to provide convincing solutions, as evidenced by the offers of leading strategy consultants.¹⁸⁰³ With more user-friendly solutions, managing the complexity of integrated renewable energy systems at the building level becomes rapidly more attractive.

Now add the vehicle-to-grid opportunity mentioned above. Several European firms sell energy and valuable ancillary services back to the grid. One, the Swiss-based Mobility House, has identified 21 such offerings. A few years ago, selling 13 of those earned an average of about €1,000 (US\$1,100) per car per year. In Ireland, where high renewable output makes real-time electricity prices fluctuate, one operator estimates potential revenues many times that large. Some automakers (or other aggregators) may dispatch customers' collective vehicle batteries as a major grid resource, compensating owners for any diminished battery life and ensuring no compromise in driving capability or experience. The financial benefit to owners could be large. And if rolled into the vehicle's purchase price, the effective discount could sell more electric vehicles sooner.¹⁸⁰⁴

Persisting Large Gaps Between Regions

Major international organizations such as the IEA, IRENA, World Bank, and REN21 have identified the gap in renewables growth between low-income and other countries as a major issue. IRENA states:

Asia has kept its leading position since the past few years, accounting for 71% of new renewables capacity in 2024, followed by Europe and North America (respectively contributed 12.3% and 7.8% to the addition), leaving a huge gap with Africa, Eurasia, Central America and the Caribbean which together only accounted for 2.8% of total renewables capacity addition.

¹⁸⁰² - Inter Solar Europe, "The Smarter E Europe 2025: 'We Are the Energy System'", Press Release, 9 May 2025, see <https://www.intersolar.de/press-release/conclusion-the-smarter-e-europe-2025>, accessed 16 July 2025.

¹⁸⁰³ - Apricum, "Heat Pumps & Europe's Energy Future", White Paper, July 2025, see https://apricum-group.com/wp-content/uploads/2025/07/Apricum-heat-pump-white-paper_July-2025.pdf, accessed 7 July 2025.

¹⁸⁰⁴ - Amory Lovins, personal communication, 16 August 2025.

Despite its massive economic and development opportunities, Africa only increased its renewables capacity by 7.2%.¹⁸⁰⁵

As capacities do not allow for direct comparison between technologies, electricity generation is more revealing. Table 19 shows the contribution of solar, wind, and nuclear to overall electricity generation in relation to the world average.¹⁸⁰⁶

Table 19 · Solar, Wind, and Nuclear: Regional Electricity Generation Metrics vs. World Average in percentage

	North America	S&C America	Middle East	Africa	EU27	Asia-Pacific	World	U.S.	China	Australia	Germany	Saudi Arabia	UAE
Contribution to total electricity generation compared to world average (in percent)													
Solar	90	107	44	32	160	112	100	98	123	264	221	27	127
Wind	116	120	4	40	231	87	100	124	118	152	384	5	1
Nuclear	182	19	29	9	258	56	100	197	50	-	-	-	254
Per capita electricity generation compared to world average (in percent)													
Solar	215	97	86	5	259	97	100	342	226	727	336	94	282
Wind	278	112	8	6	351	78	100	430	226	398	529	15	3
Nuclear	434	17	56	2	416	48	100	688	91	-	-	-	565
Total	239	90	195	17	161	87	100	349	184	276	152	354	222

Sources: Electricity generation data from Energy Institute; Population data from Our World in Data; and WNISR calculations, 2025

Note: Continents and regions correspond to traditional geographical grouping used by the Energy Institute.

Africa shows a particularly low deployment of solar and wind power. When considering the generation per capita, the differences are even more extreme, as per capita electricity consumption in the E.U. is ten times higher and in North America 14 times higher than in Africa on average. This is alarming as population growth in the coming decades will likely mainly occur in Africa. Natural conditions on this continent, on the other hand, are ideal for developing PV, as solar irradiation is higher and seasonal differences are smaller than in places farther from the equator. Just as cellphones leapfrogged over landline phones, solar power is an increasingly powerful tool for development, especially in rural and peri-urban areas where grid power is absent, slow, and costly, but local entrepreneurs and simple finance (even via scratchcards) are rapidly exploiting that gap.

For many years, distributed renewables have been proposed to provide electricity-based energy services to rural communities, but volumes have remained low.¹⁸⁰⁷ The 2024 surge in investment in minor markets highlighted earlier in this chapter may indicate an improvement. However, the recent cuts to foreign aid by the Trump administration are causing a reshuffling of energy infrastructure financing across the continent, which hurts many programs and projects.¹⁸⁰⁸

¹⁸⁰⁵ - IRENA, “Renewables Boom Highlights Growing Regional Divide”, Press Release, 10 July 2025, see <https://www.irena.org/News/pressreleases/2025/Jul/Renewables-Boom-Highlights-Growing-Regional-Divide>, accessed 16 July 2025.

¹⁸⁰⁶ - Data based on Energy Institute, “Statistical Review of World Energy 2025”, June 2025, op. cit. Additional population data; see Our World in Data, “Population—Population, 10,000 BCE to 2023”, 15 July 2024, see <https://ourworldindata.org/grapher/population>, accessed 21 July 2025.

¹⁸⁰⁷ - John Everington, “The Small Green Solution to Africa’s Big Electricity Problem”, *The Banker*, 17 January 2024, see <https://www.thebanker.com/content/6fa113aa-957d-5doa-85ab-c590ccc74571>, accessed 17 July 2025.

¹⁸⁰⁸ - Kim Harrisberg, “USAID Cuts Hurt Debated Energy Plans in Africa”, *Context*, 24 April 2025, see <https://www.context.news/just-transition/usaaid-cuts-hurt-debated-energy-plans-in-africa>, accessed 21 July 2025.

Some argue this could also be an opportunity for greater reliance on local resources.¹⁸⁰⁹ New calculations using recent battery costs reveal very interesting amortization times for small-scale projects also in urban areas.¹⁸¹⁰ After the withdrawal of the U.S. and aid reductions by Europe, China is said to become an increasingly attractive funding partner for large-scale projects. This may involve increasing interest in nuclear energy.¹⁸¹¹

Another region, in **Table 19**, showing little progress with renewables is the Middle East—despite excellent conditions for solar energy and no lack of regional capital. The share of solar in total electricity production in the region is less than half of the worldwide average. Of particular interest are Saudi Arabia and the United Arab Emirates.

Saudi Arabia, the world's top petroleum-exporting country, achieves only 37 percent of the solar energy per capita compared to the E.U. and one-quarter of the total electricity generation share compared to the global average. However, recent efforts to build a post-petroleum economy are showing some results with 163 percent growth in solar energy generation in 2024 vs. 2023.

The UAE, ranking eighth in petroleum production, and proudly hosting IRENA since its foundation in 2009, has achieved above-global values for the solar share in electricity generation, but still considerably lower than in the E.U., while wind energy is nearly absent. On the other hand, the UAE's nuclear power share in overall electricity is far above the global average, exceeds that of the U.S., and is nearly on par with the E.U. (see **Table 19**).

With President Trump's recent u-turn in American AI and chip policy, local electricity generation policies in the region gained additional international visibility. The U.S. has agreed to help the UAE and Saudi Arabia become AI powers and build large data centers.¹⁸¹² AI geopolitics is at the center of the international security debate,¹⁸¹³ and data center electricity consumption is central to the discussion on the rapidly growing demand for highly concentrated

¹⁸⁰⁹ - *Experts' Opinions*, "Are the U.S. Aid Cuts an Opportunity for African Governments to Become More Self-Reliant?", as published by DevelopmentAid, 5 May 2025, see <https://www.developmentaid.org/news-stream/post/194908/us-aid-cuts-opportunity-for-africa>; and Nick Ferris, "Trump Ended Obama's Flagship Project to Power Africa – but the Dream Is Not Dead", *The Independent*, 11 July 2025, see <https://www.the-independent.com/climate-change/trump-obama-africa-power-aid-b2785866.html>; both accessed 21 July 2025.

¹⁸¹⁰ - Madani Drave, Felix Mannerhagen et al., "Solar Power Potential in Africa: A Case Study on Cost Reduction in a Malian Household Through Photovoltaic Solar Power and Lithium-Ion Battery Storage", *Electricity*, Vol. 6, Issue 1, 11 February 2025, see <https://www.mdpi.com/2673-4826/6/1/5>, accessed 21 July 2025.

¹⁸¹¹ - African Energy Week, "Atomic Alliances: China's Strategic Push into Africa's Nuclear Energy Sector", African Energy Chamber, 18 April 2025, see <https://aecweek.com/atomic-alliances-chinas-strategic-push-into-africas-nuclear-energy-sector/>, accessed 2 June 2025; and Lse Ideas, "China's Strategic Pursuit of Nuclear Energy Dominance in Africa", The China-Global South Project, 10 April 2025, see <https://chinaglobalsouth.com/analysis/chinas-strategic-pursuit-of-nuclear-energy-dominance-in-africa/>, accessed 9 June 2025.

¹⁸¹² - Alison Snyder and Dave Lawler, "Trump's Gulf Gamble: Helping UAE and Saudi Become AI Powers", *Axios*, 18 May 2025, see <https://www.axios.com/2025/05/18/trump-gulf-ai-deals-saudi-uae-security-china-risk>, accessed 22 July 2025; and Hussain Shahid, "The Silicon Dunes: UAE's Grand Design to Rewire the Future of Global AI", *Modern Diplomacy*, 19 May 2025, see <https://modern diplomacy.eu/2025/05/19/the-silicon-dunes-uaes-grand-design-to-rewire-the-future-of-global-ai/>; also Charles Chebli, "The UAE: The Future Hub for Mega AI/GPU Solar-Powered Data Centers as Global Digital Corridors", Senior Sales Account Manager, Dell Technologies, on LinkedIn, 6 February 2025, see <https://www.linkedin.com/pulse/uae-future-hub-mega-aigpu-solar-powered-data-centers-global-chebli-ozif8f/>; both accessed 31 July 2025.

¹⁸¹³ - Mark Leonard, Jeremy Shapiro and Tom Wright, "Live from the Aspen Security Forum: America's Inward Turn", European Council on Foreign Relations, 21 July 2025, see <https://ecfr.eu/podcasts/episode/live-from-the-aspen-security-forum-americas-inward-turn/>; and Colin H. Kahl and Jim Mitre, "The Real AI Race", *Foreign Affairs*, 9 July 2025, see <https://www.foreignaffairs.com/united-states/china-real-artificial-intelligence-race-innovation>; both accessed 22 July 2025.

firm dispatchable electricity.¹⁸¹⁴ As a key hub for U.S. efforts to maintain AI dominance, the region will see considerable growth in electricity consumption. Agreed U.S.-supported AI hubs in the UAE are designed to comprise data centers consuming 5 GW. Khazna, the infrastructure provider, is betting on solar. Nuclear and gas, however, are also in the still somewhat opaque power mix.¹⁸¹⁵

STATUS AND TRENDS IN CHINA, THE EUROPEAN UNION, INDIA, AND THE UNITED STATES

China

China dominates the world of solar and wind power in a double sense: It dominates the value chains for producing solar and wind power equipment on the global markets, and it dominates the deployment of solar and wind power with outstanding numbers at home.¹⁸¹⁶

In 2024, China alone accounted for 40 percent of the global solar electricity generation, and the same is true for wind. But solar grew by 44 percent, more than three times as fast as wind, which grew 13 percent. In contrast, China's nuclear power accounted for 16 percent of global nuclear electricity production and grew only by 3.7 percent. Growth rates of total electricity, solar, and wind power were all around 55 percent higher than at the global level, while nuclear lagged behind with a 27 percent higher than global growth rate. Compared with national electricity production, solar power grew 6.5 times as fast, wind 1.9 times, and nuclear 0.6 times—i.e., nuclear power lost market share.¹⁸¹⁷ On a per capita basis, as we saw earlier, Chinese solar power production is less impressive, reaching two-thirds of the level of the U.S. and Germany and only one-third that of Australia (see Table 19).

Figure 73 and Figure 74 show, in a historical perspective, that the evolution of renewable power in China has followed a coherent, continuous strategy. From 2020 onwards, the nuclear curves are flattening compared to wind and solar. After a modest increase in nuclear power, wind has taken the leading role, followed by solar. In 2024, solar and wind generated over four times

¹⁸¹⁴ - IEA, “Energy and AI – Analysis”, April 2025, see <https://www.iea.org/reports/energy-and-ai>, accessed 10 April 2025; and Laure de Roucy-Rochegonde and Adrien Buffard, “AI, Data Centers and Energy Demand: Reassessing and Exploring the Trends”, French Institute of International Relations, 24 February 2025, see <https://www.ifri.org/en/papers/ai-data-centers-and-energy-demand-reassessing-and-exploring-trends-o>, accessed 22 July 2025. For a complementary-critical analysis, see Amory B Lovins, “Artificial Intelligence Meets Natural Stupidity: Managing the Risks”, Stanford Energy, as of 30 June 2025, see https://integrative-design-for-radical-energy-efficiency.stanford.edu/sites/extreme_energy_efficiency/files/media/file/data-centersaiel-corrdr-17-30june2025_o.pdf, accessed 28 July 2025.

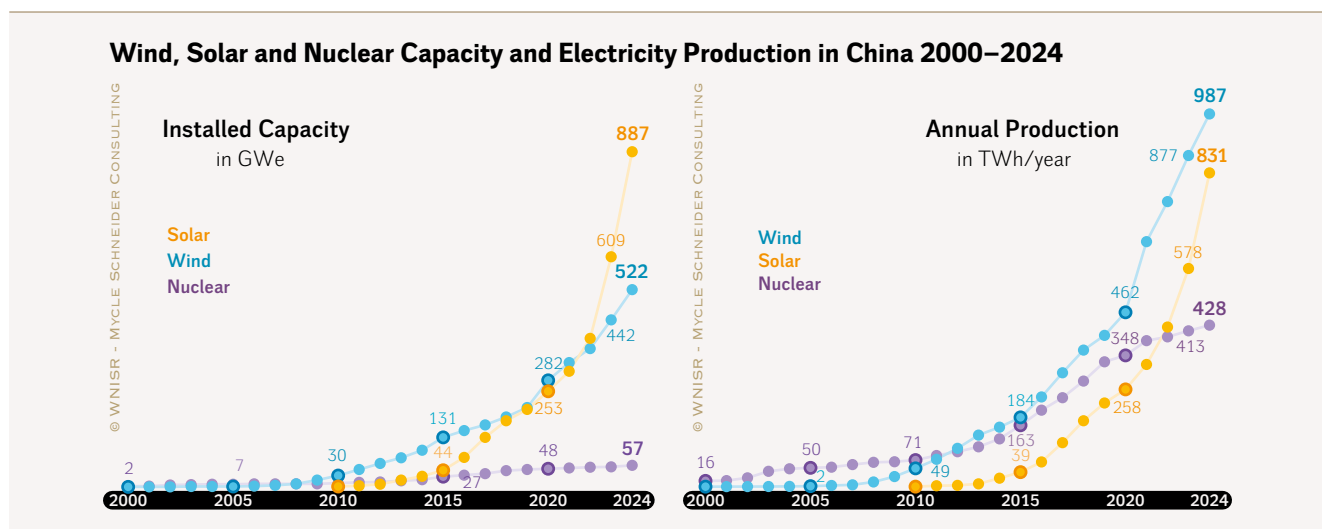
¹⁸¹⁵ - Pooja Chandak, “Khazna’s AUH6: A Solar-Powered Hub For AI Advancements In Abu Dhabi”, SolarQuarter, 29 February 2024, see <https://solarquarter.com/2024/02/20/khaznas-auh6-a-solar-powered-hub-for-ai-advancements-in-abu-dhabi/>; and Sameer Hashmi, “The Gulf Bets Big on AI as It Seeks the ‘New Oil’”, BBC, 30 July 2025, see <https://www.bbc.com/news/articles/cvg8z2mx5o8o>; also Energy Connects, “TAQA and EWEC Drive UAE’s AI Strategy and Net Zero Goals with New Energy Infrastructure Projects”, 3 April 2025, see <https://www.energyconnects.com/news/utilities/2025/april/taqa-and-ewec-drive-uae-s-ai-strategy-and-net-zero-goals-with-new-energy-infrastructure-projects/>; all accessed 31 July 2025.

¹⁸¹⁶ - Khushboo Goyal, “China’s Domination Over Global Solar PV Supply Chain”, REGlobal, 13 January 2025, see <https://reglobal.org/chinas-domination-over-global-solar-pv-supply-chain/>; and IEA, “Special Report on Solar PV Global Supply Chains”, August 2022, see https://www.oecd.org/en/publications/special-report-on-solar-pv-global-supply-chains_9e8bo121-en.html; also Luke Patey and Byford Tsang, “Last Gasp: Securing Europe’s Wind Industry from Dependence on China”, ECFR, 1 July 2025, see <https://ecfr.eu/publication/last-gasp-securing-europes-wind-industry-from-dependence-on-china/>; all accessed 1 August 2025; and Gaëtan Masson et al., “Snapshot of Global PV Markets - 2025”, Photovoltaic Power Systems Programme, International Energy Agency, April 2025, see https://iea-pvps.org/wp-content/uploads/2025/04/Snapshot-of-Global-PV-Markets_2025.pdf accessed 31 May 2025.

¹⁸¹⁷ - All calculations on the basis of Energy Institute, “Statistical Review of World Energy”, June 2025, op. cit.

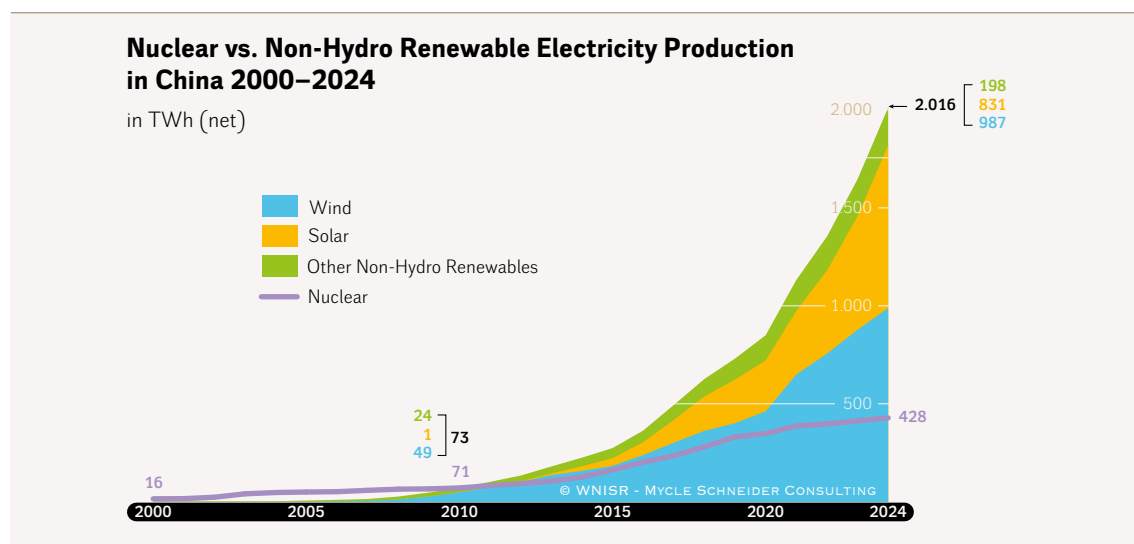
more power than nuclear (see Figure 73). Since 2010, output of solar increased by a factor of over 800, wind by a factor of 20, and nuclear by a factor of six (see Figure 74).

Figure 73 · Wind, Solar, and Nuclear Installed Capacity and Electricity Production in China



Notes: see under Figure 67.

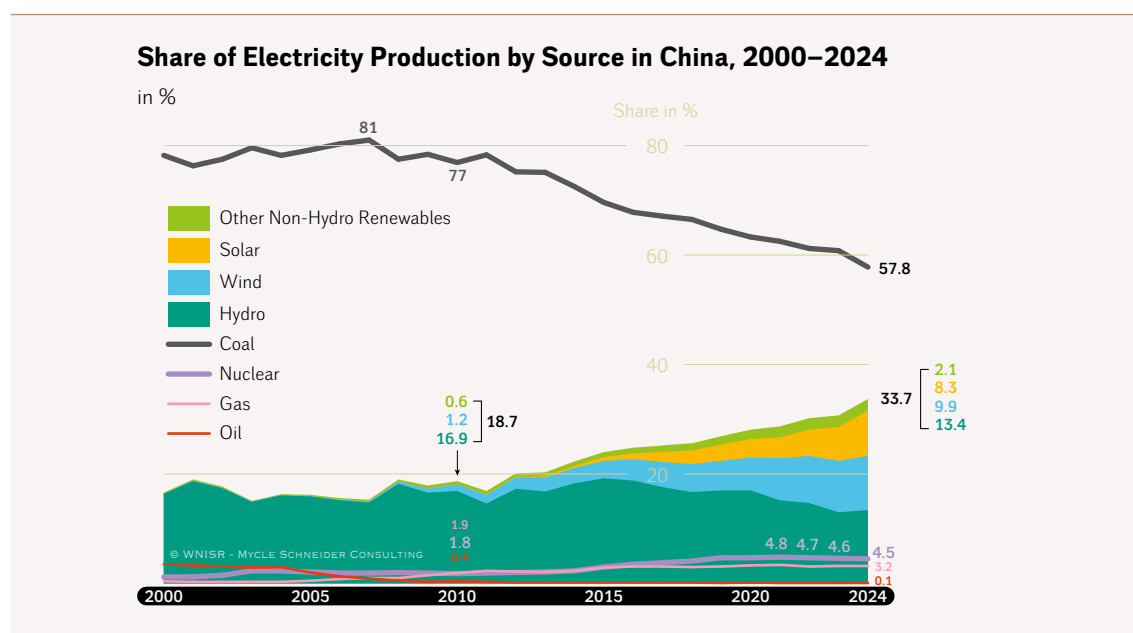
Figure 74 · Nuclear vs. Non-Hydro Renewables in China, 2000–2024



Note: see Figure 67 for comparison.

As Figure 75 illustrates, compared to overall electricity generation, the share of nuclear power has even declined in recent years. After reaching its apex in 2021 with 4.8 percent—about half of the global value—the share of nuclear power dropped by 0.1 percentage points every year to 4.5 percent in 2024. It is also remarkable that the share of coal—while still excessively high—has declined by more than 20 percentage points, from over 80 percent in 2007 to less than 58 percent in 2024.

Figure 75 · Electricity Generation Mix in China, 2000–2024



Source: Energy Institute, 2025

Notes: see under Figure 67.

For more than a decade now, China has made considerable efforts to also lead in the battery space: first by electrifying two-wheelers, then by deploying electric buses and cars, and not long ago by entering the stationary electricity storage business. In global battery supply chains, too, China controls over 80 percent of every step.¹⁸¹⁸ At the end of 2024, 60 percent of all grid-scale BESS were installed in China.¹⁸¹⁹ Indeed, in 2024, China increased new grid-connected battery capacity by 130 percent to reach a total of 74 GW/168 GWh.¹⁸²⁰ Batteries will likely further boost the adoption of solar power.

In every phase of the energy transition, at least since the beginning of this century, China has been instrumental in cracking the resistance of incumbent industries in America and Europe by creating and dominating markets that offered highly competitive energy technologies. The outstanding average annual GDP growth rate of 12 percent between 2000 and 2024¹⁸²¹ has given leeway for new industries, without too much opposition from domestic incumbents. Meanwhile, the renewables industry is a key part of a strong, independent economic force in China labelled “clean energy” that also comprises electricity grids, energy storage, EVs,

¹⁸¹⁸ - Volta Foundation, “Battery Report 2024”, January 2025, op. cit., p. 27.

¹⁸¹⁹ - Energy Institute, “Statistical Review of World Energy 2025”, June 2025, op. cit.

¹⁸²⁰ - CNESA, “China National Energy Administration Released Official Report Highlighting 130% Growth in Installed Capacity of Energy Storage”, China Energy Storage Alliance, 3 August 2025, see <http://en.cnesa.org/latest-news/2025/8/3/china-releases-official-energy-storage-report-highlighting-130-growth-in-installed-capacity>, accessed 5 August 2025.

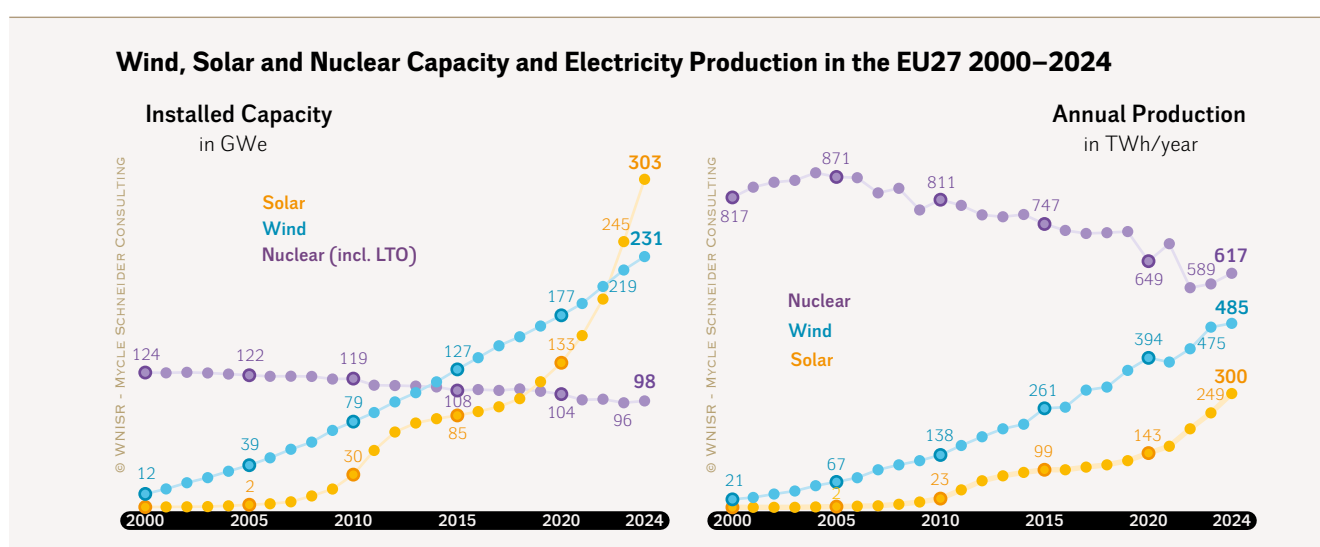
¹⁸²¹ - Calculated from data of World Bank, “GDP (current US\$) - China”, 2025, see <https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=CN>, accessed 1 August 2025.

railways, and nuclear power, and it contributed 10 percent of China's GDP and a quarter of China's GDP growth in 2024.¹⁸²²

European Union

As Figure 76 illustrates, in comparison with the corresponding graphs for China, India, and the U.S. (see Figure 73, Figure 78, and Figure 79), renewable energies took off much earlier in the E.U. than in other continents. However, growth has not been as steep as in China.

Figure 76 · Wind, Solar, and Nuclear Capacity and Electricity Production in the EU27



Sources: WNISR with Energy Institute, IRENA, and IAEA-PRIS, 2025

Notes: see under Figure 67.

In 2024, wind contributed 17 percent to the overall electricity generation, while solar contributed 11 percent. Nuclear power still outpaced both solar and wind individually with a 23 percent share, of which 59 percent was generated in one country, France. The wind plus solar contribution of 28 percent to the total electricity production, however, not only outcompetes the nuclear share in the E.U., but is also much higher than in China (18 percent) or the U.S. (17 percent) and nearly twice the global average (15 percent). Figure 77 shows how the growth of renewables is bringing down the consumption of fossil fuels, with solar and wind alone generating just about as much power as all fossil fuels combined.

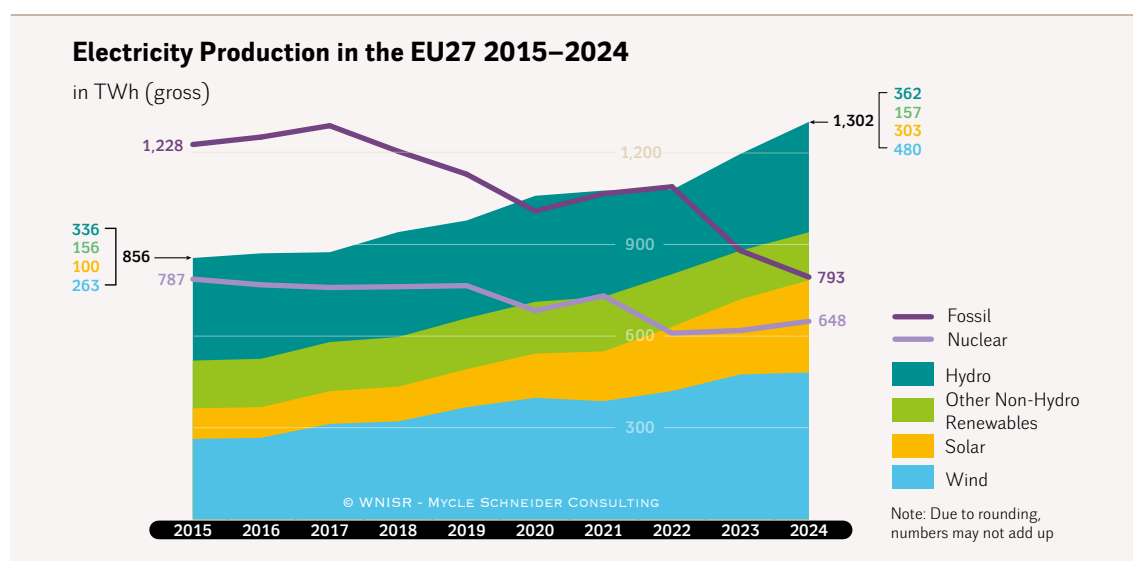
European growth rates for solar and wind in 2024, however, have been underwhelming, with solar growth (20 percent) at 0.7 times the average global rate and wind growth (2 percent) at 0.2 times the global rate. In contrast, nuclear power has made more progress in Europe than globally, achieving a growth rate of 1.65 times the worldwide average and surpassing nuclear

¹⁸²² - Lauri Myllyvirta, Qi Qin, and Chengcheng Qiu, "Analysis: Clean Energy Contributed a Record 10% of China's GDP in 2024", Centre for Research on Energy and Clean Air, 29 February 2025, see <https://energyandcleanair.org/analysis-clean-energy-contributed-a-record-10-of-chinas-gdp-in-2024/>; and OECD, "Government Support in the Solar and Wind Value Chains", No. 288, January 2025, see https://www.oecd.org/en/publications/government-support-in-the-solar-and-wind-value-chains_d82881fd-en.html; both accessed 1 August 2025.

growth in both China and the U.S.—although, with only 4.8 percent, it is still not even a quarter of the E.U.’s solar growth.

In fact, the E.U.’s nuclear growth is exclusively due to production in France that saw recovery from some very bad years (see [France Focus](#)). French reactors increased generation by 41.3 TWh in 2024, while the overall EU27 output increased by only 28.4 TWh. In other words, in the rest of the E.U., nuclear output declined by 13 TWh.

Figure 77 · Electricity Generation in the EU27 by Fuel, 2015–2024



Source: EMBER, 2025

However, these overall numbers for the EU27 (which accounts for 72 percent of the electricity generation of the continent without Russia) conceal considerable differences within Europe. The two largest E.U. economies, Germany and France, have followed very different strategies.

In 2024, nuclear power accounted for 67 percent of electricity generation in France. In Germany, it was zero. In Germany, wind and solar energy made up 43 percent, while in France they accounted for 13 percent. Solar electricity in Germany grew by 16 percent, while in France it grew by 10 percent. The growth rate of overall electricity generation in France was 9 percent with domestic consumption increasing by only 3 TWh or 0.7 percent. French electricity exports jumped 48 percent to 103 TWh for record net exports of 89 TWh.¹⁸²³

An intensely used trading system interconnects European countries, making comparisons more difficult. On balance, in 2024, France exported 16 percent of the electricity it generated (the equivalent of around 130 percent of its solar plus wind or 23 percent of its nuclear power generation). Germany imported about 5 percent of its consumption, while solar plus wind

¹⁸²³ - Own calculations on the basis of Energy Institute, “Statistical Review of World Energy 2025”, June 2025, op. cit. Figures on France based on RTE, “Bilan électrique 2024 - Synthèse”, Réseau de Transport d’Electricité Français/France’s transmission system operator, February 2024, see <https://analysesetdonnees.rte-france.com/bilan-electrique-2024/synthese>, accessed 28 March 2025.

provided 41 percent. Italy, also without its own nuclear power, imported 16 percent of its consumption, while generating 32 percent of its consumption with renewables.¹⁸²⁴

Increasingly, the E.U. institutions influence the member states' energy policies, although the European Commission is not directly responsible for energy policy as it is for trade policies. Presented in December 2019, the European Green Deal, encompassing a wide range of policies, aims at making Europe climate-neutral by 2050. It has provided a strong push for renewables across all E.U. countries. European institutions are urging for more interconnection capacities between countries and for other steps to facilitate a truly integrated European energy market. This would increase overall flexibility and encourage optimal siting of generation and consumption. Current energy generation statistics reflect past decisions and policies.

Meanwhile, the political landscape has changed. Since 2022, energy-supply-security considerations and geopolitical threats have increasingly influenced the agenda. For the political majorities in the E.U. and its member states, accelerating the energy transition has become less of a priority compared to a year ago. SolarPower Europe writes in its mid-year analysis of the E.U. renewables market:

After exceptional expansion in 2022 (+47%) and 2023 (+51%), growth flattened at 3.3% in 2024. For 2025, the market is expected to contract for the first time in nearly a decade, with a projected – 1.4% growth under the Medium Scenario. The current downturn is driven primarily by the rooftop segment, particularly residential solar systems. In many major Member States, primarily households and SMEs are postponing investment in solar installations following lowering electricity price trends and weakened support frameworks. In many cases, rooftop solar incentives have been withdrawn or scaled back without effective alternatives, resulting in a short rush and sudden market decline.

Looking at the economics of solar power, the objective conditions are not as bad as the sentiment, which has been influenced by the hefty anti-renewable policies of the Trump administration. Small private investors immediately react to changes in financial support before returning to a more rational approach, as is happening with the heat-pump and e-mobility markets in Germany.¹⁸²⁵

In Europe, following Russia's full-scale invasion of Ukraine and the subsequent energy crisis, energy-supply security is gaining importance, perhaps more so than on other continents. While climate concerns, therefore, might have lost some of their priority, renewables and the energy transition are increasingly being considered as essential tools for gaining energy-supply

¹⁸²⁴ - Additional import and export data from: Terna, "Terna: Electricity Consumption Increases by 2.2% in 2024", 16 January 2025, see <https://www.terna.it/en/media/press-releases/detail/electricity-consumption-2024>, accessed 15 September 2025; and AGEb, "Bruttostromerzeugung in Deutschland nach Energieträgern", AG Energiebilanzen, 2025.

¹⁸²⁵ - Benjamin Wehrmann, "Heat Pump Sales in Germany Surge but Must Double to Hit Expansion Targets – Industry", *Clean Energy Wire*, 28 July 2025, see <https://www.cleanenergywire.org/news/heat-pump-sales-germany-surge-must-double-hit-expansion-targets-industry>; and European Alternative Fuels Observatory, "Germany: BEV Registrations Surge by 54% in April 2025", European Commission, 8 May 2025, see <https://alternative-fuels-observatory.ec.europa.eu/general-information/news/germany-bev-registrations-surge-54-april-2025>, both accessed 3 August 2025.

security.¹⁸²⁶ Also, in a direct military sense, the security advantages of renewables that have been evident in Ukraine are being appreciated in the E.U.¹⁸²⁷

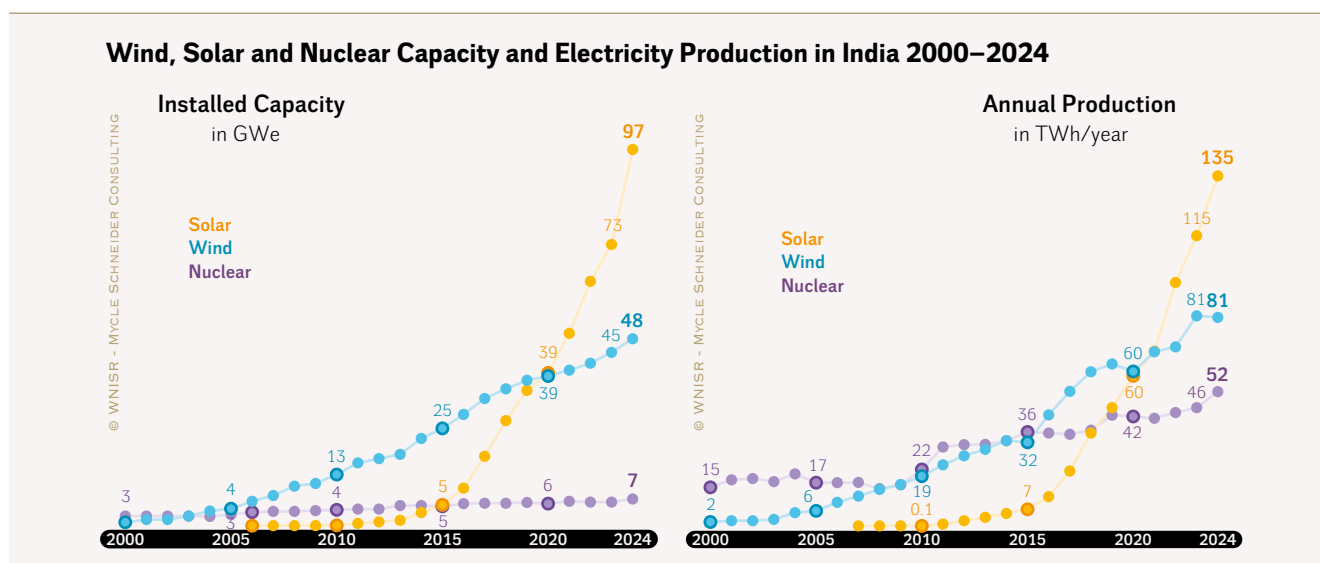
India

As Figure 78 shows, renewable capacities have continued their growth path, while annual wind generation stagnated, caused not by missing capacity growth but by weaker-than-usual winds.

However, the PV capacity growth of 34 percent corresponds to the world average, while PV electricity generation grew by 17 percent, versus 28 percent globally. That means there is hope that India is catching up in the global context, as wind plus solar generation still accounts for only 11 percent of total electricity generation, compared to the 15 percent worldwide average. On a per capita basis, it looks much worse: Indian PV power generation reaches only 36 percent of the world average, wind only 18 percent.¹⁸²⁸

Nuclear, on the other hand, has seen a 13 percent generation increase in 2024, which in absolute terms (+6.5 TWh) accounts for just over one third of the solar increase (+21 TWh).

Figure 78 · Wind, Solar, and Nuclear Installed Capacity and Electricity Production in India



Sources: WNISR with Energy Institute, IRENA, IAEA-PRIS, 2025

Notes: see under Figure 67.

¹⁸²⁶ - Violeta Klyviene and Matjaž Sušec, “Renewable Energy Can Fuel Increased Energy Security”, European Stability Mechanism, 24 July 2024, see <https://www.esm.europa.eu/blog/renewable-energy-can-fuel-increased-energy-security>; Kingsmill Bond, Sam Butler-Sloss and Daan Walter, “Energy Security in an Insecure World”, EMBER, April 2025, see <https://ember-energy.org/latest-insights/energy-security-in-an-insecure-world>; and Global Renewables Alliance, “Energy Security”, 15 April 2025, see <https://globalrenewablesalliance.org/security/>; all accessed 3 August 2025.

¹⁸²⁷ - Caspar Hobhouse, “Keeping the Lights on: How Ukraine Can Build a Resilient Energy System (and Why This Matters to the EU)”, European Union Institute for Security Studies, 28 March 2025, see <https://www.iss.europa.eu/publications/commentary/keeping-lights-how-ukraine-can-build-resilient-energy-system-and-why>, accessed 3 August 2025.

¹⁸²⁸ - Calculations on the basis of Energy Institute, “Statistical Review of World Energy—Consolidated Dataset”, June 2025, op. cit.

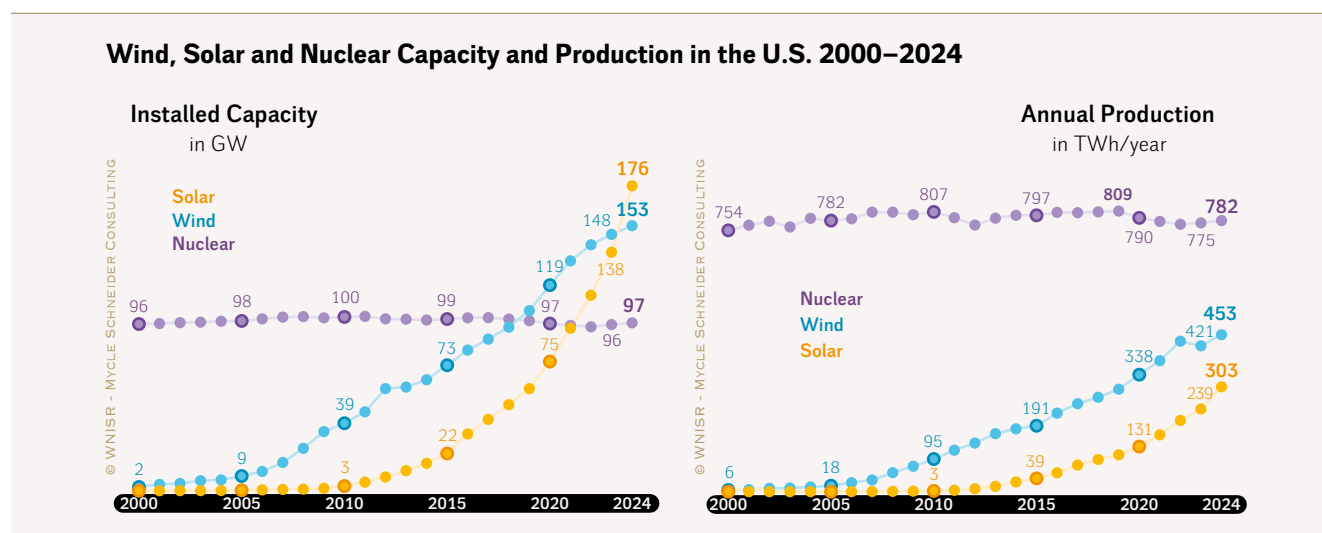
In its efforts to triple solar power by 2030, the Indian government bets strongly on expanding rooftop installations. The Ministry of New and Renewable Energy reports just under 19 GW “grid-connected solar rooftop” as of end of June 2025.¹⁸²⁹ A net-metering program is supposed to boost adoption, but meets several hurdles, not least the opposition of utilities. It may well be that not all installations behind the meter—estimated at 5 GW—are appearing in the statistics.¹⁸³⁰

United States

Unlike in China, the E.U., and India, and unlike the worldwide average, wind plus solar electricity production in the U.S. is still lower than the output of nuclear reactors. Nuclear power generation has been relatively stable over the past twenty years, but in 2024 it grew slightly, making up for losses in recent years.

Wind and solar in 2024 have grown respectively by 3.5 percent and 28 percent in capacity, and by 7.7 percent and 27 percent in electricity generation. That corresponds quite precisely to worldwide growth rates. U.S. wind and solar together produced 17 percent of total electricity generation, slightly exceeding the 15 percent worldwide. With 14.8 percent of global electricity generation, the U.S. is a heavyweight, but consumes less than half as much electricity as China.

Figure 79 · Wind, Solar, and Nuclear Installed Capacity and Electricity Production in the United States



Notes: see under Figure 67.

¹⁸²⁹ - Ministry of New and Renewable Energy, “Physical Achievements”, Government of India, 31 July 2025, see <https://mnre.gov.in/en/physical-progress/>, accessed 2 August 2025; and Gaëtan Masson, Melodie de l’Epine and Izumi Kaizuka, “Trends in Photovoltaic Applications 2024”, IEA-PPSP, 2024, op. cit.

¹⁸³⁰ - Vibhuti Garg, “Solar Rooftop in India Shifting Gears: From Laggard to Leader”, Institute for Energy Economics and Financial Analysis, 27 March 2024, see <https://ieefa.org/resources/solar-rooftop-india-shifting-gears-laggard-leader>; and Arjun Gupta, Shilpi Sharma, and Nuvodita Singh, “Can Rooftop Solar Power India’s Cities?”, Rocky Mountain Institute, 2025, see <https://rmi.org/insight/can-rooftop-solar-power-indias-cities/>; all accessed 2 August 2025.

Within the U.S., there are significant differences between states. Unlike in Europe, there is no nation-wide electricity market. The rules of electricity markets differ considerably, and so do the shares of renewables and nuclear, as well as their developments.

Most notable is the development in Texas, traditionally a conservative oil state governed by Republicans, where traditional proponents of strong support schemes for renewables would not expect a boom in renewables. However, the deregulated energy-only market with nodal pricing, authorities that ensure no monopolies can cripple free competition, streamlined permitting processes, and a reluctance toward state subsidies have led to a surge in solar that has outpaced California in 2024. Between 2015 and 2020, utility-scale solar power capacity experienced an average annual growth rate of 73 percent, which somewhat slowed to a still remarkable 46 percent between 2020 and 2024.¹⁸³¹

In recent years, Texas has also become the epicenter of BESS growth. By the end of 2024, Texas had an installed capacity of almost 9.7 GW of grid-connected batteries, expected to more than double in 2025 to 20.1 GW. Only three years earlier, in 2022, battery capacity stood at 2.8 GW. At the same time, fossil-fueled plants have been retired, notably 7.3 GW of coal and gas closed between 2018 and 2023.¹⁸³²

Under the Trump administration, however, this economically motivated success story risks slowing down. In a political climate that opposes renewables and favors fossil fuels, local politicians try to pass legislation to prioritize fossil fuels.¹⁸³³ Texas legislators in early 2025 nearly passed a new law severely restricting and penalizing new and existing renewable generation but reversed course, apparently influenced by local renewable investors and beneficiaries and by fears that without fast-growing renewables, the state could not keep its lights on.¹⁸³⁴

The struggle in Texas reflects an overall trend in the U.S. The Trump administration is attempting to reverse the efforts of the Biden administration to accelerate the energy transition through a wide range of initiatives. In 2024, the Biden efforts, especially with the so-called Inflation Reduction Act or IRA signed into law in 2022, were unfolding. But with the election of Trump and his first executive orders starting 20 January 2025, the wind changed. While many local Republican officials are defending the positive effects of the law on their local economies, essential institutions and programs are being severely damaged.¹⁸³⁵ Many observers, however, are maintaining that the economic strength of renewables will limit harm by the new federal policies, as many local and state governments continue to support the transition, many

¹⁸³¹ - Isabel Hoyos and Gernot Wagner, “How States Like Texas Are Driving the Clean Energy Boom in the Trump Era”, Columbia Business School, 24 March 2025, see <https://business.columbia.edu/insights/climate/texas-clean-energy-boom-trump-era>; and Hyae Ryung Kim, Marcelo Cibie et al., “Scaling Solar”, Columbia Business School, 10 July 2025, see <https://business.columbia.edu/sites/default/files-efs/imce-uploads/CKI/CKI%20Solar-250723.pdf>; both accessed 2 August 2025.

¹⁸³² - ERCOT, “Report on Existing and Potential Electric System Constraints and Needs”, Electric Reliability Council of Texas, December 2024, see <https://www.ercot.com/files/docs/2024/12/20/2024-report-on-existing-and-potential-electric-system-constraints-and-needs.pdf>, accessed 5 August 2025.

¹⁸³³ - J. David Goodman, Brad Plumer, and Ivan Penn, “Renewable Energy Is Booming in Texas. Republicans Want to Change That.”, *The New York Times*, 14 May 2025, see <https://www.nytimes.com/2025/05/14/us/politics/renewable-energy-republicans.html>, accessed 2 August 2025.

¹⁸³⁴ - Amory Lovins, personal communication, 16 August 2025.

¹⁸³⁵ - Simone Shah, “How Trump Is Trying to Undo the Inflation Reduction Act”, *TIME*, 28 February 2025, see <https://time.com/7262600/how-trump-is-trying-to-undo-the-inflation-reduction-act/>; and Olivia Guarna and Amy Turner, “100 Days of Trump 2.0: The Inflation Reduction Act”, *Climate Law Blog*, 29 April 2025, see <https://blogs.law.columbia.edu/climatechange/2025/04/29/100-days-of-trump-2-0-the-inflation-reduction-act/>; both accessed 3 August 2025; also *The Economist*, “Donald Trump’s War on Renewables”, 31 July 2025, see <https://www.economist.com/briefing/2025/07/31/donald-trumps-war-on-renewables>, accessed 31 July 2025.

corporations continue to buy increasing amounts of renewable power to get its low and stable prices, and markets tend to beat politics.¹⁸³⁶ See also [United States Focus](#) for details.

CONCLUSION: A PIVOTAL YEAR

From this year's analysis of the deployment of renewables and nuclear power, several key points emerge that corroborate the systemic considerations in the preceding chapter. These developments may later be considered to have been a turning point in the history of worldwide electricity and energy systems.

- ➔ Solar electricity generation is closing in on advancing wind energy and hardly-increasing nuclear power generation, and it continues to grow steeply while increasing its cost advantage. Photovoltaics has consolidated its role as the forthcoming central pillar of energy systems. In April 2025, for the first time, solar outpaced global nuclear power generation on a monthly basis, and it did so again in May and June 2025.
- ➔ The significant decline in battery storage costs has reached a tipping point. The deployment of stationary battery systems both at utility scale and behind the meter has started to soar in some geographies at unprecedented growth rates and is changing the economics of renewable power. Despite fluctuations in generation, solar and wind power are becoming available to deliver power around the clock at very competitive costs.
- ➔ Signs are amplifying of a revolution behind the meter, as seen by powerful examples in Pakistan and South Africa. Combining rooftop solar with batteries now allows for high degrees of self-sufficiency at increasingly competitive costs everywhere, and it is already winning cost comparisons in some regions. Building owners decide and invest on their own to improve energy supply security and drive down costs, including mobility. Avoiding or minimizing permitting and land-use issues, as well as excluding grid access problems—usually associated with utility-scale solar—considerably accelerates implementation.
- ➔ The global divide between rich and poor countries concerning renewable deployment may start to shrink. While actual differences in generation figures are still scandalous—especially considering the phenomenal potential for renewables in the south, solar above all—investment data show considerable improvement. Indeed, microgrids with PV and batteries offer attractive alternatives where public grids are weak. The global divide in PV equipment manufacturing, however, remains: China dominates global markets.
- ➔ Nuclear power, unlike renewables, is confronted with a declining market share. Capacity and production are stalling. Despite an intense campaign for the revival of nuclear energy, investments have increased only marginally in the global energy landscape. Governments favoring nuclear power are finding they can have only as much of it as they can force taxpayers to pay for, since capital markets generally perceive too much financial risk for too little return in a dauntingly competitive market already over 90 percent captured by renewables.

¹⁸³⁶ - Olivia Raimonde and Amanda Kolson Hurley, “Trump’s Tax Bill Would Dampen, But Not Quash, the Clean Energy Buildout”, *Bloomberg*, 5 June 2025, see <https://www.bloomberg.com/news/articles/2025-06-05/trump-s-tax-bill-would-dampen-but-not-quash-the-clean-energy-buildout>; and Ryan Kennedy, “Is Trump Just a Bump in the Road for US Solar?”, *pV magazine*, 22 March 2025, see <https://www.pv-magazine.com/2025/03/22/is-trump-just-a-bump-in-the-road-for-us-solar/>; also SEIA, “The Solar Surge in Trump Country, in 4 Charts”, Solar Energy Industries Association, 6 May 2025, see <https://seia.org/blog/solar-surge/>; and Laurence Ricky, “The Future of Solar Energy in 2025 and Beyond”, *Energy America*, 17 April 2025, see <https://ea-global.us/the-future-of-solar-energy-in-2025-and-beyond/>; all accessed 3 August 2025.

- ➔ Political priorities are shifting. While climate change contributes to an increasing sense of insecurity and anxiety about the future, its priority on the political agenda has declined. Security, including energy-supply security, and economic concerns have become more critical. In this political climate, important forces are seeking relief with “proven solutions” and teaming up with incumbent interests. Others emphasize that renewables provide the best energy supply security and are now the least-cost option. In this debate, the political and economic weight of the renewables sector, both in terms of capital and of employment, has continued to grow. The main obstacle to further acceleration is widespread misunderstanding and misrepresentation of renewable power’s reliability when properly integrated with demand- and supply-side resources to keep the grid in balance.

There are two countervailing trends. On the one hand, renewables have reached technical, economic, and systemic maturity. It’s no longer mainly the political will and the wish to mitigate climate change, but above all the sheer economic competitiveness of new technologies and systems that has started to vigorously transform the energy system. On the other hand, political forces tied to the old system and new geopolitical drivers are hindering the transformation. Policymakers must decide whether their goal is to enable the new energy system or protect the old one. Those choices have major consequences; some soon, some later.

While the political battle around energy policy is intensifying in several countries, economic forces are moving on. Under political pressure, especially from the U.S. government, companies have started “greenhushing”, as opposed to greenwashing. The magazine *The Economist* reports that “companies which are continuing to take action to decarbonise have grown more reluctant to parade their efforts.”¹⁸³⁷ It is becoming increasingly challenging to predict the impact of politics and policies on actual developments, and fortune-telling is not within WNISR’s mandate. Renewables have become much more independent from subsidies and support frameworks. On the other hand, against the backdrop of China’s dominance in renewable equipment markets and rising geopolitical tensions, trade and industry policies have become more influential.

Independent reporting on factual developments, therefore, is increasingly important for understanding what happens in the energy and electricity sectors. Available statistical reports are insufficient. This chapter illustrates that differentiating between installations in front of and behind the meter as well as monitoring in detail the developments in storage and grid systems is indispensable. More generally, for understanding change in the global energy system, it is not sufficient to look at the supply side—it never was. Consumption structures and the interconnecting infrastructure and technologies are essential parts of the picture and are transforming rapidly.

¹⁸³⁷ - *The Economist*, “The Remarkable Rise of ‘Greenhushing’”, 29 July 2025, see <https://www.economist.com/business/2025/07/29/the-remarkable-rise-of-greenhushing>, accessed 3 August 2025.

ANNEX 1 – OVERVIEW BY REGION AND COUNTRY

AFRICA

South Africa



South Africa hosts the only commercial nuclear power plant on the African continent, consisting of two 900-MW reactors located at Koeberg, near Cape Town. Both reactors started operating in the mid-1980s. In July 2024, the plant passed the end of its originally projected 40-year lifespan. Following extensive upgrading work, the operating license of Koeberg-1 has been renewed in July 2024 for an additional 20 years, while Koeberg-2 has been permitted to keep operating until November 2025, by when its owners, South Africa's national power utility Eskom, hope to gain a license extension to run also this unit for another 20 years.¹⁸³⁸

With the country having in recent years experienced a prolonged period of acute power shortages, the decision to keep the Koeberg plant operational for a further 20 years, while not uncontested,¹⁸³⁹ always seemed likely because insufficient new power generation capacity was under development to compensate for Koeberg's 1800 MW. With power shortfalls still looming and efforts to reduce carbon emissions in South Africa's coal-dominated electricity generation,¹⁸⁴⁰ nuclear newbuild—in addition to the projected growth in renewables—is being actively considered¹⁸⁴¹. While discussions regarding the optimal way forward continue, an updated roadmap defining the country's preferred future electricity provision modes is expected to be finalized soon.¹⁸⁴²

In 2023, South Africa had been experiencing persistent power cuts and record electricity shortfalls that at times exceeded 6 GW.¹⁸⁴³ 2024 saw an unexpected and remarkable

¹⁸³⁸ - Eskom, "Koeberg Operating Licence Extended for Further 20 Years", Press Release, 15 July 2024, see <https://www.eskom.co.za/koeberg-operating-licence-extended-for-further-20-years/>, accessed 10 August 2024.

¹⁸³⁹ - SAFCEI, "SAFCEI Lodges Appeal Against Koeberg's Lifetime Extension", Southern African Faith Communities' Environment Institute, 4 March 2025, see <https://safcei.org/safcei-lodges-appeal-against-koeberg%E2%80%99s-lifetime-extension/>, accessed 2 June 2025.

¹⁸⁴⁰ - EMBER, "South Africa", Updated 10 April 2025, see <https://ember-energy.org/countries-and-regions/south-africa>, accessed 2 June 2025.

¹⁸⁴¹ - Lyse Comins, "Ramokgopa: Nuclear Is Part of SA's Energy Mix", *The Mail & Guardian*, 12 September 2024, see <https://mg.co.za/the-green-guardian/2024-09-12-ramokgopa-nuclear-is-part-of-sas-energy-mix/>, accessed 2 June 2025.

¹⁸⁴² - Terence Creamer, "Concern Lingers Over Both Content of Updated IRP and Lack of Consultation", *Engineering News*, 8 May 2025, see <https://www.engineeringnews.co.za/article/concern-lingers-over-both-content-of-updated-irp-and-lack-of-consultation-2025-05-08>, accessed 2 June 2025.

¹⁸⁴³ - *BusinessTech*, "Stage 6 Load Shedding Extended as Units at Four Stations Go Down", 21 April 2023, see <https://businesstech.co.za/news/energy/682105/stage-6-load-shedding-extended-as-units-at-four-stations-go-down/>, accessed 20 August 2023.

turnaround, with rolling blackouts ending in March until the end of the year.¹⁸⁴⁴ Some of the factors responsible for the improved outlook were detailed in [WNISR2024](#). The good run continued into 2025, although rolling blackouts again had to be implemented over several short spells, typically of about three days, between 31 January and 25 April.¹⁸⁴⁵ One of these, from 7–10 March, was explicitly in part blamed on an unplanned outage of the single unit then operating at Koeberg.¹⁸⁴⁶

Developments Related to Koeberg's Lifetime Extension

Once again, only one of Koeberg's two units has been operational at a time for practically the entire reporting period. This was at first due to the need to complete the upgrading work at Unit 1 required to secure a 20-year lifetime extension beyond the plant's projected 2024 closure date. Once that exercise had been accomplished for the second unit in December 2024 after a year-long outage,¹⁸⁴⁷ this was soon followed by the renewed shutdown of Koeberg-1 for refueling, maintenance and tests to the containment structure expected to be completed by July 2025,¹⁸⁴⁸ a procedure that is later to be replicated with Koeberg-2, where the next refueling and maintenance outage has provisionally been scheduled for 8 September 2025 to 27 March 2026¹⁸⁴⁹. Hence, Koeberg is expected to continue operating at maximally 50 percent capacity for most of the remainder of 2025.

To approve the 20-year lifetime extension of Koeberg, the South African National Nuclear Regulator required a series of maintenance operations and instrumental replacements to be carried out. The most significant of these was the replacement of the two sets of three steam generators. These replacements and associated work were finally completed at the end of December 2024,¹⁸⁵⁰ more than two years after the originally projected end date.

An initial 7-month long attempt to replace the steam generators of Koeberg-2 in 2022 was ultimately aborted. Thereafter these replacements and related work were performed on

¹⁸⁴⁴ - Eskom, "Eskom Marks Its Longest Stretch of Uninterrupted Power Supply in Five Years, with Loadshedding Suspended for 240 Consecutive Days and Diesel Savings Amounting to R16.33 Billion Year-on-Year.", Press Release, 22 November 2024, see <https://www.eskom.co.za/eskom-marks-its-longest-stretch-of-uninterrupted-power-supply-in-five-years-with-loadshedding-suspended-for-240-consecutive-days-and-diesel-savings-amounting-to-r16-33-billion-year-on-year/>, accessed 10 June 2025.

¹⁸⁴⁵ - Eskom, "Eskom Suspends Loadshedding Following Recovery of Emergency Reserves – Summer Outlook Remains Unchanged.", Press Release, 2 February 2025, see <https://www.eskom.co.za/eskom-suspends-loadshedding-following-recovery-of-emergency-reserves-summer-outlook-remains-unchanged/>, accessed 2 June 2025; and Eskom, "State of the System - Winter 2024 Outlook Briefing", Media Briefing, 26 April 2024, see https://www.eskom.co.za/wp-content/uploads/2024/04/20240425_State_of_the_system_Draft_postDPE_26-April_FINAL6a.pptx, accessed 10 July 2024.

¹⁸⁴⁶ - Eskom, "Eskom Implements Stage 3 Loadshedding From 14:00 Today and Anticipates To Be in This Mode Until Monday at 05:00, Following 98% Availability of Power Supply, Due to Loss Of 2700MW Over the Past 14 Hours. To Replenish Emergency Reserves Over the Weekend – Ongoing High Levels of Planned Maintenance Continue.", Press Release, 7 March 2025, see <https://www.eskom.co.za/eskom-implements-stage-3-loadshedding-from-1400-today-and-anticipates-to-be-in-this-mode-until-monday-at-0500-following-98-availability-of-power-supply-due-to-loss-of-2700mw-over-the-past-14-hours/>, accessed 2 June 2025.

¹⁸⁴⁷ - Eskom, "Eskom Synchronises Koeberg Nuclear Power Station Unit 2 with National Grid Following Extensive Upgrades", Press Release, 31 December 2024, see <https://www.eskom.co.za/eskom-synchronises-koeberg-nuclear-power-station-unit-2-with-national-grid-following-extensive-upgrades/>, accessed 10 June 2025.

¹⁸⁴⁸ - Eskom, "Koeberg Unit 2 Successfully Restored to Service Following Unplanned Outage, Delivering 930MW of Reliable Baseload Power to South Africa", Press Release, 10 March 2025, see <https://www.eskom.co.za/koeberg-unit-2-successfully-restored-to-service-following-unplanned-outage-delivering-930mw-of-reliable-baseload-power-to-south-africa/>, accessed 1 June 2025.

¹⁸⁴⁹ - Eskom, "Koeberg Nuclear Power Station—Inspection & Test—User Requirement Specification", approved 22 April 2024.

¹⁸⁵⁰ - Eskom, "Eskom Synchronises Koeberg Nuclear Power Station Unit 2 with National Grid Following Extensive Upgrades", Press Release, 31 December 2024, see <https://www.eskom.co.za/eskom-synchronises-koeberg-nuclear-power-station-unit-2-with-national-grid-following-extensive-upgrades/>, accessed 10 June 2025.

Koeberg-1 from December 2022 to November 2023. Koeberg-2 was then again switched off on 11 December 2023 to undergo the same work (see [WNISR2023](#) and [2024](#) for more details). The date for the return to service of Koeberg-2, which had in April 2024 been projected to be in September of that year,¹⁸⁵¹ was again not met. The unit was finally reconnected to the grid on 30 December 2024 with full output achieved ten days thereafter.¹⁸⁵² For approximately one month in early 2025, both Koeberg units operated together, the first time since 2022 that full capacity could be maintained for such a period.¹⁸⁵³

The final costs of the upgrades and related activities linked to the Koeberg lifetime extension certification have not been made public to date. These had in 2010 been estimated at ZAR20 billion (US\$₂₀₁₀ 2.7 billion),¹⁸⁵⁴ and in 2024 a senior source at Koeberg quoted a figure of ZAR25 billion,¹⁸⁵⁵ but several observers believe these are likely to be significantly higher,¹⁸⁵⁶ especially considering that the South African Rand-US Dollar exchange rate changed from about ZAR7.5 to US\$ in 2010 to about ZAR18 to US\$ in 2025.¹⁸⁵⁷

In July 2024, the operating license for Koeberg-1 was renewed for 20 years to 21 July 2044.¹⁸⁵⁸ The National Nuclear Regulator also granted a short-term extension to the existing operating license of Koeberg-2 to 9 November 2025, arguing that it only came into commercial operation in November 1985, more than a year after Koeberg-1 had reached that milestone.¹⁸⁵⁹

Other developments related to the Koeberg lifetime extension include an outage of the only recently refurbished Koeberg-1 unit starting on 11 September 2024 that led to ten days at zero power output.¹⁸⁶⁰ The initiating event was only made public five days after it happened, and was ascribed to a failure of one of the isolation/block valves.¹⁸⁶¹ The incident ironically occurred just five days after an operational safety assessment by the IAEA expressed satisfaction that apparently most of the recommended measures to deal with previously identified safety issues

¹⁸⁵¹ - Eskom, “State of the System - Winter 2024 Outlook Briefing”, Media Briefing, 26 April 2024, see https://www.eskom.co.za/wp-content/uploads/2024/04/20240425_State_of_the_system_Draft_postDPE_26-April_FINAL6a.pptx, accessed 10 July 2024.

¹⁸⁵² - Eskom, “Eskom Synchronises Koeberg Nuclear Power Station Unit 2 with National Grid Following Extensive Upgrades”, Press Release, 31 December 2024, op. cit.

¹⁸⁵³ - Eskom, “Eskom Data Portal”, Undated, see <https://www.eskom.co.za/dataportal/>, last accessed 10 June 2025.

¹⁸⁵⁴ - Chris Yelland, “R2obn Life Extension of Koeberg Power Station Poses Significant Risks for South Africa”, *Daily Maverick*, 28 November 2021, see <https://www.dailymaverick.co.za/article/2021-11-28-r2obn-life-extension-of-koeberg-power-station-poses-significant-risks-for-south-africa/>, accessed 20 July 2023.

¹⁸⁵⁵ - Kristin Engel, “Koeberg: The Factors Marring Life Extension Plans”, *Daily Maverick*, 10 September 2024, see <https://www.dailymaverick.co.za/article/2024-09-10-koeberg-the-factors-marring-life-extension-plans/>, accessed 2 June 2025.

¹⁸⁵⁶ - Terence Creamer, “R2obn Koeberg Life-Extension Cost Estimate of 2010 Now ‘Significantly Different’”, *Engineering News*, 27 September 2022, see <https://www.engineeringnews.co.za/article/r2obn-koeberg-life-extension-cost-estimate-of-2010-now-significantly-different-2022-09-27>, accessed 31 August 2023.

¹⁸⁵⁷ - South African Reserve Bank, “Selected Historical Rates—Rand per US Dollar”, 14 July 2025, see <https://www.resbank.co.za/en/home/what-we-do/statistics/key-statistics/selected-historical-rates>, accessed 14 July 2025.

¹⁸⁵⁸ - Eskom, “Koeberg Operating Licence Extended for Further 20 Years”, Press Release, 15 July 2024, op. cit.

¹⁸⁵⁹ - NNR, “National Nuclear Regulator (NNR) Approves the Request from Eskom to Separate the Operational Timelines for Koeberg Unit 1 and Unit 2”, Press Release 1/5/6/2, National Nuclear Regulator, 26 January 2024, see https://nnr.co.za/wp-content/uploads/2024/01/NNR-Media-Release-Regulatory-approval-granted-to-separate-Koeberg-Unit1-and-Unit2_260124.pdf, accessed 22 April 2024.

¹⁸⁶⁰ - Eskom, “Eskom Data Portal”, Undated, op. cit.

¹⁸⁶¹ - Kristin Engel, “Koeberg Offline After Unexpected Shutdown and Planned Maintenance”, *Daily Maverick*, 16 September 2024, see <https://www.dailymaverick.co.za/article/2024-09-16-both-koeberg-units-offline-after-unexpected-shutdown-and-planned-maintenance/>, accessed 2 June 2025.

had been attended to.¹⁸⁶² Outstanding items of concern include the need to test the effectiveness of the containment structures, as this is one of the procedures planned during the current refueling and maintenance outage.¹⁸⁶³ Early in 2025, the Southern African Faith Communities' Environment Institute (SAFCEI) launched a, as of mid-2025, still ongoing legal appeal against the decision to grant Koeberg-1 the 20-year life extension, arguing that it should not have been issued until all safety issues previously identified had been adequately addressed.¹⁸⁶⁴

In 2023, Koeberg's power generation had dropped to 8.13 TWh, almost 20 percent down from the previous year. In 2024, the annual output dropped further to 7.8 TWh, with a corresponding share of only 3.8 percent in the national electricity mix.¹⁸⁶⁵ On 2 March 2025, the refurbished Koeberg-2 was forced to shut down for a week due to a "steam leak on the reheat system".¹⁸⁶⁶ While the exact cause of the problem was not explained further, a mention was made of the discovery of two unspecified "defects" that necessitated a further delay in the restoration of operation.¹⁸⁶⁷ This unplanned outage was also one of the contributors to the national electricity shortfall that precipitated one of the spells of rolling blackouts in 2025.¹⁸⁶⁸

Developments Related to Potential Newbuild

In December 2023, it was announced that a Request for Proposals (RFP) for nuclear newbuild projects would be issued by March 2024.¹⁸⁶⁹ The intention to initiate work on adding 2.5 GW of new nuclear capacity was gazetted in January 2024.¹⁸⁷⁰ SAFCEI and Earthlife Africa, two organizations that had in 2017 led a successful legal challenge to stop the then envisaged 9.6-GW Russian-led nuclear newbuild,¹⁸⁷¹ again aimed to obtain a court order to halt the RFP on the basis that it had been issued without the stipulated level of consultation. Instead of waiting

¹⁸⁶² - Energize, "Nuclear Agency Completes Long-Term Safety Review of Koeberg", 10 September 2024, see <https://www.energize.co.za/article/nuclear-agency-completes-long-term-safety-review-of-koeberg>, accessed 2 June 2025.

¹⁸⁶³ - IAEA, "IAEA Concludes Long Term Operation Safety Review at South Africa's Koeberg Nuclear Power Plant", Press Release 83/2024, International Atomic Energy Agency, 6 September 2024, see <https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operation-safety-review-at-south-africas-koeberg-nuclear-power-plant>, accessed 20 February 2025.

¹⁸⁶⁴ - SAFCEI, "SAFCEI Lodges Appeal Against Koeberg's Lifetime Extension", 4 March 2025, op. cit.

¹⁸⁶⁵ - Eskom, "Eskom Data Portal", personal communication, data transmitted on 2 July 2025.

¹⁸⁶⁶ - Note: After the steam has gone through the high-pressure turbine, it is piped through moisture separator/reheaters before entering the low-pressure turbines. Eskom, "Koeberg Unit 2 Successfully Restored to Service Following Unplanned Outage, Delivering 930MW of Reliable Baseload Power to South Africa", Press Release, 10 March 2025, op. cit.

¹⁸⁶⁷ - Terence Creamer, "Exasperated Ramokgopa Warns of 'Casualties' After Latest Loadshedding Bout", *Engineering News*, 8 March 2025, see <https://www.engineeringnews.co.za/article/exasperated-ramokgopa-warns-of-casualties-after-latest-loadshedding-bout-2025-03-08>, accessed 14 July 2025.

¹⁸⁶⁸ - TimesLIVE, "Load-Shedding Lifted for Now but Concerns Over Out-Of-Action Koeberg", 9 March 2025, see <https://www.timeslive.co.za/news/south-africa/2025-03-09-load-shedding-lifted-for-now-but-concerns-over-out-of-action-koeberg/>, accessed 1 June 2025.

¹⁸⁶⁹ - Terence Creamer, "South Africa to Release 2 500 MW Nuclear RFP By March, Despite Electricity Plan Review", *Engineering News*, see <https://www.engineeringnews.co.za/article/south-africa-to-release-2-500-mw-nuclear-rfp-by-march-despite-electricity-plan-review-2023-12-12>, accessed 28 June 2024.

¹⁸⁷⁰ - *BusinessTech*, "South Africa Launches Plan to Get 2,500MW of New Nuclear Energy", 29 January 2024, see <https://businesstech.co.za/news/energy/746051/south-africa-launches-plan-to-get-2500mw-of-new-nuclear-energy-2/>, accessed 28 June 2024; and Minister of Electricity, "Government Notice—Determination Under Section 34(1) Of The Electricity Regulation Act, 2006 (Act No.4 Of 2006)", *Staatskoerant*, No. 50037, published 26 January 2024, see https://www.gov.za/sites/default/files/gcis_document/202401/50037gon4274.pdf, accessed 11 July 2024.

¹⁸⁷¹ - News24, "'Justice Is Served', Say Applicants in Nuclear Court Bid", *Business*, 26 April 2017, see <https://www.news24.com/fin24/justice-is-served-say-applicants-in-nuclear-court-bid-20170426>, accessed 30 August 2023.

for this legal process to unfold, the Minister decided in August 2024 to withdraw the RFP and to initiate a more thorough consultative process.¹⁸⁷²

In early January 2024, the Ministry of Mineral Resources and Energy had published a draft of a new Integrated Resource Plan for Electricity (IRP).¹⁸⁷³ The IRP is effectively a roadmap that guides South African government interventions to develop electricity generating infrastructure, and is intended to be updated every couple of years. The document published in January 2024 was effectively withdrawn for redrafting after it received unusually severe and widespread criticism for a range of demonstrated flaws.¹⁸⁷⁴

In December 2024 a revised draft IRP was distributed to selected stakeholders for consideration. This version includes a schedule presented as the “Proposed Balanced Plan” in which two new nuclear generating units of 1250 MW each would come on line in 2036 and 2037 respectively, with two further 1350-MW units becoming operational in 2038 and 2039 respectively.¹⁸⁷⁵ This is presumably the scenario that was preferred by the developers of that iteration of the IRP, though whether subsequent discussions endorsed this scenario has not been made public.

Various analysts are still very critical of the revised draft IRP, e.g., stating that “Technologies such as gas and nuclear were effectively forced into the scenarios despite the model not selecting them as optimal solutions.”¹⁸⁷⁶ In May 2025, the IRP was reported to be still under discussion at the National Economic Development and Labour Council (Nedlac), described by the Minister as the final step before he would table the IRP at the Cabinet.¹⁸⁷⁷

Given past pronouncements by the Minister of Electricity,¹⁸⁷⁸ it is likely that additional nuclear power generation will be included in the revised IRP. Once released, the new IRP will also indicate if the projected new nuclear would be in the form of traditional large-scale plants or SMRs, with interest groups representing both these options actively lobbying. However an inclusion in the IRP should merely be seen as a statement of intent, and many proposed developments listed in past IRPs have failed to materialize due to financial, technological, and/or other reasons. The South African Nuclear Energy Corporation (NECSA) reportedly provided the South African Electricity Minister with a ZAR60 billion (US\$3.3 billion) cost estimate for a

¹⁸⁷² - Terence Creamer, “Ramokgopa Withdraws 2.5 GW Nuclear-Procurement Determination Citing Lack of Public Consultation”, *Engineering News*, 16 August 2024, see <https://www.engineeringnews.co.za/article/ramokgopa-withdraws-25-gw-nuclear-procurement-determination-citing-lack-of-public-consultation-2024-08-16>, accessed 1 June 2025.

¹⁸⁷³ - Department of Mineral Resources and Energy, “IRP 2023—Integrated Resource Plan 2023”, 2024, see <https://www.dmre.gov.za/mining-minerals-energy-policy-development/integrated-resource-plan/irp-2023>, accessed 2 June 2025.

¹⁸⁷⁴ - OUTA, “IRP 2023: Tear This Up, Start Again and Do It Properly”, Organisation Undoing Tax Abuse, 19 March 2024, see <http://www.oua.co.za/blog/newsroom-1/post/irp-2023-tear-this-up-start-again-and-do-it-properly-1328>, accessed 28 June 2024.

¹⁸⁷⁵ - Department for Mineral Resources and Energy, “Integrated Resource Plan 2024”, Government of South Africa, December 2024, see <https://ru.scribd.com/document/858938701/Integrated-Resource-Plan-2024>, accessed 15 July 2025.

¹⁸⁷⁶ - Max Marx, “IRP 2025 Contradicts Own Model and Forces Nuclear and Gas, Expert Says”, *Energize*, 8 May 2025, see <https://www.energize.co.za/article/irp-2025-contradicts-own-model-and-forces-nuclear-and-gas-expert-says-o>, accessed 15 July 2025.

¹⁸⁷⁷ - Terence Creamer, “Ramokgopa Reaffirms Nedlac Deliberations on IRP To Be ‘Last Step’ Before Cabinet Approval”, *Engineering News*, 14 May 2025, see <https://www.engineeringnews.co.za/article/ramokgopa-reaffirms-nedlac-deliberations-on-irp-to-be-last-step-before-cabinet-approval-2025-05-14>, accessed 31 May 2025.

¹⁸⁷⁸ - Lyse Comins, “Ramokgopa: Nuclear is part of SA’s energy mix”, *The Mail & Guardian*, 12 September 2024, op. cit.; and Parliament of South Africa, “Announcements, Tablings and Committee Reports”, 31 October 2024, see <https://www.parliament.gov.za/storage/app/media/Docs/atc/co1576c2-d849-41cf-971e-87f5641a3893.pdf>, accessed 10 June 2025.

nuclear newbuild, an amount that would according to the Minister, if actually realizable, not be financeable through the national fiscus.¹⁸⁷⁹

Past efforts to initiate nuclear newbuild had been seen to favor Russia's Rosatom.¹⁸⁸⁰ While Rosatom retains a presence in South Africa, there are now signs of increasingly significant other partnerships linked to energy projects. China in particular has become more directly involved in solar plant construction,¹⁸⁸¹ and this increased activity now also encompasses nuclear projects¹⁸⁸². An offer from Iran to assist in potential nuclear builds was widely reported,¹⁸⁸³ but any such activity would not be substantial given that Iran has no full-scale nuclear plant provider capacity.

In the area of waste management, the National Radioactive Waste Disposal Institute (NRWDI) has indicated that it intends to take over the management of the Vaalputs radioactive waste disposal site from the current operator, NECSA.¹⁸⁸⁴ As the national statutory body for radioactive waste management, the NRWDI is authorized to take this step, which it views as an income generating opportunity.

The development of small modular reactors has again been frequently talked about in South Africa. Most significantly, Electricity Minister Ramokgopa indicated that he favored restarting the Pebble Bed Modular Reactor (PBMR) program that had been actively driven in South Africa in the years up to 2009, when it was abandoned due to rising costs and lack of progress (see *South Africa Focus* in *WNISR2023*).¹⁸⁸⁵

While the period July 2024–June 2025 saw much improved electricity supply and greatly reduced power cuts in South Africa, this was largely the result of increased generation from the country's existing coal plants. In 2024, 86.2 percent of Eskom's electricity was produced from coal (84.0 percent in 2023), an unchanged 3.2 percent was contributed by solar, while the wind and nuclear fractions slightly dropped from respectively 5.9 percent and 4.1 percent in 2023 to 5.4 percent and 3.9 percent in 2024.¹⁸⁸⁶

These figures exclude electricity generated through “behind the meter” solar rooftop installations, which has not been properly quantified, but appears to have increased

¹⁸⁷⁹ - Khulekani Magubane, “South Africa to Spend R60bn on Nuclear Build Programme; SA Likely to Entertain Bids from US, China, Russia, France and South Korea”, *TimesLIVE*, 4 May 2025.

¹⁸⁸⁰ - Marianne Thamm, “How South Africans Thwarted Secret Putin/Zuma Nuclear Deal”, *Daily Maverick*, 19 December 2019, see <https://www.dailymaverick.co.za/article/2019-12-19-how-south-africans-thwarted-secret-putin-zuma-nuclear-deal/>, accessed 30 August 2023.

¹⁸⁸¹ - Njenga Hakeenah, “South Africa's Largest Private Solar Project to Power Chinese Chrome Smelting Factory”, *The China-Global South Project*, 18 February 2025, see <https://chinaglobalsouth.com/2025/02/18/south-africas-largest-private-solar-project-to-power-chinese-chrome-smelting-factory/>, accessed 2 June 2025.

¹⁸⁸² - African Energy Week, “Atomic Alliances: China's Strategic Push into Africa's Nuclear Energy Sector”, *African Energy Chamber*, 18 April 2025, see <https://aecweek.com/atomic-alliances-chinas-strategic-push-into-africas-nuclear-energy-sector/>, accessed 2 June 2025.

¹⁸⁸³ - Wendell Roelf, “South Africa Open to Nuclear Project Bids from Russia or Iran, Minister Says”, *Reuters*, 17 February 2025, see <https://www.reuters.com/world/africa/south-africa-open-nuclear-project-bids-russia-or-iran-minister-says-2025-02-17/>, accessed 2 June 2025.

¹⁸⁸⁴ - Terence Creamer, “NRWDI Outlines Plan for New Facility to Store Koeberg Spent Fuel Offsite from 2030”, *Engineering News*, 19 June 2025, see <https://www.engineeringnews.co.za/article/nrwdi-outlines-plan-for-new-facility-to-store-koeberg-spent-fuel-offsite-from-2030-2025-06-19>, accessed 2 July 2025.

¹⁸⁸⁵ - Rebecca Campbell, “South Africa Will Reactivate the PBMR Small Modular Reactor Project”, *Engineering News*, see <https://www.engineeringnews.co.za/article/south-africa-will-reactivate-the-pbmr-small-modular-reactor-project-2025-05-20>, accessed 15 July 2025.

¹⁸⁸⁶ - Eskom, “Eskom Data Portal”, see <https://www.eskom.co.za/dataportal/>, accessed 2 July 2025.

substantially at the height of the South African power crisis, highlighted by the fact that Eskom's electricity distribution has decreased from 222 TWh in 2019 to 206 TWh in 2024.¹⁸⁸⁷

One way to estimate trends in South African solar energy installations is to quantify solar panel imports. Given the dominance of Chinese-built solar appliances in South Africa, that figure may be determined from Chinese PV export data.¹⁸⁸⁸ Such data shows a major acceleration of Chinese-built solar panels entering South Africa from equivalents of 1.3 GW in 2022 to 4.3 GW in 2023, which then only slightly dropped to 3.8 GW in 2024 (Eskom's power supplies improved in parallel).¹⁸⁸⁹ While the actual added solar capacity is subject to significant uncertainty, with for example 2023 the addition estimated to be a substantially lower 3.3 GW¹⁸⁹⁰ elsewhere, the growing migration to alternatives to Eskom electricity is evidently now lowering Eskom's future electricity sale projections and thereby weakening the case for further nuclear builds.

THE AMERICAS

Argentina



In 2024, Argentina's three nuclear reactors,

- ➔ Atucha-1, start of operation 1974, net capacity 340 MWe,
- ➔ Atucha-2, start of operation 2016, net capacity 693 MWe, and
- ➔ Embalse, start of operation 1984, net capacity 608 MWe

produced 10.5 TWh of electricity (10 TWh net), a 6.9 percent share of overall electricity generation and an increase from 9 TWh in 2023.¹⁸⁹¹ At its highest in 1990–1991, nuclear power's share was about 14.4 percent (even 19.8 percent according to PRIS data) with just 56 percent of the current nuclear capacity available, which indicates substantial growth of non-nuclear electricity generation in Argentina (see previous versions of WNISR). Atucha-1 was built by Siemens-KWU, while the construction of Atucha-2 was initiated by Siemens-KWU, then abandoned, and later completed by the operator Nucleoeléctrica Argentina S.A. (NA-SA) with the help of external contractors. Apart from a demonstration plant in Germany, the design of both Atucha reactors, a pressurized heavy water design with natural uranium fuel, heavy water cooled and moderated, was built only in Argentina. The CANDU (Canadian Deuterium Uranium) reactor at Embalse was built by Atomic Energy of Canada Limited (AECL).

¹⁸⁸⁷ - Ibidem.

¹⁸⁸⁸ - EMBER, "China's Solar PV Exports", 2025, see <https://ember-energy.org/data/china-solar-exports-data>, accessed 27 July 2025.

¹⁸⁸⁹ - EMBER, "Global Electricity Review 2025", April 2025, see <https://ember-energy.org/latest-insights/global-electricity-review-2025>, accessed 27 July 2025.

¹⁸⁹⁰ - Tasneem Bulbulia, "South Africa's Solar PV Market Expected to Become One of the World's Largest this Year", *Engineering News*, 5 March 2024, see <https://www.engineeringnews.co.za/article/south-africas-solar-pv-market-expected-to-become-one-of-the-worlds-largest-this-year-2024-03-05>, accessed 27 July 2025.

¹⁸⁹¹ - Energy Institute, "Statistical Review of World Energy 2025—Consolidated Dataset", June 2025, see https://www.energyinst.org/_data/assets/excel_doc/0008/1656215/EI-Stats-Review-ALL-data.xlsx, accessed 27 June 2025.

Atucha-1

Atucha-1 was designed for the equivalent of 32 years of full-power operation, which was reached in 2018. Nucleoeléctrica aims for a lifetime extension of 20 years. Following a framework agreement with the regulator, the prolonged operation of the unit was divided into two phases, each conditioned by specific regulatory requirements. Stage A of the lifetime extension began in 2018. Since the unit had already reached the end of its original lifetime, continued operation required amendments to its operating license, allowing it to operate until September 2024. Stage B shall begin once the reactor resumes operation after undergoing extensive refurbishment, modernization, and inspection work. That second phase of long-term operation is expected to last from early 2027 to 2046; the refurbishment outage began in September 2024 and is scheduled to last about 30 months.¹⁸⁹²

While the reactor core design of both Atucha units features lower neutron fluxes in the reactor pressure vessel walls, making them less susceptible to neutron embrittlement than other pressurized water reactors, the new design lifetime will be close to 70 years, even if the license is still conditional on passing the Periodic Safety Reviews (PSR) every ten years. Retrofitting will certainly help, but reaching current state of the art safety standards will be very difficult if not impossible.

Atucha-2

Atucha-2 was ordered from Siemens-KWU in 1979 as a larger version of Atucha-1. As a consequence of the 1982 Falklands War, the construction was delayed because Siemens-KWU lost access to licensed technology for Argentina and was forced to develop substitute technology. Construction came to a complete halt in the 1990s following a major economic crisis in Argentina. By the time Argentina was ready to restart construction works, Siemens-KWU ceased to exist as a company and Framatome, the successor, had no intention of finishing the construction. Nucleoeléctrica decided to complete the construction on its own. Finally, grid connection occurred on 27 June 2014, but it took until 26 May 2016 to reach commercial operation.¹⁸⁹³

According to IAEA-PRIS, the load factors of both Atucha units remained mediocre in 2024 at 68.8 percent and 67.6 percent, respectively. For information on the operational history of the Atucha plant so far, refer to [previous editions of WNISR](#).

Embalse

Embalse, which started operating in 1983, was shut down at the end of 2015 for major overhaul, including replacing hundreds of pressure tubes, to enable it to operate for up to 30 more years,

¹⁸⁹² - ARN, “Central Nuclear Atucha I - Operación a Largo Plazo”, Autoridad Regulatoria Nuclear/Nuclear Regulatory Authority, Updated 7 June 2024, see <https://www.argentina.gob.ar/arn/uso-de-la-tecnologia-nuclear-segura-en-argentina/central-nuclear-atucha-i-operacion-largo-plazo>, accessed 8 June 2024; and ARN, “Resolución 463/2024”, *Boletín Oficial República Argentina*, 27 September 2024, see <https://www.boletinoficial.gob.ar/detalleAviso/primera/314891/20241001>, accessed 24 October 2024; also Marcelo Liendo, “Preparation of LTO of Atucha I NPP”, Technical Advisor, Atucha Unit I NPP, presented at “Nuclear Innovation Conference”, 5–6 June 2024, see <https://nic2024.eu/wp-content/uploads/2024/06/Marcelo-Liendo-%E2%80%93-Atucha-Unit-I-NPP.pdf>; and NA-SA, “Nucleoeléctrica aseguró los fondos para la extensión de vida de Atucha I”, 26 September 2025, see <https://www.na-sa.com.ar/es/prensa/nucleoelectrica-aseguro-los-fondos-para-la-extension-de-vida-de-atucha-i-393>; both accessed 28 July 2025.

¹⁸⁹³ - ARN, “La ARN otorgó la Licencia de Operación de la Central Nuclear Atucha II”, Press Release, 26 May 2016, see <https://www.argentina.gob.ar/noticias/la-arn-otorgo-la-licencia-de-operacion-de-la-central-nuclear-atucha-ii>, accessed 31 August 2025.

to 2049. Like Atucha-1, to continue operation, in addition to extensive work linked to the lifetime extension program, Embalse must perform a major PSR every ten years. It eventually returned to service in May 2019, with the refurbishment project estimated to have cost US\$2.15 billion.¹⁸⁹⁴ In August 2019, the regulator (ARN) renewed the operating license for ten years to 2029, when the next PSR is due.¹⁸⁹⁵

Other nuclear activities: CAREM25, ACR-300, and Atucha-3

While 2024 was a rather smooth year for Argentina's operating power reactors, major decisions were taken about the country's long-term projects, CAREM25 and Atucha-3.

Already in 1980, the development of an Argentinean PWR, CAREM (Central Argentina de Elementos Modulares), with only 25 MWe began.¹⁸⁹⁶ The work was first performed jointly by engineering and manufacturing company INVAP (Investigación Aplicada) and the National Atomic Energy Commission (Comisión Nacional de Energía Atómica or CNEA) but was then taken over by CNEA alone. The construction of a demonstration plant began near the Atucha site in February 2014, with startup planned for 2018. In 2005, CNEA had estimated construction cost at US\$105 million,¹⁸⁹⁷ but by construction start in 2014, estimates had risen to ARS3.5 billion (US\$₂₀₁₄ 433 million).¹⁸⁹⁸ In 2021, estimated cost had further increased to US\$750 million,¹⁸⁹⁹ and by 2024, over US\$600 million had reportedly been spent with a further US\$260–300 million needed for completion.¹⁹⁰⁰ By then, commissioning was expected in 2028, a decade later than envisaged at construction start.¹⁹⁰¹ Following a change in government after the election of Javier Milei as president of Argentina in 2023, the chairperson of CNEA was replaced. The new CNEA president, Germán Guido Lavalle, declared the end of the CAREM project in late 2024. CAREM would not fit into the “commercially viable” category, as he reportedly said in an internal statement “let's be intellectually honest, we are not going to sell 50 CAREMs, we know that...this reactor is not economically competitive. You only have to

¹⁸⁹⁴ - WNA, “Nuclear Power in Argentina”, World Nuclear Association, May 2024, see <https://world-nuclear.org/information-library/country-profiles/countries-a-f/argentina>, accessed 20 August 2024; and Ministry of Economy, “La Central Nuclear Embalse vuelve a proveer energía a la red”, Government of Argentina, 30 May 2019, see <https://www.argentina.gob.ar/noticias/la-central-nuclear-embalse-vuelve-proveer-energia-la-red>, accessed 3 June 2019.

¹⁸⁹⁵ - ARN, “La ARN otorgó la Licencia de Operación para el segundo ciclo de la Central Nuclear Embalse”, 12 September 2019, see <https://www.argentina.gob.ar/noticias/la-arn-otorgo-la-licencia-de-operacion-para-el-segundo-ciclo-de-la-central-nuclear-embalse>, accessed 29 July 2025.

¹⁸⁹⁶ - IAEA, “Technology Roadmap for Small Modular Reactor Deployment”, No. NR-T-1.18, IAEA Nuclear Energy Series, International Atomic Energy Agency, 2021, see https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1944_web.pdf, accessed 20 August 2024.

¹⁸⁹⁷ - Ibidem.

¹⁸⁹⁸ - WNN, “Construction of CAREM Underway”, 10 February 2014, see <http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html>, accessed 20 August 2024.

¹⁸⁹⁹ - GI-Hub, “CAREM 25 (prototype)”, Public-Private Infrastructure Advisory Facility, World Bank, 25 January 2021, see <https://www.gihub.org/quality-infrastructure-database/case-studies/carem-25-prototype/>, accessed 20 August 2024.

¹⁹⁰⁰ - NEI Magazine, “New President of CNEA Reveals Plans for Nuclear Development in Argentina”, 4 June 2024, see <https://www.neimagazine.com/news/new-president-of-cnea-reveals-plans-for-nuclear-development-in-argentina/>, accessed 27 June 2024; and Maria de Los Angeles Orfila, “Spending Cuts Imperil Argentina's Ambitious Nuclear Research Programs”, *Science.org*, 15 May 2024, see <https://www.science.org/content/article/spending-cuts-imperil-argentina-s-ambitious-nuclear-research-programs>, accessed 20 August 2024.

¹⁹⁰¹ - Candelaria Grimberg and Horacio Soria, “Argentina Budget Cuts Hitting Nuclear Energy Ambitions, Atomic Body Says”, *Reuters*, 2 May 2024, see <https://www.reuters.com/business/energy/argentina-budget-cuts-hitting-nuclear-energy-ambitions-atomic-body-says-2024-05-02/>, accessed 3 May 2024.

stand in front of the construction site to realize that this is not a small modular reactor.”¹⁹⁰² As reported in WNISR2024, this would have been the most expensive nuclear power plant per MW ever built, and construction had been halted due to budget cuts imposed under Milei which prompted a “critical design review”.

However, another project might take over as the Argentinean SMR flagship project. In 2024, INVAP received a patent from the U.S. Patent Office for the ACR-300 design.¹⁹⁰³ The patent covers a small, compact pressurized water reactor with steam generators and pressurizer directly attached to the reactor pressure vessel, with three or four loops. According to some sources, an unspecified U.S. investor had been found to finance the design’s refinement to a 300 MWe three loop reactor, and funding for a design company with roughly 50 scientific employees was allocated.¹⁹⁰⁴

While the current government of Argentina will not pursue efforts of recent years for a Chinese-built Hualong reactor at Atucha-3 for geopolitical reasons¹⁹⁰⁵ (for the history of the Atucha-3 project refer to [previous editions of the WNISR](#)), the ACR-300 might take this position in planning, including up to four units at Atucha.

In late 2024, President Milei, flanked by IAEA Director General Rafael Grossi, announced the creation of a national Nuclear Plan and an Argentina Nuclear Council in charge of developing it.¹⁹⁰⁶ The head of the newly formed council, Demian Reidel, reportedly stated:

The first step in this plan is the construction of an SMR at the Atucha site. Although the technology is new, thanks to the advanced state of engineering, technical support from the IAEA, and the firm political commitment of President Milei, there is a high probability that Argentina will be the first nation to produce and commercialize this innovative nuclear reactor model. This milestone will not only ensure our energy sovereignty, but also allow us to replicate this success throughout the country and export this technology to the world.¹⁹⁰⁷

In May 2025, Reidel explained the first phase to be that of operating four SMRs with a total capacity of 1.2 GW within five years.¹⁹⁰⁸

Power Mix and Energy Policies

According to the Energy Institute, in 2024, Argentina’s electricity generation was dominated by natural gas (54 percent), followed by hydro (19.5 percent), non-hydro renewables (15 percent),

¹⁹⁰² - Nicolás Deza, “La CNEA descarta el proyecto CAREM y explora otros diseños de reactores modulares pequeños”, *Econo Journal*, 30 December 2024, see <https://econojournal.com.ar/2024/12/la-cnea-descarta-el-proyecto-carem/>, accessed 29 July 2025.

¹⁹⁰³ - Pablo Florido, Rodolfo Carlevaris and Alberto Patrignani, “United States Patent—Compact Reactor with Horizontal Steam Generators and Pressurizer”, INVAP S.E., Patent No. 12,057,240 B2, 6 August 2024.

¹⁹⁰⁴ - Informed insider, personal communication, 16 July 2025.

¹⁹⁰⁵ - Informed insider, personal communications, 2025.

¹⁹⁰⁶ - Office of the President of Argentina, “El presidente Javier Milei al anunciar el Plan Nuclear Argentino: ‘La energía nuclear tendrá su retorno triunfal’”, Press Release, 20 December 2024, see <https://www.argentina.gob.ar/noticias/el-presidente-javier-milei-al-anunciar-el-plan-nuclear-argentino-la-energia-nuclear-tendra>, accessed 29 July 2025.

¹⁹⁰⁷ - Nicolás Deza, “El gobierno creará un consejo nuclear para desarrollar reactores modulares de tecnología nacional y la minería de uranio”, *Econo Journal*, 20 December 2024, see <https://econojournal.com.ar/2024/12/el-gobierno-creara-un-consejo-nuclear-para-desarrollar-reactores-modulares-de-tecnologia-nacional-y-la-mineria-de-uranio/>, accessed 29 July 2025.

¹⁹⁰⁸ - Victoria Mendizábal, “Demián Reidel: ‘Nuestro país se ganó la lotería geológica’”, interview with Demián Reidel, National Nuclear Council, Government of Argentina, *La Nación*, 23 May 2025, see <https://www.lanacion.com.ar/economia/IA/demian-reidel-nuestro-pais-se-gano-la-loteria-geologica-nid23052025/>, accessed 29 July 2025.

nuclear (7 percent), oil (4 percent), and other sources including coal for the remaining share.¹⁹⁰⁹ There were only small changes in the electricity mix from 2023 to 2024.

Regarding new nuclear projects, Argentina demonstrated that due to long planning and construction times of nuclear power plants the risk of sunken investment in case of political change is considerable. While previous Argentinean governments were committed to the CAREM project, the current government, which is still pro-nuclear but with an emphasis on economics, abandoned 40 years of investments, only to foster a completely new design, which might need another two decades to arrive at a demonstration plant. Only time will tell if the political environment offers 20 years of stable support.

Brazil



Brazil's two commercial nuclear reactors—Angra-1 and -2—are operated by state-controlled company Eletronuclear at the Central Nuclear Almirante Alvaro Alberto (CNAAA) site and in 2024 provided 15 TWh (net), an increase of 8.8 percent over the previous year, or 2.1 percent (a negligible increase of less than 0.1 percentage points) of national electricity. Construction of the third reactor, that resumed at the end of 2022, was halted again in 2023, and is considered “suspended” in WNISR’s data.

The first contract for Angra-1 was awarded to Westinghouse in 1970. The 609-MW PWR went critical in 1981 and received a license for a 20-year lifetime extension in November 2024, allowing for operations until December 2044.¹⁹¹⁰ Eletronuclear estimates that total investment for lifetime extension works amounts to BRL3.2 billion (US\$497 million), of which BRL2.5 billion (US\$389 million) are to be spent between 2025 and 2029.¹⁹¹¹

Angra-2 is a German-designed PWR with a capacity of 1275 MW that was connected to the grid in July 2000, 24 years after construction initially started. A 30-year license set to expire in 2041 was issued in 2011, but Eletronuclear has announced that it will likely request a 20-year extension.¹⁹¹²

The Angra-3 saga is one of the most chaotic in modern energy history in Brazil, the largest Latin American economy and the eleventh in the world. Preparatory work for the 1340-MW PWR designed by Siemens/KWU started in the early 1980s. It is unclear how much progress was made before a lengthy interruption starting in 1986. Construction eventually restarted in June 2010—the unit was then to be commissioned in 2016—but has been interrupted or stalled several times since. The administration of then-President Jair Bolsonaro (2019–2022)

¹⁹⁰⁹ - Energy Institute, “Statistical Review of World Energy 2025—Consolidated Data”, June 2025, see https://www.energyinst.org/___data/assets/excel_doc/0008/1656215/EI-Stats-Review-ALL-data.xlsx, accessed 27 June 2025.

¹⁹¹⁰ - CNEN, “CNEN autoriza extensão da operação de Angra 1 por mais 20 anos”, Comissão Nacional de Energia Nuclear/National Nuclear Energy Commission, 22 November 2024, see <https://www.gov.br/cnen/pt-br/assunto/ultimas-noticias/cnen-autoriza-extensao-da-operacao-de-angra-1-por-mais-20-anos>, accessed 6 May 2025.

¹⁹¹¹ - Eletronuclear, “Notas explicativas da administração às demonstrações financeiras do exercício findo em 31 de dezembro de 2024 (Em milhares de reais, exceto quando indicado de outra forma)”, 2025, see <https://www.eletronuclear.gov.br/Quem-Somos/Governanca/Documents/Balan%C3%A7os/2024/4.%20NOTAS%20EXPLICATIVAS%20ELETRONUCLEAR%202024.pdf>, accessed 4 September 2025.

¹⁹¹² - Eletrobras, “Angra Nuclear Power Station Initiatives for Long Term Operation”, 24 November 2013, see <https://www.aben.com.br/Arquivos/205/205.pdf>, accessed 12 May 2025.

picked up efforts to complete the project setting in motion a major shakeup of Brazil's energy industry landscape. However, the succeeding government of President Luiz Inácio “Lula” da Silva was ultimately left with the task of issuing the formal decision and setting the conditions for the decades-old project to be completed. Beyond the lengthy assessment phase and difficult decision-making process at the federal-level, Eletronuclear met (and seemingly solved) new legal disputes in the past two years, first with local government which withheld the necessary permits for resumption of civil works, then with the consortium hired to implement them, leading to the termination of the contract in June 2024. (See WNISR2023 and WNISR2024 for an overview of past events.)

In September 2024, Brazil's National Bank for Economic and Social Development (BNDES) submitted a critical and long-awaited study to Eletronuclear and the Ministry of Mines and Energy. This financial assessment is legally to serve as basis for the National Energy Policy Council (Conselho Nacional de Política Energética or CNPE) to reach a definitive decision and determine the financial model of the project. The study, which had been commissioned in 2019, confirmed that about BRL12 billion (US\$₂₀₂₄ 2.2 billion) had already been invested in the project since 2010, and that completion would require a further BRL23 billion (US\$₂₀₂₄ 4.3 billion), while abandoning the project would cost BRL21 billion (US\$₂₀₂₄ 3.9 billion). The proposed tariff amounted to BRL653.31/MWh (~US\$₂₀₂₄ 121/MWh), with commercial operation expected in 2031.¹⁹¹³ Per latest announcements construction is about two thirds complete.

“New inefficiencies or other delays in the work can no longer be incorporated into the price to be approved, making the respective costs a risk for the concessionaire, and no longer costs to be covered by consumers.”

The Minister of Mines and Energy, who chairs the CNPE—composed of other ministers and appointed councils—grants the project his unwavering support. However, upon convening on the matter since receiving BNDES' assessment, the council postponed its decision twice,¹⁹¹⁴ and as of mid-2025, a new date had not been set.

Apparently weary of the possibility of new delays and cost-overruns, and well-aware of tariff raises that came with each renewed attempt at resuming the project, the Federal Court of Accounts (TCU) consistently reissues the recommendation that “new inefficiencies or other delays in the work can no longer be incorporated into the price to be approved, making the respective costs a risk for the concessionaire, and no longer costs to be covered by consumers.”¹⁹¹⁵

However, a further development that could significantly impact the terms of the financial model arose when in February 2025, Eletrobras and the federal government reached a settlement

¹⁹¹³ - Eletronuclear, “Eletronuclear recebe estudo do BNDES sobre Angra 3”, Press Release, 3 September 2024, see <https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Eletronuclear-recebe-estudo-do-BNDES-sobre-Angra-3.aspx>, accessed 17 September 2024.

¹⁹¹⁴ - Marcela Ayres and Bernardo Caram, “Brazil's Government Split Over Multi-Billion Dollar Nuclear Plant Completion”, *Reuters*, 18 February 2025, see <https://www.reuters.com/world/americas/brazils-government-split-over-multi-billion-dollar-nuclear-plant-completion-2025-02-18/>, accessed 4 September 2025.

¹⁹¹⁵ - TCU, “TCU segue atento para que consumidor não seja prejudicado com eventual retomada de Angra 3 – Notícias”, Tribunal de Contas da União/Federal Court of Accounts, Brazil, 18 February 2025, see <https://portal.tcu.gov.br/imprensa/noticias/tcu-segue-atento-para-que-consumidor-nao-seja-prejudicado-com-eventual-retomada-de-angra-3>, accessed 8 April 2025.

agreement—in a broader power struggle over state influence in the company’s governance—exempting Eletrobras from future investment in the project.¹⁹¹⁶ Eletrobras is Brazil’s biggest utility and, until its privatization in 2022, it was the parent entity of Eletronuclear. In order to maintain nuclear activities under state control, major restructuring was performed at the time, resulting in the creation of Empresa Brasileira de Participações em Energia Nuclear e Binacional (ENBPar) which took over Eletronuclear. Eletrobras however maintained a 67.95 percent interest in Eletronuclear’s capital, and a minority voting share of 35.9 percent. In 2022, ENBPar and Eletrobras entered into an agreement which kept the latter on-the-hook for financing the completion of Angra-3. Under the new agreement with the federal government, signed in March 2025, Eletrobras is to provide BRL2.4 billion (US\$424 million) for Angra-1’s lifetime extension, while the 2022 Investment Agreement is suspended and is to be terminated “if and when” resumption of construction at Angra-3 is decided.¹⁹¹⁷

Nevertheless, Eletrobras remains “liable for any existing guarantees [it] provided for Eletronuclear’s financings prior to [its] privatization,” which as of December 2024, amounted to BRL6.1 billion (US\$ 1.1 billion) according to the company. It is now looking to sell its shares warning that

Even if the Settlement Agreement becomes effective, there are factors beyond our control that may affect its success. For example, BNDES may not be able to design a structure that ensures the economic and financial viability of the Angra 3 project that will be suitable for, and approved by, all stakeholders.¹⁹¹⁸

In the absence of CNPE’s approval, Eletronuclear President Raul Lycurgo confirmed at a parliamentary hearing on 27 May 2025 that the Angra-3 project remains frozen. Lycurgo reminded that Eletronuclear spends close to BRL1 billion (US\$176.5 million) per year to maintain the project alive, including BRL100 million (US\$17.6 million) on staff wages, BRL120 million (US\$21.2 million) for mothballing equipment, and BRL800 million (US\$141 million) for servicing debt on project financing.¹⁹¹⁹ A heavy burden for Eletronuclear which has already implemented various austerity measures, including cutting departments and management positions.¹⁹²⁰ The company also requested a deferral of its debt payments to Caixa and BNDES until 2026, which had previously been suspended from July to December 2024.¹⁹²¹

¹⁹¹⁶ - Eletrobras, “Câmara de Mediação e de Conciliação da Administração Pública Federal”, 28 February 2025, see https://www.gov.br/agu/pt-br/comunicacao/noticias/copy_of_fatorelevante.pdf, accessed 4 September 2025.

¹⁹¹⁷ - Ibidem; and *Nucleonics Week*, “Brazil’s Eletronuclear Seeks Debt Relief as Costs Mount on Stalled Angra-3 Reactor”, 4 June 2025; also Eletrobras, “Centrais Elétricas Brasileiras S.A.—Eletrobras—Form 20-F”, filed with U.S. Securities and Exchange Commission, April 2025, see <https://api.mziq.com/mzfilemanager/v2/d/abb77a17-3348-4bc7-849a-154998e06ca3/009592d8-aad1-2322-9d5b-ad3b83a85e59?origin=1>, accessed 3 September 2025.

¹⁹¹⁸ - Eletrobras, “Centrais Elétricas Brasileiras S.A.—Eletrobras—Form 20-F”, filed with U.S. Securities and Exchange Commission, April 2025, op. cit.

¹⁹¹⁹ - *Nucleonics Week*, “Brazil’s Eletronuclear Seeks Debt Relief as Costs Mount on Stalled Angra-3 Reactor”, 4 June 2025; and Janary Júnior, “Obra parada de Angra 3 custa R\$ 1 bilhão ao ano; especialistas defendem retomada - Notícias”, Câmara dos Deputados, 27 May 2025, see <https://www.camara.leg.br/noticias/1163294-obra-parada-de-angra-3-custa-r-1-bilhao-ao-ano-especialistas-defendem-retomada/>, accessed 23 August 2025.

¹⁹²⁰ - Eletronuclear, “Com recordes de geração e avanços estratégicos, Eletronuclear publica Relatório Anual 2024”, Press Release, 4 June 2025; and Eletronuclear, “Eletronuclear realiza ajustes de gestão com medidas de austeridade para viabilizar Angra 3”, Press Release, 7 February 2025, see <https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Eletronuclear-realiza-ajustes-de-gestao-com-medidas-de-austeridade-para-viabilizar-Angra-3.aspx>, accessed 4 September 2025.

¹⁹²¹ - Janary Júnior, “Obra parada de Angra 3 custa R\$ 1 bilhão ao ano; especialistas defendem retomada - Notícias”, Câmara dos Deputados, 27 May 2025, see <https://www.camara.leg.br/noticias/1163294-obra-parada-de-angra-3-custa-r-1-bilhao-ao-ano-especialistas-defendem-retomada/>, accessed 23 August 2025.

In March 2025, Minister Silveira penned a letter asking his fellow Minister of Finance to intervene for the two banks to grant such a waiver, pointing to ENBPar communication warning of the “imminent risk of insolvency” of Eletronuclear and “the urgent need for actions to ensure the financial sustainability of Eletronuclear, given that, despite the efforts already undertaken by the Company’s management, such as a significant reduction in operating expenses and extraordinary measures to generate resources, the cash flow forecast for 2025 shows the persistence of the financial deficit, jeopardizing the operational continuity of the Angra 1 and Angra 2 facilities.”¹⁹²²

As a TCU representative said in May:

The cost of not making a decision about what to do with Angra 3 is the worst of all. The Brazilian nuclear program depends heavily on Angra 3.¹⁹²³

A thought seemingly shared by President Lula, who in June 2025, reportedly insisted for the CNEP to retable the issue and come to an agreement by end of the year.¹⁹²⁴ If and when the project is greenlit, a program has to be developed, and a tender organized before an Engineering, Procurement and Construction (EPC) contract can be established. Experience shows such a process can take years.

Despite the uncertainty that Angra-3 casts over the industry’s mid-term prospects, further newbuild initiatives are already being sporadically discussed (see [WNISR2024](#)), including the possibility of deploying Small Modular Reactors (SMRs).¹⁹²⁵ The National Energy Plan 2050 (PNE2050), released under the previous administration, had included the technology as potential component of Brazil’s energy mix starting “after 2030”. More recently, cooperation with Russia on SMR deployment has reportedly been high on the agenda.¹⁹²⁶ The country has also embarked in the development of its own 3–5-MW “microreactor”, which it hopes to bring to commercialization by mid-2033 to 2035.¹⁹²⁷

However, the latest approved Ten-Year Energy Expansion Plan, released in April 2025, sees no capacity additions from nuclear in the entire reporting period up to 2034, except from

¹⁹²² - Alexandre Silveira, “Solicitação de gestão junto à Caixa Econômica Federal e ao BNDES para prorrogação dos pagamentos referentes ao serviço das dívidas da Eletronuclear.”, Minister of Mines and Energy, addressed to Fernando Haddad, Minister of Finance, Government of Brazil, as released by *Poder360*, March 2025, see <https://static.poder360.com.br/2025/04/Oficio-no-1092025GM-MME.pdf>, accessed 4 September 2025.

¹⁹²³ - Janary Júnior, “Obra parada de Angra 3 custa R\$ 1 bilhão ao ano; especialistas defendem retomada - Notícias”, Câmara dos Deputados, 27 May 2025, op. cit.

¹⁹²⁴ - João Paulo Caires and Caio Barcellos, “Lula cobra ministros por retomada das obras de Angra 3”, *Poder360*, 25 June 2025, see <https://www.poder360.com.br/poder-energia/lula-cobra-ministros-por-retomada-das-obras-de-angra-3/>, accessed 24 August 2025.

¹⁹²⁵ - Clayton Silva, “SMR – Projects, Opportunities and Challenges”, Energy Research Analyst, Energy Research Office, Government of Brazil, presented at the International Nuclear Atlantic Conference, 8 May 2024, see <https://www.epe.gov.br/sites-pt/sala-de-imprensa/noticias/SiteAssets/Paginas/Forms/AllItems/Clayton%20-%20INAC%202024%20%20.pdf>, accessed 24 August 2025; and Science, Technology and Innovation Commission, “Audiência Pública Extraordinária (semipresencial”, Câmara dos Deputados, Parliament of Brazil, 11 June 2025, see <https://escriba.camara.leg.br/escriba-servicosweb/html/76703>, accessed 23 August 2025.

¹⁹²⁶ - Victor Alves, “Brazil and Russia Edge Closer on Nuclear Deal”, *bne IntelliNews*, 15 May 2025, see <https://www.intellinews.com/brazil-and-russia-edge-closer-on-nuclear-deal-381380/>, accessed 4 September 2025.

¹⁹²⁷ - Ministry of Science, Technology and Innovation, “MCTI e FINEP investem R\$ 30 milhões para projeto de microrreator nuclear”, Press Release, Government of Brazil, 17 June 2025.

Angra-3 which is mentioned as still subject to studies and approval.¹⁹²⁸ SMRs are described as promising, but still having major challenges to overcome, such as technological or regulatory.

Under the Bolsonaro Government a new regulatory agency, referred to as ANSN (Autoridade Nacional de Segurança Nuclear) was reassigned CNEN's (Comissão Nacional de Energia Nuclear) responsibilities to monitor, regulate, and inspect nuclear activities and facilities. CNEN remains in charge of planning, overall policy, and advocacy for nuclear energy.¹⁹²⁹

But since its inception in 2021–2022, ANSN has not functioned (see also past WNISR editions) due to lack of staffing at all levels. The Court of Accounts alerted in March 2025 about the lack of a proper management plan, an appropriate budget, and adequate personnel. For that matter, it gave 120 days to the government to deliver a sound management plan to guarantee a proper functioning of the agency.¹⁹³⁰ As of mid-2025, there is no indication that such a plan has been submitted.

As reported in previous editions, Brazil is expanding its uranium enrichment capacities and expects to service the entire fuel supply requirements of its then three (potential) reactors by 2037.

Energy Trends

In 2024, renewables (including hydro) represented 87.3 percent of power generation. Hydroelectricity, the main source of power, reached 413.2 TWh (gross) in 2024, while output from wind increased by 13 percent to 108.5 TWh and from solar by close to 41 percent to 71.3 TWh. Their respective share in the power mix stood at 55.4 percent (hydro), 14.5 percent (wind), and 9.6 percent (solar). Brazil is the world's fourth largest producer of wind power and the sixth largest of solar PV.¹⁹³¹

According to IRENA, Brazil added 3.8 GW of wind capacity (+13 percent) and an impressive 15 GW of solar (+40 percent) over 2024.¹⁹³²

However, both the output and share of fossil fuels increased in 2024, representing a combined 10.1 percent—compared to 8.6 percent the previous year—with oil at 1.4 percent, coal at 2.2 percent, and gas at 6.5 percent.

In November 2024, Brazil, who will host COP30 in November 2025, announced its new target to reduce greenhouse gas emissions in 2035 by 67 percent compared to 2005-levels.¹⁹³³

¹⁹²⁸ - Ministry of Mines and Energy, “PDE 2034—Plan Decenal de Expansão de Energia 2034”, April 2025, Government of Brazil, see https://www.gov.br/mme/pt-br/assuntos/secretarias/sntep/publicacoes/plano-decenal-de-expansao-de-energia/pde-2034/relatorio_aprovado/pde2034_aprovado.pdf/view, accessed 4 September 2025.

¹⁹²⁹ - Government of Brazil, “Sancionada a lei que cria a da Autoridade Nacional de Segurança Nuclear”, 10 November 2022, see <https://www.gov.br/casacivil/pt-br/assuntos/noticias/2021/outubro/sancionada-a-lei-que-cria-a-da-autoridade-nacional-de-seguranca-nuclear>, accessed 11 June 2025.

¹⁹³⁰ - TCU, “TCU identifica riscos na estruturação da Autoridade Nacional de Segurança Nuclear”, Press Release, 7 March 2025, see <https://portal.tcu.gov.br/imprensa/noticias/tcu-identifica-riscos-na-estruturacao-da-autoridade-nacional-de-seguranca-nuclear>, accessed 14 April 2025.

¹⁹³¹ - Energy Institute, “Statistical Review of World Energy—Consolidated Dataset”, June 2025, op. cit.

¹⁹³² - IRENA, “Renewable Energy Statistics 2025”, July 2025, op. cit.

¹⁹³³ - Government of Brazil, “Brazil's NDC—National Determination to Contribute and Transform”, as released by the United Nations Framework Convention on Climate Change Secretariat, 13 November 2024, see <https://unfccc.int/documents/643337>, accessed 14 May 2025.

The government is also working on updating its National Climate Plan ahead of COP30.¹⁹³⁴ The country is trying to regain its climate leadership after the effects of Bolsonaro's regime. Though prompt to implement such a reversal, the current administration has since passed sets of contradictory policies, including on oil drilling. With the global focus on COP30, the international attention will also be directed towards Brazil's domestic policies and measures to achieve its targets, including the decarbonization of its energy sector. It is now clear, that nuclear expansion will not play any role, at least not in the short term.

Canada



Canada's reactor fleet consists of 17 CANDU reactors with a total net capacity of 12.7 GW. Two reactors (Pickering-1 and Pickering-4) were closed on 1 October 2024 and 31 December 2024 respectively.¹⁹³⁵ As of June 2025, three reactors (Bruce-3, Bruce-4, and Darlington-4) are being refurbished since 28 February 2023, 31 January 2025, and 18 July 2023 respectively.¹⁹³⁶ Two of the units being refurbished have reached Long-Term Outage (LTO) status as of mid-2025.

According to Statistics Canada, nuclear reactors supplied 81.74 TWh (net) in 2024, slightly lower than the 84.57 TWh produced in 2023.¹⁹³⁷ In 2024, nuclear energy constituted 13.4 percent of the total electricity generated in Canada, a slight decline from 2023. All but one of the nuclear reactors are located in the province of Ontario, where nuclear power contributed 50.9 percent of the electricity generated in 2024, below the 53.2 percent in 2023.¹⁹³⁸

Refurbishment

Canada is in the process of refurbishing several of its ageing CANDU reactors, which “involves replacing core reactor components” such as “fuel channels, feeder pipes, calandria tubes and end fittings.”¹⁹³⁹ The reactor that was most recently refurbished was Darlington-1, which took close to two years and nine months for this process to be completed in late 2024.¹⁹⁴⁰ According to the Darlington Refurbishment Program Annual Report from December 2024, the program had cost CAD11.1 billion (US\$₂₀₂₄ 8.1 billion) till that point; of that, Unit 1 alone had

¹⁹³⁴ - Ministry of Environment and Climate Change, “Plano Clima”, Undated, Government of Brazil, see <https://www.gov.br/mma/pt-br/acao-a-informacao/perguntas-frequentes/mudanca-do-clima/plano-clima/plano-clima>, accessed 2 June 2025.

¹⁹³⁵ - OPG, “OPG Reports 2024 Financial Results”, Press Release, Ontario Power Generation, 4 March 2025, see <https://www.opg.com/reporting/financial-reports/release/opg-reports-2024-financial-results/>, accessed 29 June 2025; and David Dalton, “Pickering-4 Nuclear Plant In Canada Permanently Shut Down”, *NucNet*, 3 January 2025, see <https://www.nucnet.org/news/pickering-4-nuclear-plant-in-ontario-permanently-shut-down-1-5-2025>, accessed 4 January 2025.

¹⁹³⁶ - IESO, “Planning and Forecasting—Annual Planning Outlook—Ontario's Electricity System Needs: 2026-2050”, Independent Electricity System Operator, April 2025, see <https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/2025/2025-Annual-Planning-Outlook.pdf>, accessed 19 June 2025.

¹⁹³⁷ - Statistics Canada, “Electric Power Generation, Monthly Generation by Type of Electricity”, Government of Canada, Updated 2 June 2025, see <https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510001501>, accessed 22 June 2025.

¹⁹³⁸ - IESO, “Year-End Data—2024 Year in Review”, Independent Electricity System Operator, as of 22 June 2025, see <https://ieso.ca/en/Corporate-IESO/Media/Year-End-Data#yearenddata>, accessed 22 June 2025.

¹⁹³⁹ - OPG, “Darlington Refurbishment Performance Update Q1 2024—Frequently Asked Questions”, Ontario Power Generation, 2024, see <https://www.opg.com/projects-services/projects/nuclear/darlington-refurbishment/>, accessed 23 June 2024.

¹⁹⁴⁰ - OPG, “Darlington Nuclear's Unit 1 Successfully Refurbished Months Ahead Of Schedule”, Ontario Power Generation, 18 November 2024, see <https://www.opg.com/news-resources/newsroom/our-stories/story/darlington-nuclear-unit-1-successfully-refurbished>, accessed 3 January 2025; and IESO, “Planning and Forecasting—Annual Planning Outlook—Ontario's Electricity System Needs: 2026-2050”, April 2025, op. cit.

accounted for CAD1.7 billion (US\$₂₀₂₄ 1.2 billion) and was estimated to amount to a total cost of CAD1.98 billion (US\$₂₀₂₄ 1.4 billion).¹⁹⁴¹

As mentioned above, three reactors (Bruce-3, Bruce-4, and Darlington-4) are currently going through this process. These projects are scheduled for completion respectively by 12 December 2026 (Bruce-3), 1 January 2028 (Bruce-4), and 23 July 2026 (Darlington-4).¹⁹⁴² (See Table 20.)

Table 20 · Status of Canadian Nuclear Fleet - PLEX and Expected Closures

Reactor	Operator	Grid Connection	Refurbishment ^(a) (Provisional Jan. 2020) ^(b)	Planned Closure	Licensed to ^(c)
Bruce-1	Bruce Power	1977	Restarted in 2012	2064	2028
Bruce-2		1976	Restarted in 2012		
Bruce-3		1977	01/03/23–12/12/26 (01/01/23–30/06/26)		
Bruce-4		1978	31/01/2025–01/01/2028 (01/01/25–31/12/27)		
Bruce-5		1984	30/09/26–30/09/29 (01/07/26–30/06/29)		
Bruce-6		1984	16/01/20–08/09/23 ^(d) (01/01/20–19/10/23)		
Bruce-7		1986	30/09/28–01/10/31 (01/07/28–30/06/31)		
Bruce-8		1987	30/09/30–01/10/33 (01/07/30–30/06/33)		
Darlington-1	OPG	1990	14/02/22–02/12/24 (15/10/21–15/12/24)	2055	30/11/2025
Darlington-2		1990	10/16–06/20 ^(e)		
Darlington-3		1992	30/07/20–17/07/23 ^(f) (15/02/20–15/06/23) ^(g)		
Darlington-4		1993	19/07/23–01/08/26 (01/05/23–31/05/26)		
Pickering-5	OPG	1982	30/09/26–01/12/30 ^(h)	Expected Lifetime Extension for up to 30 years ⁽ⁱ⁾	2028 ^(j)
Pickering-6		1983	30/09/26–01/06/32 ^(h)		
Pickering-7		1984	30/09/26–17/07/33 ^(h)		
Pickering-8		1986	30/09/26–31/08/34 ^(h)		
Point Lepreau	NB Power	1982	03/2008–03/2012	2044–2045 ^(k)	June 2032

Sources: compiled by WNISR with IESO, Operators and CNSC, 2025

Notes: **OPG** = Ontario Power Generation.

a – Unless otherwise mentioned, IESO, “Annual Planning Outlook - Ontario’s Electricity System Needs: 2026–2050”, April 2025.

b – IESO, “Annual Planning Outlook - A View of Ontario’s Electricity System Needs”, January 2020, see <http://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Annual-Planning-Outlook-Jan2020.pdf?la=en>, accessed 1 August 2020.

c – As listed on Canadian Nuclear Safety Commission’s (CNSC) website for each station, as of 24 June 2025.

Bruce: <https://www.cnscccsn.gc.ca/eng/reactors/power-plants/nuclear-facilities/bruce-nuclear-generating-station/index.cfm>;

Darlington: <https://www.cnscccsn.gc.ca/eng/reactors/power-plants/nuclear-facilities/darlington-nuclear-generating-station/index.cfm>;

Pickering: <https://www.cnscccsn.gc.ca/eng/reactors/power-plants/nuclear-facilities/pickering-nuclear-generating-station/index.cfm>;

Point Lepreau: <https://www.cnscccsn.gc.ca/eng/reactors/power-plants/nuclear-facilities/point-lepreau-nuclear-generating-station/index.cfm>.

¹⁹⁴¹ – OPG, “Darlington Refurbishment Program Annual Report: 2024 Report”, Ontario Power Generation, December 2024, see https://www.oeb.ca/sites/default/files/OPG_OEB_DRP%20Annual%20Reporting_2024.pdf, accessed 20 June 2025.

¹⁹⁴² – IESO, “Planning and Forecasting—Annual Planning Outlook—Ontario’s Electricity System Needs: 2026–2050”, April 2025, op. cit., Figure 11, p. 33.

d – Refurbishment of Bruce-6 was completed in September 2023. See Bruce Power, “Bruce Power’s Unit 6 Connected to Ontario’s Electricity Grid Following Major Component Replacement Outage”, 8 September 2023, see <https://www.brucepower.com/2023/09/08/bruce-powers-unit-6-connected-to-ontarios-electricity-grid-following-major-component-replacement-outage/>, accessed 26 June 2024.

e – Refurbishment of Darlington-2 was completed in June 2020, with the reactor being reconnected to the grid on 2 June 2020; see OPG, “Darlington Unit 2 Powers on—Refurbishment Now Complete on First Unit”, 4 June 2020, see <https://www.opg.com/news/darlington-unit-2-powers-on/>, accessed 28 July 2020.

f – IESO2025 now uses 01/09/20–05/09/23. Darlington-3 was taken offline in July 2020, with refurbishment starting in September 2020; see OPG, “Refurbishment of Darlington Nuclear’s Unit 3 Now Underway”, 3 September 2020, see <https://www.opg.com/news/refurbishment-of-darlington-nuclears-unit-3-now-underway/>, accessed 23 June 2025.

The refurbishment was completed in July 2023, with the reactor being reconnected to the grid on 17 July 2023.

See OPG, “OPG Celebrates the Early Completion of Darlington Unit 3”, Press Release, Ontario Power Generation, 18 July 2023, see https://www.opg.com/media_releases/opg-celebrates-the-early-completion-of-darlington-unit-3/, accessed 19 July 2023.

g – In the December 2020 issue of the IESO outlook the dates were changed to 30/07/2020–02/01/2024.

See IESO, “Annual Planning Outlook - Ontario’s Electricity System Needs: 2022-2040”, December 2020, see <https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Annual-Planning-Outlook-Dec2020.ashx>, accessed 12 June 2021.

h – Provisional schedule, as presented in IESO, “Annual Planning Outlook - Ontario’s Electricity System Needs: 2026-2050”, April 2025.

i – Pickering 5–8 are planned to be taken offline in September 2026 to undergo refurbishment for an expected further lifetime extension for up to 30 years. See Government of Ontario, “Ontario Advancing Plan to Refurbish Pickering Nuclear Generating Station”, Press Release, 23 January 2025, see <https://news.ontario.ca/en/release/1005620/ontario-advancing-plan-to-refurbish-pickering-nuclear-generating-station>, accessed 23 June 2025.

j – OPG holds a 10-year operating license for the Pickering nuclear station, which expires on 31 August 2028. OPG is authorized to operate Units 5–8 until 31 December 2026.

k – In 2021, NB Power applied for a 25-year operating license renewal, which was granted for 10 years. Retirement is scheduled for 2044/45. See NB Power, “2023 Integrated Resource Plan: Pathways to a Net-Zero Electricity System”, 2023, see <http://www.nbpower.com/en/about-us/our-energy/integrated-resource-plan/>.

The third nuclear plant in Ontario at Pickering has not yet started this process. In January 2024, the Ontario Government announced that it supported refurbishing four of these reactors (Units 5–8, also referred to as “Pickering B”).¹⁹⁴³ In October 2024, the Canadian Nuclear Safety Commission (CNSC) approved the continued operation of Pickering Nuclear’s Units 5 to 8 to the end of 2026.¹⁹⁴⁴ CNSC is scheduled to hold public hearings in April and June 2026 to consider OPG’s application to refurbish Pickering Units 5 through 8.¹⁹⁴⁵

Other Updates

Canada has been actively promoting Small Modular Reactors (SMRs) for around a decade (see [chapter on SMRs](#)). But over the last couple of years, a number of large nuclear reactor projects have also been proposed. These include projects at sites with existing nuclear reactors as well as new sites.

When viewed in terms of planning, the most advanced among these proposals is to build four large nuclear reactors with a capacity of 4.8 GW at the Bruce site, which already hosts eight reactors. Plans for Bruce-C can be dated back to July 2023, when Ontario’s government announced the start of pre-development work.¹⁹⁴⁶ In February 2024, the federal government

¹⁹⁴³ – Ontario Government, “Ontario Supporting Plan to Refurbish Pickering Nuclear Generating Station”, Press Release, 30 January 2024, see <https://news.ontario.ca/en/release/1004128/ontario-supporting-plan-to-refurbish-pickering-nuclear-generating-station>, accessed 14 April 2024.

¹⁹⁴⁴ – CNSC, “Commission authorizes Ontario Power Generation Inc. to Operate Pickering Nuclear Generating Station Units 5 to 8 until December 31, 2026”, Press Release, Canadian Nuclear Safety Commission, 11 October 2024, see <https://www.canada.ca/en/nuclear-safety-commission/news/2024/10/commission-authorizes-ontario-power-generation-inc-to-operate-pickering-nuclear-generating-station-units-5-to-8-until-december-31-2026.html>, accessed 13 October 2024.

¹⁹⁴⁵ – CNSC, “Participant Funding for Ontario Power Generation’s Application to Refurbish the Pickering Nuclear Generating Station and Renew its Pickering Nuclear Generating Station and Waste Management Facility Licences”, Updated 18 July 2025, see <https://www.cnsccsn.gc.ca/eng/the-commission/participant-funding-program/opportunities/2025-07-opg-pngs/>, accessed 17 August 2025.

¹⁹⁴⁶ – Ontario Government, “Province Starts Pre-Development Work for New Nuclear Generation to Power Ontario’s Growth”, Press Release, 5 July 2023, see <https://news.ontario.ca/en/release/1003240/province-starts-pre-development-work-for-new-nuclear-generation-to-power-ontarios-growth>, accessed 11 July 2024.

offered CAD50 million (US\$36.5 million) for preliminary work.¹⁹⁴⁷ And in June 2025, the Impact Assessment Agency of Canada and the Canadian Nuclear Safety Commission (CNSC) invited “Indigenous Nations and communities and the public to review and provide feedback on the draft Integrated Tailored Impact Statement Guidelines (draft Integrated Guidelines) and the draft Public Participation Plan (draft Plan).”¹⁹⁴⁸

*The anticipated time when the project would start generating power
is 2045—twenty years from now.*

This pace of project development is not an indication of how fast these reactors would be completed. In its initial project description, Bruce Power has laid out an “anticipated project schedule” that envisions three to four years for the impact assessment to be completed, three years after that for site preparation, and “construction and commissioning” to take “approximately 14 years”; taken together the anticipated time when the project would start generating power is 2045—twenty years from now.¹⁹⁴⁹

Another proposed project with large reactors is in the Peace River area of Northern Alberta and is being proposed by a private company called Energy Alberta. As with the proposed Bruce project, the Impact Assessment Agency of Canada and the Canadian Nuclear Safety Commission invited review and feedback on the draft Integrated Tailored Impact Statement Guidelines (the draft Integrated Guidelines) and the draft Public Participation Plan (draft Plan).¹⁹⁵⁰

Unlike Bruce-C, Energy Alberta envisions commissioning the first of four large reactors by 2035, with subsequent units starting operations in 2038, 2040, and 2043.¹⁹⁵¹ Energy Alberta had earlier proposed a nuclear power plant in the same region back in 2009, but then sold the proposal to Bruce Power—which eventually cancelled the project in 2011.¹⁹⁵²

The third proposed project with large reactors is in Port Hope in Ontario; this began with a request made in January 2025 by the Ontario government to Ontario Power Generation (OPG)

¹⁹⁴⁷ - Kate McKenna, “Ottawa Pledging \$50M for Bruce Power Nuclear Plant Expansion”, *CBC News*, 29 February 2024, see <https://www.cbc.ca/news/politics/nuclear-money-bruce-power-expansion-1.7127490>, accessed 23 June 2024; and Natural Resources Canada, “Government of Canada Announces \$50 million for Ontario’s Expansion of Clean, Reliable and Affordable Nuclear Energy”, Press Release, 29 February 2024, see <https://www.canada.ca/en/natural-resources-canada/news/2024/02/government-of-canada-announces-50-million-for-ontarios-expansion-of-clean-reliable-and-affordable-nuclear-energy.html>, accessed 11 July 2024.

¹⁹⁴⁸ - Impact Assessment Agency of Canada, “Bruce C Nuclear Project - Public Comments Invited and Information Sessions on the Draft Integrated Tailored Impact Statement Guidelines and Public Participation Plan”, Press Release, as published on *Cision Newswire*, 12 June 2025, see <https://www.newswire.ca/news-releases/bruce-c-nuclear-project-public-comments-invited-and-information-sessions-on-the-draft-integrated-tailored-impact-statement-guidelines-and-public-participation-plan-840068204.html>, accessed 22 June 2025.

¹⁹⁴⁹ - Bruce Power, “Bruce C Nuclear Project: Initial Project Description”, August 2024, see <https://iaac-aeic.gc.ca/o50/documents/p88771/158463E.pdf>, accessed 10 July 2025.

¹⁹⁵⁰ - Impact Assessment Agency of Canada, “Peace River Nuclear Power Project”, Updated 9 July 2025, see <https://iaac-aeic.gc.ca/o50/evaluations/proj/89430>, accessed 10 July 2025.

¹⁹⁵¹ - Energy Alberta, “Peace River Nuclear Power Project Initial Project Description—Report No. CA0038431-24003-R-RevoO”, 11 April 2025, see <https://iaac-aeic.gc.ca/o50/documents/p89430/161347E.pdf>, accessed 22 June 2025.

¹⁹⁵² - Taylor Lambert, “Private Sector Advances Proposal for Large-Scale Nuclear Power Plant in Northern Alberta”, *CBC News*, 8 October 2024, see <https://www.cbc.ca/news/canada/edmonton/private-sector-advances-proposal-for-large-scale-nuclear-power-plant-in-northern-alberta-1.7345039>, accessed 22 June 2025; and *CBC News*, “Bruce Power Dropping Alberta Nuclear Plant Proposal”, 13 December 2011, see <https://www.cbc.ca/news/canada/edmonton/bruce-power-dropping-alberta-nuclear-plant-proposal-1.1046668>, accessed 8 October 2018.

“to explore opportunities for new nuclear energy generation” at its Wesleyville site.¹⁹⁵³ Some unnamed officials have been reported as saying that “the site could support” 8–10 GW of nuclear capacity, but according to the press report “the same officials declined to provide a cost estimate for such a project, saying it was too premature.”¹⁹⁵⁴ Since 2018, Port Hope has been undergoing a CAD₂₀₁₂ 1.28 billion (US\$₂₀₁₂ 985 million) “cleanup operation” to deal with “radioactive tailings” produced while Eldorado, a former Crown corporation, refined uranium and radium between 1933 and 1988.¹⁹⁵⁵ The budget was increased to CAD2.6 billion (US\$1.9 billion).

Bruce Power’s initial project description listed four large reactor designs: the Monark (modified CANDU) design from AtkinsRéalis, the EPR design from Électricité de France (EDF), the Advanced Boiling Water Reactor (ABWR) design from GE-Hitachi, and Westinghouse’s AP-1000 design.¹⁹⁵⁶ But the company maintains:

A reactor technology has not been selected at this time... The Impact Assessment will use a technology neutral approach, which involves the consideration of multiple technologies... Bruce Power’s evaluation of prospective nuclear technologies will focus on the value for ratepayers, opportunities for Indigenous Nations and Communities, socioeconomic benefits for the Clean Energy Frontier region of Bruce, Grey and Huron counties, as well as a number of factors including safety, reliability and cost.¹⁹⁵⁷

Nevertheless, there is some reason to expect that the Monark design is a leading contender. In March 2025, the federal government “entered into a preliminary agreement with AtkinsRéalis to support the development and modernization” of the Monark design with a promise to “lend AtkinsRéalis a maximum of CAD304 million (US\$220.7 million) over four years to finance half of the design project.”¹⁹⁵⁸ Over the past year, former natural resources minister of New Brunswick province, Mike Holland, and the energy minister of Ontario province, Todd Smith, both joined AtkinsRéalis “within a couple of weeks” of resigning from public office, Holland as director of business development for North America in July 2024, and Smith as vice-president of marketing and business development for Atkins subsidiary Candu Energy in August 2024.¹⁹⁵⁹

¹⁹⁵³ - Ontario Government, “Ontario Exploring New Nuclear Energy Generation in Port Hope”, Press Release, 15 January 2025, see <https://news.ontario.ca/en/release/1005585/ontario-exploring-new-nuclear-energy-generation-in-port-hope>, accessed 22 June 2025.

¹⁹⁵⁴ - *The Canadian Press*, “Ontario Eyes Large, New Nuclear Plant Near Port Hope”, as published by *CBC News*, 15 January 2025, see <https://www.cbc.ca/news/canada/toronto/nuclear-power-port-hope-ontario-1.7431803>, accessed 22 June 2025.

¹⁹⁵⁵ - Philip Lee-Shanok, “\$1.3B Cleanup of Port Hope Finally Underway after Decades of Massive Planning”, *CBC News*, 1 April 2018, see <https://www.cbc.ca/news/canada/toronto/port-hope-radioactive-waste-cleanup-finally-underway-1.4600654>, accessed 22 June 2025.

¹⁹⁵⁶ - Bruce Power, “Bruce C Nuclear Project: Initial Project Description”, August 2024, op. cit.

¹⁹⁵⁷ - Bruce Power, “The Bruce C Project—Frequently Asked Questions”, as of 10 July 2025, see <https://www.brucepower.com/the-bruce-c-project/>, accessed 10 July 2025; and Bruce Power, “Bruce C Project: Planning for the Next Generation.”, August 2024, see https://www.brucepower.com/wp-content/uploads/2024/08/240394A-IPD-Glossy_Publication_Rooo_Accessible_AX.pdf, accessed 22 June 2025.

¹⁹⁵⁸ - Natural Resources Canada, “Canada Invests in the Next Generation of Canadian-Made, Clean, Affordable Nuclear Energy”, Press Release, Government of Canada, 5 March 2025, see <https://www.canada.ca/en/natural-resources-canada/news/2025/03/canada-invests-in-the-next-generation-of-canadian-made-clean-affordable-nuclear-energy.html>, accessed 22 June 2025.

¹⁹⁵⁹ - Mitchell Beer, “Federal Conflict Rules Would Have Barred New Brunswick, Ontario Cabinet Ministers from New Corporate Posts, Expert Says”, *The Energy Mix*, 17 September 2024, see <https://www.theenergymix.com/exclusive-federal-conflict-rules-would-have-barred-new-brunswick-ontario-cabinet-ministers-from-new-corporate-posts-expert-says-old/>, accessed 22 June 2025.

The Monark design was first announced in November 2023¹⁹⁶⁰ but the project gained momentum after AtkinsRéalis reached an agreement in February 2024 with Atomic Energy of Canada Ltd., a federal Crown corporation, “to collaborate for the purpose of successfully deploying CANDU® reactors in Canada and internationally and to expand their intellectual property licensing agreement.”¹⁹⁶¹ More recently, AtkinsRéalis chose a number of preferred suppliers, in particular, “BWX Technologies, which has manufactured major components such as steam generators for Candu plants for decades,” as summed up by *The Globe and Mail*.¹⁹⁶²

Energy Alberta’s proposal for Peace River also envisions deploying up to four Monark reactors.¹⁹⁶³

Total renewable energy capacity (incl. hydro) in Canada as of the end of 2024 amounted to 110.5 GW, up from 108.9 GW in 2023, and 96 GW in 2015.¹⁹⁶⁴ The bulk of renewable capacity is hydropower which constituted 83.5 GW, up from 79.4 GW in 2015; during the same period, wind energy capacity went from 11.2 GW to 18.4 GW, and solar energy capacity more than doubled from 2.9 GW to 6.1 GW, while nuclear installed capacity (including reactors in LTO for refurbishment) dropped from 13.7 GW to 12.7 GW.

In 2024, wind turbines contributed 45.8 TWh and solar power plants contributed 5.2 TWh respectively according to data from Statistics Canada.¹⁹⁶⁵ Together with hydro power, which contributed 341.8 TWh or 56 percent, renewables contributed 64.5 percent of all electrical energy supplied in Canada. As mentioned above, nuclear contributed 13.4 percent of supplied electricity.

Canadian Government targets for reducing carbon dioxide emissions, either for 2030 or 2050, place much emphasis on nuclear power.¹⁹⁶⁶ The latest of the energy regulator’s Canada’s Energy Future reports that came out in 2023 did develop scenarios for a path to net zero by 2050 that projected roughly a tripling of nuclear energy generation capacity in Canada.¹⁹⁶⁷ Nevertheless, these scenarios are based on unrealistic assumptions about implementation timescales and

¹⁹⁶⁰ - AtkinsRéalis, “AtkinsRéalis Introduces 1,000 MW CANDU® MONARK™ Reactor; Nuclear Power for a Net Zero, Energy Independent Future”, Press Release, 28 November 2023, see <https://www.atkinsrealis.com/en/media/press-releases/2023/28-11-2023>, accessed 10 July 2025.

¹⁹⁶¹ - AtkinsRéalis, “AtkinsRéalis and AECL Enter into Memorandum of Understanding to Collaborate and Expand Intellectual Property Agreement, Accelerating Development of CANDU® MONARK™ Reactor”, Press Release, 22 February 2024, see <https://www.atkinsrealis.com/en/media/press-releases/2024/2024-02-22>, accessed 10 July 2025; and Matthew McClearn, “AtkinsRéalis, Atomic Energy of Canada to Partner on Development of New Monark Nuclear Power Reactor”, *The Globe and Mail*, 22 February 2024, see <https://www.theglobeandmail.com/business/article-atkinsrealis-atomic-energy-of-canada-to-partner-on-development-of-new/>, accessed 22 February 2024.

¹⁹⁶² - Matthew McClearn, “AtkinsRéalis Recruits Preferred Suppliers for Modernized Candu Reactors”, *The Globe and Mail*, 2 April 2025, see <https://www.theglobeandmail.com/business/article-atkinsrealis-recruits-preferred-suppliers-for-modernized-candu/>, accessed 2 April 2025; and AtkinsRéalis, “AtkinsRéalis Signs Preferred Vendor Agreements with Eight CANDU Nuclear Suppliers”, Press Release, 2 April 2025, see <https://www.atkinsrealis.com/en/media/trade-releases/2025/2025-04-02>, accessed 10 July 2025.

¹⁹⁶³ - Energy Alberta, “Peace River Nuclear Power Project Initial Project Description—Report No. CA0038431-24003-R-RevoO”, 11 April 2025, op. cit.

¹⁹⁶⁴ - IRENA, “Renewable Capacity Statistics 2025”, International Renewable Energy Agency, March 2025, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Mar/IRENA_DAT_RE_Capacity_Statistics_2025.pdf, accessed 26 March 2025.

¹⁹⁶⁵ - Statistics Canada, “Electric Power Generation, Monthly Generation by Type of Electricity”, Updated 2 June 2025, op. cit.

¹⁹⁶⁶ - Environment and Climate Change Canada, “Canada’s 2030 Emissions Reduction Plan”, Updated 22 June 2022, Government of Canada, see https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf, accessed 20 August 2024; and Canada Energy Regulator, “Canada’s Energy Future 2023—Energy Supply and Demand Projections to 2050”, 2023, see <https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2023/canada-energy-futures-2023.pdf>, accessed 11 August 2023.

¹⁹⁶⁷ - Canada Energy Regulator, “Canada’s Energy Future 2023—Energy Supply and Demand Projections to 2050”, 2023, op. cit.

costs of potential future reactors, typically small modular reactors, that would be 2.5 to 4 times lower than estimated costs of SMRs currently in the planning.¹⁹⁶⁸

Mexico



Laguna Verde nuclear power plant (LVNPP), located in Alto Lucero de Gutiérrez Barrios, in the southeastern state of Veracruz, is Mexico's only nuclear installation. The state utility Comisión Federal de Electricidad (Federal Electricity Commission), commonly referred to as CFE, owns and operates two Mark II General Electric (GE) Boiling Water Reactors (BWRs) there.

In 2024, LVNPP generated 11.7 TWh, almost identical to the close to 11.8 TWh produced in 2023, and down from a maximum of 12.9 TWh reached in 2018.¹⁹⁶⁹ It contributed 3.9 percent of the country's electricity.

Mexico decided in the mid-1960s to build a nuclear power plant. In 1966, CFE and the National Commission for Nuclear Energy (CNEN) began the initial studies.¹⁹⁷⁰ But the construction of the first reactor began only in 1976 and that of the second one in 1977.

After delays and setbacks, the first unit was connected to the grid in 1989 and the second one in 1994, each with an original design capacity of 654 MW net, a 20-year operating license, and an estimated 40-year lifespan. In 1999, the Ministry of Energy authorized an amendment to the license of Unit 2 for a 5-percent capacity increase, followed by a similar procedure for Unit 1 in 2004.

A further ~US\$600 million upgrading project was launched in 2007 to increase the output of both units by an additional 20 percent. It was completed in 2011, bringing the plant's net capacity to 1.5 GW.¹⁹⁷¹

In 2015, CFE applied for an uncommon 30-year lifetime extension to allow the reactors to operate for 60 years. In most countries, although procedures are diverse, lifetime extensions are either by 10-year periods (like in Belgium or France) or 20-year periods (like in the U.S.). In March 2019, the IAEA completed a Safety Aspects of Long-Term Operation (SALTO) review mission at the plant and made recommendations as part of the process to prepare for lifetime extension.¹⁹⁷² The license renewal was granted in July 2020 by the Ministry of

¹⁹⁶⁸ - M. V. Ramana and Susan O'Donnell, "Wishful Thinking about Nuclear Energy Won't Get Us to Net Zero", *The Hill Times*, 3 July 2023, see <https://www.hilltimes.com/story/2023/07/03/wishful-thinking-about-nuclear-energy-wont-get-us-to-net-zero/391721/>, accessed 5 September 2023.

¹⁹⁶⁹ - Energy Institute, "Statistical Review of World Energy 2025—Consolidated Dataset", 74th Edition, June 2025, see https://www.energyinst.org/_data/assets/excel_doc/0006/1656348/Statistical-Review-of-World-Energy-Data.xlsx, accessed 27 June 2025.

¹⁹⁷⁰ - IAEA, "Country Nuclear Power Profiles 2022 Edition—Mexico", Updated 2022, see <https://www-pub.iaea.org/MTCD/publications/PDF/cnpp2022/countryprofiles/Mexico/Mexico.htm>, accessed 19 August 2025.

¹⁹⁷¹ - Government of Mexico, "National Report Presented by the United Mexican States to Meet the Requirements of the Convention on Nuclear Safety 2010-2012", August 2013, see https://www.gob.mx/cms/uploads/attachment/file/183045/National_Report-Mexico_2012.pdf; and Alejandro Merino Teillet, "CN Laguna Verde Power Uprate and Modernization Project", Iberdrola, via Wayback Machine, captured 13 July 2011, see <https://web.archive.org/web/20110713000747/http://www.iberdrolaingenieria.com/ibding/contenido/documentacion/05.pdf>, both accessed 18 August 2025.

¹⁹⁷² - IAEA, "SALTO Mission to Laguna Verde—Mission Report—Executive Summary", International Atomic Energy Agency, 5 March 2019, see https://www.iaea.org/sites/default/files/documents/review-missions/41_laguna_verde_salto_executive_summary.pdf, accessed 21 August 2024.

Energy (commonly known as Sener), in the middle of the coronavirus pandemic, to allow for the operation of Unit 1 until July 2050.¹⁹⁷³ The license for Unit 2—initially set to expire in April 2025—was extended in August 2022 by Sener, allowing the reactor to run until April 2055.¹⁹⁷⁴ Reactor operation remains subject to periodic safety reviews.

Since the beginning, LVNPP has faced technical issues that have impacted its performance, like radioactive steam leaks, contaminated water discharges, and unplanned shutdowns (scrams). Therefore, the annual load factors have varied greatly, and as of year-end 2024, lifetime load factors remained below 80 percent for Unit 1 and just above 81 percent for Unit 2.¹⁹⁷⁵

In addition, according to the International System on Occupational Exposure's (ISOE) latest review, "Laguna Verde's historical collective dose both on-line and during refueling outages, which are carried out every 18 months, is higher than the BWR average."¹⁹⁷⁶

The open dry spent-fuel storage facility (known as ISFSI) was envisaged to be fully operational in 2016 but started up two years later due to delays in the international tender organization and the delivery of the special storage containers. Then, it received fewer containers than planned according to the original scheme. It was not until 2023 that the storage facility received the 13 containers initially planned.¹⁹⁷⁷

Energy Policy—Will the Sheinbaum Administration Initiate a Major Shift?

Mexico's electricity mix is highly dependent on fossil fuels, which represented over 75 percent of the gross production in 2024 (with 62.4 percent gas, 9.5 percent oil, and 3.5 percent coal power production). Renewables accounted for 21 percent (7.2 percent solar, 6.6 percent hydro, 5.6 percent wind, and 1.7 percent geothermal and other types of production). Nuclear represented 3.5 percent of the total (gross) generation.¹⁹⁷⁸

This situation is partially due to the administration of former President Andrés Manuel López Obrador (2018–2024), whose policies favored fossil fuels. His successor and protégée, President Claudia Sheinbaum, intends to provide more support for renewables and energy storage.

The Mexican government has partially reversed the 2013 energy reform that opened up the market to private investment. The counter-reform has reestablished the public companies' hegemony, has imposed new rules for private participation, and has put the regulators, until

¹⁹⁷³ - Ministry of Energy, "La Secretaría de Energía renueva la licencia de operación a Unidad 1 de la Central Nuclear Laguna Verde", Government of Mexico, 17 July 2020, see <http://www.gob.mx/sener/articulos/la-secretaria-de-energia-renueva-la-licencia-de-operacion-a-unidad-1-de-la-central-nuclear-laguna-verde?idiom=es>, accessed 7 May 2021.

¹⁹⁷⁴ - CFE, "La Central Nucleoeléctrica Laguna Verde Refrenda Su Compromiso Con el Medio Ambiente y la Seguridad Energética de México, al Obtener la Extensión de Licencia de Operación de su Unidad 2 Por 30 Años Más", Press Release, Comisión Federal de Electricidad/Federal Electricity Commission, 25 August 2022, see <https://app.cfe.mx/Aplicaciones/OTROS/Boletines/boletin?i=2634>, accessed 28 August 2024.

¹⁹⁷⁵ - IAEA-PRIS, "Country Statistics—Laguna Verde-1", Updated 7 June 2025, see <https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=420>; and IAEA-PRIS, "Country Statistics—Laguna Verde-2", Updated 7 June 2025, see <https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=421>; both accessed 8 June 2025.

¹⁹⁷⁶ - International System on Occupational Exposure, "ISOE Country Reports 2022", IAEA, and Nuclear Energy Agency, Revised 20 March 2024, see <https://next.isoe-network.net/publications/pub-resources/annual-country-reports/4869-2022-isoe-country-reports/file.html>, accessed 5 May 2025.

¹⁹⁷⁷ - CFE, "Informe anual 2023", 25 April 2024, see <https://www.cfe.gob.mx/finanzas/reportes-financieros/Reportes%20Anuales%20Documentos/Informe%20Anual%202023.pdf>, accessed 14 June 2025.

¹⁹⁷⁸ - Energy Institute, "Statistical Review of World Energy 2025—Consolidated Dataset", June 2025, op. cit.

recently independent, under governmental control. Therefore, the state is judge and player at the same time, since state-controlled regulators will oversee companies like Pemex and CFE.¹⁹⁷⁹

Under the Sheinbaum administration, nuclear newbuild appears out of the picture. Even though the latest National Electric System's Development Program 2024–2038 (PRODESEN)—like the previous 2023–2037 edition—accounts for 2.35 GW of new nuclear capacity to be deployed in 2028–2038,¹⁹⁸⁰ there are no official plans to add reactors to Laguna Verde nor to build another plant (like small nuclear reactors). A few days into her presidency, in October 2024, Sheinbaum dismissed any such plans.¹⁹⁸¹ Indeed, as of mid-2025, her electricity strategy does not include more nuclear power.

In addition, CFE's 2024–2028 business plan does not include any nuclear energy investments.¹⁹⁸²

After Sheinbaum took office, there was a communication push by the nuclear union and columnists to develop more nuclear energy, but it failed to change her stance.¹⁹⁸³

An issue of concern is the U.S. President Donald Trump lashing out at Mexico, more than in his previous term, focusing on issues like migration, drug policies, and bilateral trade. Even though Trump is pushing nuclear newbuild in his country, he has not stated anything regarding the deployment of the technology in Mexico. In 2018, during his first tenure in office, both countries signed a nuclear cooperation agreement¹⁹⁸⁴ that entered into force in 2022 and allows for the transfer of nuclear technology and related information.¹⁹⁸⁵

Sheinbaum is an environmental scientist and energy expert who used to be a researcher at the Institute of Engineering at UNAM, and a contributor to the Intergovernmental Panel on Climate Change (IPCC). She became a politician in the early 2000s, when she served as Mexico

¹⁹⁷⁹ - Ministry of Energy, “Presenta Secretaría de Energía la Legislación Secundaria para el sector energético”, Government of Mexico, 29 January 2025, see <https://www.gob.mx/sener/es/articulos/presenta-secretaria-de-energia-la-legislacion-secundaria-para-el-sector-energetico?idiom=es>, accessed 18 August 2025; and Diario Oficial de la Federación, “DECRETO por el que se expiden la Ley de la Empresa Pública del Estado, Comisión Federal de Electricidad; la Ley de la Empresa Pública del Estado, Petróleos Mexicanos; la Ley del Sector Eléctrico; la Ley del Sector Hidrocarburos; la Ley de Planeación y Transición Energética; la Ley de Biocombustibles; la Ley de Geotermia y, la Ley de la Comisión Nacional de Energía; se reforman diversas disposiciones de la Ley del Fondo Mexicano del Petróleo para la Estabilización y el Desarrollo y, se reforman, adicionan y derogan diversas disposiciones de la Ley Orgánica de la Administración Pública Federal.”, 18 March 2025, see https://www.dof.gob.mx/nota_detalle.php?codigo=5752329&fecha=18/03/2025#sc.tab=0, both accessed 18 August 2025.

¹⁹⁸⁰ - Ministry of Energy, “Programa de Desarrollo del Sistema Eléctrico Nacional 2023-2037—PRODESEN 2023-2037, Government of Mexico, 29 May 2023, see <http://www.gob.mx/sener/en/articulos/programa-de-desarrollo-del-sistema-electrico-nacional-2023-2037>, accessed 15 May 2025

¹⁹⁸¹ - Energy Analytics Institute, “Sheinbaum Says Mexico Not Looking to Boost Nuclear Energy”, 10 October 2024, see <https://energy-analytics-institute.org/2024/10/10/sheinbaum-says-mexico-not-looking-to-boost-nuclear-energy/>, accessed 12 May 2025.

¹⁹⁸² - CFE, “Plan de negocios 2024-2028”, December 2023, see <https://www.cfe.gob.mx/finanzas/Documents/Plan%20de%20Negocios%202024-2028.pdf>, accessed 15 June 2025.

¹⁹⁸³ - Yeshua Ordaz, “Energía nuclear, opción limpia y ágil para el país: Expertos”, *Milenio*, 18 December 2024, see <https://www.milenio.com/negocios/energia-nuclear-opcion-limpia-agil-expertos>; and Gabriel Quadri de la Torre, “Renacimiento nuclear, México al margen”, *El Economista*, 6 February 2025, see <https://www.eleconomista.com.mx/opinion/renacimiento-nuclear-mexico-margen-20250206-745372.html>; both accessed 1 May 2025

¹⁹⁸⁴ - Governments of Mexico and the United States, “Mexico and the United States Sign Nuclear Energy Cooperation Agreement”, Press Release, 7 May 2018, see <https://www.gob.mx/sre/en/prensa/mexico-and-the-united-states-sign-nuclear-energy-cooperation-agreement>, accessed 5 May 2025

¹⁹⁸⁵ - U.S. Department of State, “U.S.-Mexico Civil Nuclear Cooperation Agreement Enters into Force”, Government of the United States, 3 November 2022, see <https://2021-2025.state.gov/u-s-mexico-civil-nuclear-cooperation-agreement-enters-into-force/>, accessed 2 May 2025.

City's Secretary of Environment under Mayor López Obrador, before acting as the metropolis' mayor herself between 2018 and 2023.¹⁹⁸⁶

Sheinbaum's energy policy appears somewhat contradictory. On one hand, her support for Pemex and CFE means maintaining the role of fossil fuels, and her backing for natural gas infrastructure including gas-fired power plants deepens Mexico's dependence on U.S. gas. On the other hand, her government is preparing a new climate policy—the Nationally Determined Contribution or NDC—which would take the emissions reduction target from 35 percent to 40 percent by 2030.¹⁹⁸⁷ Under the previous administration, the country committed to a net-zero target by 2050, but it lacks a roadmap with middle-term goals.¹⁹⁸⁸ The updated NDC is expected to be ready before COP30, to be held in the northwestern city of Belem (Brazil) in November 2025.¹⁹⁸⁹

Meanwhile, pushed by gas consumption, deforestation, livestock, and agriculture, Mexico's greenhouse gas emissions have been growing; in 2024, its emissions reached 882 million tons of CO₂e according to the government.¹⁹⁹⁰ The country is the second largest polluter in Latin America after Brazil and among the world's top 15 emitters.

Laguna Verde's Difficult Lifetime Extension

President Sheinbaum faces budgetary constraints which eventually could affect CFE's performance and, therefore, LVNPP's. In the first quarter of 2025, CFE registered a net loss in income of almost MXN 16.1 billion (US\$836 million), reversing the positive trend from the previous three years.¹⁹⁹¹ The main drivers are debt, electricity consumption subsidies, and generation costs.¹⁹⁹²

The future of the nuclear plant looks rather bleak, as its historical problems would keep a toll on its performance and the lack of appropriate budget appropriations might hinder proper maintenance and upgrading of the facilities. As the 2022 SALTO review pointed out, IAEA's technical team noted that the plant still needed to:

Perform a comprehensive periodic safety review to identify potential safety improvements for LTO [Long-Term Operation].

¹⁹⁸⁶ - Martha Pskowski, "Mexico Elected a Climate Scientist. But Will She Be a Climate President?", *Inside Climate News*, 7 June 2024, see <https://insideclimatenews.org/news/07062024/mexico-president-elect-claudia-sheinbaum-climate-policy/>, accessed 1 June 2025.

¹⁹⁸⁷ - Semarnat, "Mensaje de la secretaria de Medio Ambiente y Recursos Naturales, Alicia Bárcena Ibarra, en la Cumbre México-Reino Unido", Secretaría de Medio Ambiente y Recursos Naturales/Ministry of Environment and Natural Resources, 9 April 2025, see <https://www.gob.mx/semarnat/documentos/mensaje-de-la-secretaria-de-medio-ambiente-y-recursos-naturales-alicia-barcena-ibarra-durante-el-encuentro-mexico-uk-summit>, accessed 10 April 2025.

¹⁹⁸⁸ - Ministry of Foreign Affairs, and U.S. Embassy in Mexico, "Mexico Announces New Commitments to Combat Climate Change at COP27", Press Release, Government of Mexico, 14 November 2022, op. cit.

¹⁹⁸⁹ - Semarnat, "Mensaje de la secretaria de Medio Ambiente y Recursos Naturales, Alicia Bárcena Ibarra, en la Cumbre México-Reino Unido", 9 April 2025, op. cit.

¹⁹⁹⁰ - Ibidem.

¹⁹⁹¹ - CFE, "Reporte trimestral 2025", 31 March 2025, see <https://www.cfe.gob.mx/finanzas/reportes-financieros/Reportes%20Trimestrales%20Documentos/Reporte%201er%20Trimestre%202025.pdf>, accessed 31 March 2025; and CFE, "Operational and Financial Results as of 1Q 2025—Investors Presentation", 12 May 2025, see https://www.cfe.gob.mx/finanzas/financiamiento-informacion/Quarterly%20Investor%20Presentations%20Doc/2025/120525_Presentacion%20C3%B3n_Inversionistas_Ingles_SFC.pdf, accessed 8 June 2025.

¹⁹⁹² - IMCO, "CFE tuvo una pérdida de 16.1 mil millones de pesos en el primer trimestre de 2025", Instituto Mexicano para la Competitividad, 2 May 2025, see <https://imco.org.mx/cfe-tuvo-una-perdida-de-16-1-mil-millones-de-pesos-en-el-primer-trimestre-de-2025/>, accessed 3 May 2025.

Fully implement a programme to confirm resistance of electrical components to harsh conditions, a so-called equipment qualification programme.¹⁹⁹³

On Mexico's request, the IAEA did not publish the 2022 summary report, as it did in 2019, which enlists the main issues identified during the technical visit.¹⁹⁹⁴

United States

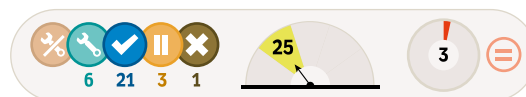
See Focus Countries – [United States Focus](#).

ASIA

China

See Focus Countries – [China Focus](#).

India



India has 21 operational nuclear power reactors, with a total net generating capacity of 7.4 GW. As of 1 July 2025, the PRIS database listed four reactors under the “suspended operation” category. However, among these, the Rajasthan-1 reactor (RAPS-1) has not generated power since 2004 and is considered permanently closed in WNISR statistics. The other three units are classified under the LTO category, with those reactors not having generated power for many years: Tarapur-1 and -2 since 2020, and Madras-1 since 2018. In December 2024, India's Minister in charge of Atomic Energy told parliament that “TAPS-1&2 and MAPS-1 are presently under project mode”;¹⁹⁹⁵ elsewhere, he has said that this “project mode” was for upgrading these reactors.¹⁹⁹⁶ The Rajasthan-3 reactor (RAPS-3) that had been shut down since October 2022 for “renovation and modernisation” after 22 years of operation, was reconnected to the grid at the end of July 2024, leaving the LTO status.¹⁹⁹⁷

¹⁹⁹³ - IAEA, “IAEA Concludes Long Term Operational Safety Review at Mexico's Laguna Verde Nuclear Power Plant”, 27 June 2022, see <https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operational-safety-review-at-mexicos-laguna-verde-nuclear-power-plant-o>, accessed 6 May 2025.

¹⁹⁹⁴ - IAEA, “Peer Review and Advisory Services Calendar—Safety Aspects of Long Term Operation (SALTO)—2022—Mexico”, International Atomic Energy Agency, Undated, see <https://www.iaea.org/services/review-missions/calendar?type=3169&year%5Bvalue%5D%5Byear%5D=2022&location=3575&status=All>, accessed 6 June 2025; and IAEA, “Safety Aspects of Long Term Operation (SALTO)”, Undated, see <https://www.iaea.org/services/review-missions/safety-aspects-of-long-term-operation-salto>, accessed 8 June 2025; and IAEA, “SALTO Mission to Laguna Verde—Executive Summary”, 2019, see https://www.iaea.org/sites/default/files/documents/review-missions/41_laguna_verde_salto_executive_summary.pdf, accessed 21 August 2024.

¹⁹⁹⁵ - Department of Atomic Energy, “Parliament Question: Atomic Power Stations”, Press Release, Government of India, 12 December 2024, see <https://www.pib.gov.in/Pressreleaseshare.aspx?PRID=2083830>, accessed 23 May 2025.

¹⁹⁹⁶ - Department of Atomic Energy, “Lok Sabha: Starred Question No. *362—Nuclear Power Plants—Answered on 26.03.2025”, Government of India, 26 March 2025, see <https://cdnbbsr.s3waas.gov.in/s35b8e4fd39d9786228649a8a8bec4e008/uploads/2025/04/202504021656679031.pdf>, accessed 17 June 2025.

¹⁹⁹⁷ - Department of Atomic Energy, “RAPS-3 Comes Back Online After Renovation & Modernisation”, Government of India, 29 July 2024, see <https://www.pib.gov.in/Pressreleaseshare.aspx?PRID=2038579>, accessed 3 June 2025.

As of mid-2025, the latest reactor to start operating is Rajasthan-7, which was connected to the grid in March 2025,¹⁹⁹⁸ and declared as operating commercially in April 2025¹⁹⁹⁹. Construction of the reactor started with first pour of concrete in July 2011, and thus the project took 164 months to complete.²⁰⁰⁰

Reactors in India generated a record 54.7 TWh in 2024 according to IAEA-PRIS data, a surge of almost 12 percent compared to the previous year. The startup in February 2024 of the Kakrapar-4 reactor contributed alone about 30 percent of the additional production.

The share of nuclear of all the grid-fed electricity in the country, after declining since 2020, has increased slightly from 3.1 percent to 3.3 percent, returning to the same level as in 2020. However, the share calculation is at odds with the Energy Institute, which reports the same figure as PRIS for generation by nuclear reactors (54.7 TWh gross/52 TWh net), but calculates that the share of all electricity produced is a little under 2.7 percent.²⁰⁰¹ The reason for the difference between the two sources is unclear.

Delays in Construction and Plans

India is building six more reactors with a combined net capacity of 4.8 GW. This includes the Prototype Fast Breeder Reactor (PFBR) that has been under construction since October 2004, the Pressurized Heavy Water Reactor (PHWR) Rajasthan-8, under construction since September 2011, and four VVER-1000s at Kudankulam, whose building started in June and October 2017 for the first two units, and June and December 2021 for the second pair (see [previous WNISR editions](#)).

The 500-MW PFBR is now nearly 15 years past the initially projected commissioning date of September 2010.²⁰⁰² Loading of fuel into the core of the PFBR finally began on 4 March 2024.²⁰⁰³ In July 2024, India's Atomic Energy Regulatory Board approved the "first approach to criticality".²⁰⁰⁴ But there has been no announcement of the reactor reaching criticality so far, and in April 2025, the commissioning date was announced as September 2026.²⁰⁰⁵

Among the VVER reactors being imported from Russia, Kudankulam-5 and -6 are scheduled to be commissioned in 2027 and 2028 respectively, while Kudankulam-3 and -4 are now expected

1998 - Department of Atomic Energy, "Rajasthan's RAPP-7 Unit Joins Northern Grid, Marking Key Milestone", Government of India, 17 March 2025, see <https://www.pib.gov.in/www.pib.gov.in/Pressreleaseshare.aspx?PRID=2111887>, accessed 17 June 2025.

1999 - IAEA-PRIS, "Country Statistics—Rajasthan-7", Updated 16 June 2025, see <https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=298>, accessed 17 June 2025.

2000 - NPCIL, "Project—Rajasthan Atomic Power Project - 7&8", Nuclear Power Corporation of India Limited, Undated, see https://www.npcil.nic.in/content/300_1_RajasthanAtomicPowerProject.aspx, accessed 6 April 2022.

2001 - Energy Institute, "Statistical Review of World Energy 2025—Consolidated Dataset", 74th Edition, June 2025, see https://www.energyinst.org/_data/assets/excel_doc/0006/1656348/Statistical-Review-of-World-Energy-Data.xlsx, accessed 27 June 2025.

2002 - MoSPI, "450th Flash Report on Central Sector Projects (Rs. 150 crore and above)", Ministry of Statistics and Programme Implementation, Government of India, May 2023, see http://www.cspm.gov.in/english/flr/FR_May_2023.pdf, accessed 28 June 2023.

2003 - IPFM, "India Begins Loading Fuel in Prototype Fast Breeder Reactor", Blog, International Panel on Fissile Materials, 4 March 2024, see https://fissilematerials.org/blog/2024/03/india_begins_loading_fuel.html, accessed 10 May 2024.

2004 - Department of Atomic Energy, "AERB Grants Permission for First Approach to Criticality of 500 MWe Prototype Fast Breeder Reactor", Press Release, 30 July 2024, see <https://www.pib.gov.in/www.pib.gov.in/Pressreleaseshare.aspx?PRID=2039099>, accessed 17 June 2025.

2005 - *The Times of India*, "First Of Its Kind Prototype-Breeder Reactor to Be Commissioned by September 2026", 19 April 2025, see <https://timesofindia.indiatimes.com/india/first-of-its-kind-prototype-breeder-reactor-to-be-commissioned-by-september-2026/articleshow/120426007.cms>, accessed 26 May 2025.

to be commissioned in 2026 and 2027.²⁰⁰⁶ When construction started, officials projected that these would start in March 2023 and in 2024.²⁰⁰⁷

Alongside these delays, the estimated costs of these reactors have also gone up (rounded figures hereafter). The PFBR's cost has more than doubled from the initially anticipated Rs.35 billion to Rs.77 billion as of May 2024.²⁰⁰⁸ The total cost for Kakrapar-3 and -4 is now estimated at Rs.225 billion, up from Rs.115 billion; similarly, Rajasthan-7 and -8 were initially estimated at Rs.123 billion but the official estimate has gone up to Rs.229 billion as of December 2024. Likewise, Kudankulam-3 and -4 were initially projected to cost Rs.399 billion but the official estimate has increased to Rs.689 billion.²⁰⁰⁹

This year, again, the Indian government announced that it was planning to build a large number of PHWRs (see *earlier editions of the WNISR*). In March 2025, the government listed four additional reactors—GHAVP-1 & -2 in Gorakhpur, Haryana and Kaiga-5 & -6 in Karnataka—as being “projects under construction”, and eight reactors—GHAVP-3 & -4, Chutka-1 & -2, Mahi Banswara-1, -2, -3 & -4—as “projects sanctioned & under pre-project activities”.²⁰¹⁰

Among the latter list, the four-unit Mahi Banswara Rajasthan Atomic Power Project received the siting approval from India's Atomic Energy Regulatory Board in May 2025.²⁰¹¹ This follows the December 2023 government announcement that it had acquired the land for the project.²⁰¹² But construction has not started, as is the case with GHAVP-3 & -4 and Chutka-1 & -2.

More dramatic is the case of the two projects in Gorakhpur and Kaiga that have been listed as being under construction for many years now. Excavation of the site for Kaiga-5 and -6 started in April 2022.²⁰¹³ For the former, in March 2018, the Nuclear Power Corporation of India Limited (NPCIL) announced that excavation of the site had commenced and that the project “is scheduled to be completed in about six years.”²⁰¹⁴ Had that project schedule been met, the reactor would have been generating power by now. But as of mid-2025, the IAEA's

²⁰⁰⁶ - Department of Atomic Energy, “Lok Sabha: Unstarred Question No- 2155—Nuclear Power Generation—Answered on 12/03/2025”, Government of India, 12 March 2025, see https://sansad.in/getFile/loksabhaquestions/annex/184/AU2155_UqC3nk.pdf?source=pqals, accessed 3 June 2025.

²⁰⁰⁷ - *The Press Trust of India*, “Building Of Units 3 & 4 Of Kudankulam Nuke Power Plant Begins”, as published in *The Deccan Herald*, 29 June 2017, see <https://www.deccanherald.com/content/619873/building-units-3-4-kudankulam.html>, accessed 13 July 2021.

²⁰⁰⁸ - As of June 2025, the conversion rate to US dollars is around Rs.85 per US dollar. However, all of the official costs for Indian nuclear projects are expressed in mixed-year Rupees and so directly converting it into other currencies using one conversion rate is misleading.

²⁰⁰⁹ - MoSPI, “Quarterly Project Implementation Status Report Costing Rs. 150 Crore & Above: Quarter-3 FY 2024-25 (October-December)”, Ministry of Statistics and Programme Implementation, Government of India, December 2024, see http://www.cspm.gov.in/english/qpsr/qrcu/qrcu/2024-25/QPISR_IIIrd_QRT.pdf, accessed 23 May 2025.

²⁰¹⁰ - Department of Atomic Energy, “Rajya Sabha: Unstarred Question No.3044—New Projects in Nuclear Energy—Answered on 27/03/2025”, Government of India, 27 March 2025, see <https://cdnbbsr.s3waas.gov.in/s35b8e4fd39d9786228649a8a8bec4e008/uploads/2025/04/202504011203905396.pdf>, accessed 26 May 2025.

²⁰¹¹ - Atomic Energy Regulatory Board, “Consent for Siting of Mahi Banswara Rajasthan Atomic Power Project (MBRAPP – 1 to 4)”, 9 May 2025, see <https://www.aerb.gov.in/storage/uploads/News/news2280M.pdf>, accessed 17 June 2025.

²⁰¹² - Department of Atomic Energy, “Lok Sabha: Starred Question No.*250—Construction of Nuclear Power Plant—Answered on 20.12.2023”, Government of India, 20 December 2023, see <https://sansad.in/getFile/loksabhaquestions/annex/1714/AS250.pdf?source=pqals>, accessed 29 June 2024.

²⁰¹³ - Department of Atomic Energy, “Excavation Begins at NPCIL's Kaiga 5&6 Project, to Increase Capacity of the Atomic Power Station to 2280 MW”, Press Release, Government of India, 28 April 2022, see <https://www.pib.gov.in/Pressreleaseshare.aspx?PRID=1821008>, accessed 27 May 2025.

²⁰¹⁴ - NPCIL, “Excavation starts on first pair of nuclear power reactors in Haryana”, Press Release, 24 March 2018, see http://www.npcil.nic.in/writereaddata/Orders/201803241054565793647news_24mar2018_01.pdf, accessed 26 March 2018.

PRIS database still does not list the reactors as being “under construction”, let alone as being operational. The only significant update dates back to December 2022, when the government announced that GHAVP-1 and -2’s “foundation piles” were completed and that “testing” as well as “construction of other buildings and structures” were “underway”.²⁰¹⁵ In June 2025, the Minister for Power reportedly announced that the first two units of the GHAVP are “expected to be commissioned by 2031” and “the remaining two by 2032”.²⁰¹⁶

Going even further back in time, the government was explicit about when most of these reactors (GHAVP-1 & -2, Kaiga-5 & -6, Chutka-1 & -2, Mahi Banswara-1 & -2) were expected to be completed. In July 2014, the Indian government spokesperson told the parliament that GHAVP-1 & -2 were planned for completion in September 2020 and March 2021 respectively, Chutka-1 & -2 were to be completed in December 2020 and June 2021 respectively, Mahi Banswara-1 & -2 in December 2021 and June 2022 respectively, and Kaiga-5 & -6 in June 2022 and December 2022 respectively.²⁰¹⁷ This history of lengthy delay between announcements and actual construction suggests that none of these reactors will be completed anytime soon.

The other set of projects that have been delayed even further are the reactors that were/are to be imported from the U.S. and France. These plans have been in the news ever since the negotiations of the U.S.-India nuclear deal between 2005 and 2008.²⁰¹⁸ In 2008, Anil Kakodkar who was then the chairman of India’s Atomic Energy Commission, had envisioned importing 40 GW of light water reactors by 2020 as a result of the nuclear deal.²⁰¹⁹

The proposal to build six AP-1000 reactors at Kovvada in Andhra Pradesh remains dormant. In February 2025, a joint statement issued by Prime Minister Modi and U.S. President Trump did not even mention this project explicitly; however, the statement did mention their “commitment to fully realize the U.S.-India 123 Civil Nuclear Agreement by moving forward with plans to work together to build U.S.-designed nuclear reactors in India through large scale localization and possible technology transfer.”²⁰²⁰ Two months later, when questioned in parliament about the status of the project, the Indian government could only point to acquiring the land for the reactors but explained that Westinghouse had submitted a “techno-commercial offer” in 2016. However, after Westinghouse filed for bankruptcy protection in 2017 and was subsequently taken over by Canadian holding Brookfield Business Partners, it “communicated that the earlier TCO [techno-commercial offer] submitted was no longer valid” and the government was waiting for a revised TCO.²⁰²¹

2015 - Department of Atomic Energy, “Lok Sabha: Unstarred Question No. 1179—Setting Up of New Nuclear Power Plants”, Written Answer, Government of India, 14 December 2022.

2016 - Anil Kakkar, “Gorakhpur Nuclear Project to Light up Homes by 2032”, *The Tribune*, 15 June 2025, see <https://www.tribuneindia.com/news/haryana/gorakhpur-nuclear-project-to-light-up-homes-by-2032/>, accessed 18 June 2025.

2017 - Government of India, “Lok Sabha: Unstarred Question No. 956—New Nuclear Reactors”, Written Answer, 16 July 2014, see https://eparlib.sansad.in/bitstream/123456789/758759/3/lsd_16_02_16-07-2014.pdf, accessed 24 May 2022.

2018 - Prerna Gupta and M. V. Ramana, “A Decade After the Nuclear Deal”, *The India Forum*, 3 April 2019, see <https://www.theindiaforum.in/article/decade-after-nuclear-deal>, accessed 17 May 2020.

2019 - Anil Kakodkar, “Evolving Indian Nuclear Energy Programme - Rationale and Perspective”, presented at the Indian Academy of Sciences, 4 July 2008, see <http://www.igcar.gov.in/igc2004/111FILE.pdf>, accessed 21 December 2016.

2020 - The White House, “United States-India Joint Leaders’ Statement”, U.S. Presidency, 13 February 2025, see <https://www.whitehouse.gov/briefings-statements/2025/02/united-states-india-joint-leaders-statement/>, accessed 1 June 2025.

2021 - Department of Atomic Energy, “Rajya Sabha: Unstarred Question No- 3683— Nuclear Reactor in Kovvada in Andhra Pradesh— Answered on 03/04/2025”, Government of India, 3 April 2025, see <https://cdnbbsr.s3waas.gov.in/s35b8e4fd39d9786228649a8a8bec4e008/uploads/2025/04/202504151058415372.pdf>, accessed 31 May 2025.

In the case of the proposed nuclear reactors to be imported from France for the Jaitapur site (see past [WNISR2022](#) and other past [WNISR](#) editions), the Indian government informed the parliament in March 2025 that “presently discussions are in progress with the French side to arrive at a viable project proposal” and “the estimated cost will emerge on conclusion of these discussions.”²⁰²² This is more than a year after India’s Foreign Secretary announced in January 2024 that France’s EDF and NPCIL were discussing details like financing mechanisms and localization components.²⁰²³ On France’s side, as of June 2025, EDF’s website announces that a “key milestone” was reached in April 2021, when EDF’s “techno-commercial binding offer [was] submitted” and that “NPCIL and EDF [would] work alongside in order to reach a General Framework Agreement in the coming months.”²⁰²⁴ That did not happen since.

Despite these lengthy delays, the government continues to set ambitious goals—a practice that dates back to the 1950s.²⁰²⁵ In the 2025–2026 budget presentation, the government announced a new one: “at least 100 GW of nuclear energy by 2047” including “at least 5 indigenously developed SMRs [Small Modular Reactors]...operationalized by 2033.”²⁰²⁶ The significance of 2047 is that it would mark 100 years since India’s independence from British colonialism. An earlier target from 1999 also had a similar rhythm to it: 20,000 MW by 2020.²⁰²⁷ As detailed in [WNISR2020](#), India’s net capacity was just 6,200 MW, less than a third of the target for that year.

When the government announced the latest target, the Chairman of the Atomic Energy Commission told the media that 100 GW by 2047 is “very achievable” but “getting land and appropriate nuclear fuel could be a limiting factor” while the “private sector can help augment capacity by building nuclear plants especially small modular reactors.”²⁰²⁸ The mention of land being a limiting factor testifies to the intensity of opposition movements that have sprung up near all nuclear reactor sites.²⁰²⁹

Whether involving the private sector is going to change anything significantly about the future of nuclear power in India remains to be seen. However, the government is reportedly considering amending laws governing the nuclear sector in India to ease participation of private

2022 - Department of Atomic Energy, “Lok Sabha: Starred Question No. 265—Jaitapur Nuclear Power Plant—Answered on 19.03.2025”, Government of India, 19 March 2025, see <https://cdnbbsr.s3waas.gov.in/s35b8e4fd39d9786228649a8a8bec4e008/uploads/2025/03/202503261719529608.pdf>, accessed 31 May 2025.

2023 - *Press Trust of India*, “India, France in Talks for Financing Mechanism, Localisation for Jaitapur N-Project”, as published by *The Economic Times*, 26 January 2024, see <https://economictimes.indiatimes.com/news/india/india-france-in-talks-for-financing-mechanism-localisation-for-jaitapur-n-project/articleshow/107174054.cms?from=mdr>, accessed 29 June 2024.

2024 - EDF India, “JNPP: The Largest Nuclear Power Plant Worldwide”, Undated, see <https://india.edf.com/en/our-activities/nuclear/jnpp-the-largest-nuclear-power-plant-worldwide>, last accessed 17 June 2025.

2025 - M. V. Ramana, “The Power of Promise: Examining Nuclear Energy in India”, *Penguin Books India*, 2012.

2026 - Nirmala Sitharaman, “Budget 2025-2026—Speech”, Minister of Finance, Government of India, 1 February 2025, see https://www.indiabudget.gov.in/doc/Budget_Speech.pdf, accessed 17 June 2025.

2027 - Anto T. Joseph, “India Plans to Be Nuke Powerhouse by 2020, Sets a 20,000 MW Target”, *The Economic Times*, 16 September 1999.

2028 - Pallava Bagla, “Budget 2025: Nirmala Sitharaman Announces Nuclear Energy Mission For ‘Viksit Bharat’”, *NDTV*, 1 February 2025, see <https://www.ndtv.com/india-news/budget-2025-nirmala-sitharaman-announces-nuclear-energy-mission-for-viksit-bharat-7610570>, accessed 17 June 2025.

2029 - Ajmal Khan, “People Against Nuclear Energy: Anti-nuclear Movements in India”, *SAGE Publications India*, 2022.

sector companies.²⁰³⁰ This is not entirely new; for example, in November 2022, the Minister responsible for Atomic Energy invited private sector companies to participate in building SMRs.²⁰³¹ In July 2024, Tata Power, part of a large industrial conglomerate in India, announced that it will “explore participation in Small Modular Nuclear Reactors, once the Government gives necessary permissions...”²⁰³² In the meanwhile, the company announced in its latest annual report that it is “preparing proactively by evaluating potential sites, securing water resources, and reviewing advanced nuclear technologies, including small modular reactors.”²⁰³³

Another part of the same conglomerate, Tata Consulting Engineers signed an agreement with GE-Hitachi in 2010 to “explore potential project design and workforce development opportunities in support of GEH’s future nuclear projects in India and around the world.”²⁰³⁴ But nothing seems to have resulted from that agreement. According to media reports, the Department of Atomic Energy expects Public-Private Partnerships to account for around 50 percent of the 100 GW target.²⁰³⁵

Power Mix

Renewable energy continues to progress rapidly in India. According to the International Renewable Energy Agency (IRENA), total renewable energy capacity (including large hydro plants) grew by a factor of 2.6 from 78.6 GW in 2015 to 204.3 GW in 2024.²⁰³⁶

In 2024, solar energy totals 97.4 GW with a 33.7 percent increase over 2023. Wind energy capacity reached 48.2 GW, an increase of 7.7 percent compared to 2023. With the grid connection of one new reactor, nuclear capacity increased by 0.6 GW. According to the Central Electricity Authority, the official data source on India’s electricity sector, the capacity of non-hydro modern renewables was 178.8 GW with hydropower at 47.9 GW as of 31 May 2025.²⁰³⁷ Coal continues to dominate with an installed capacity of 212.7 GW, also as of 31 May 2025, whereas the installed capacity of gas is 20.1 GW. But, in July 2025, the government announced that

²⁰³⁰ - Press Trust of India, “Govt Considering Amendments to Atomic Energy Act, Nuclear Liability Law”, *The New Indian Express*, 19 May 2025, see <https://www.newindianexpress.com/nation/2025/May/19/govt-considering-amendments-to-atomic-energy-act-nuclear-liability-law-2>, accessed 1 June 2025.

²⁰³¹ - Department of Atomic Energy, “Union Minister Dr Jitendra Singh Says, India Taking Steps for Development of Small Modular Reactors (SMR), with up to 300 MW Capacity to Fulfill Its Commitment to Clean Energy Transition”, Press Release, Government of India, 27 November 2022, see <https://www.pib.gov.in/Pressreleaseshare.aspx?PRID=1879298>, accessed 17 June 2025.

²⁰³² - Tata Power, “Tata Power to Invest Rs 20,000 Crore Capex in FY25: N Chandrasekaran, Chairman at Company’s 105th AGM”, Press Release, July 2024, see <https://www.tatapower.com/news-and-media/media-releases/tata-power-to-invest-20000-crore-capex-in-fy25-n-chandrasekaran-chairman-at-companys-105th-agm>, accessed 17 June 2025.

²⁰³³ - Tata Power, “Integrated Annual Report 2024-25”, 2025, see <https://www.tatapower.com/content/dam/tatapoweraemsitesprogram/tatapower/pdf-root/company-financials/annual-reports/106AnnualReport-2024-25.pdf>, accessed 17 June 2025.

²⁰³⁴ - GEH, “GE Hitachi Nuclear Energy and Tata Consulting Engineers Exploring Potential Design and Workforce Development Opportunities for New Reactor Projects”, Press Release, 17 August 2010, see <http://www.genewsroom.com/Press-Releases/GE-Hitachi-Nuclear-Energy-and-Tata-Consulting-Engineers-Exploring-Potential-Design-and-Workforce-Development-Opportunities-for-New-Reactor-Projects-224707>, accessed 28 May 2017.

²⁰³⁵ - Press Trust of India, “Govt Considering Amendments to Atomic Energy Act, Nuclear Liability Law”, 19 May 2025, op. cit.

²⁰³⁶ - IRENA, “Renewable Capacity Statistics 2025”, March 2025, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Mar/IRENA_DAT_RE_Capacity_Statistics_2025.pdf, accessed 26 March 2025.

²⁰³⁷ - Central Electricity Authority, “All India Installed Capacity”, Monthly Report, as of 31 May 2025, see https://cea.nic.in/wp-content/uploads/installed/2025/05/IC_May_2025_allocation_wise.xlsx, accessed 17 June 2025.

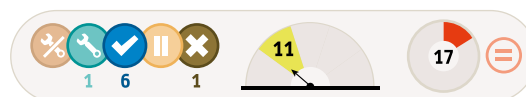
50 percent of India's installed capacity was now non-fossil fueled, 242.8 GW of 484.8 GW.²⁰³⁸ In 2015, as part of its commitments to the Paris Agreement, the Indian government declared a target of non-fossil fueled sources contributing 40 percent of the total generation capacity by 2030.²⁰³⁹

For 2024, the Energy Institute reports the combined output of modern renewables (excluding large hydropower) in India as 240.5 TWh gross—up from 221.2 TWh in 2023 (revised from the 232.8 TWh figure listed by the Energy Institute last year)—representing 11.8 percent of all the electrical energy.²⁰⁴⁰ Of this, wind energy contributed 81.5 TWh and solar energy 136.8 TWh. Since nuclear energy contributed 54.7 TWh, wind and solar power together produced nearly four times the amount of electricity that nuclear reactors produced. However, fossil fuels together generated 1,577 TWh, nearly 78 percent of all electricity generated in 2024, with coal alone comprising three-quarters of the total.

Japan

See Focus Countries – Japan Focus.

Pakistan



Pakistan operates six nuclear reactors with a combined (net) capacity of 3.3 GW. Nuclear electricity production has increased from 21.3 TWh in 2023 to a new all-time high of 21.7 TWh net in 2024, while the share of electricity from nuclear power plants increased from the 16.2-percent peak in 2023 to a record 17 percent in 2024.

All operating reactors were built by the China National Nuclear Corporation (CNNC). This includes two Hualong One reactors (Kanupp-2 and Kanupp-3) outside the city of Karachi and four CNP-300 nuclear reactors in Chashma. CNNC is also building another 1200-MW Hualong One reactor in Chashma (Unit 5). The agreement to build this reactor dates back to 2017,²⁰⁴¹ but it took over seven years to progress to the formal construction start, i.e., first pour of concrete for the base slab of the reactor building, which occurred on 30 December 2024²⁰⁴². At the function, Pakistan's Minister for Planning, Development, and Special Initiatives said that

²⁰³⁸ - Ministry of New and Renewable Energy, "India's Renewable Rise: Non-Fossil Sources Now Power Half the Nation's Grid", 14 July 2025, see <https://www.pib.gov.in/PressReleasePage.aspx?PRID=2144627>, accessed 31 August 2025.

²⁰³⁹ - Urmi A. Goswami, "India's Renewable Energy Targets Catch the Attention of Global Investors, Still Need Ground Work", *The Economic Times*, 2 July 2016, see <https://economictimes.indiatimes.com/news/politics-and-nation/indias-renewable-energy-targets-catch-the-attention-of-global-investors-still-need-ground-work/articleshow/53015707.cms>, accessed 18 August 2025; and Government of India, "India's Intended Nationally Determined Contribution", Press Release, 2 October 2015, see https://moef.gov.in/uploads/2017/08/Press_Statement__INDC_English.pdf, accessed 31 August 2025.

²⁰⁴⁰ - Energy Institute, "Statistical Review of World Energy 2025", 2025, op. cit.

²⁰⁴¹ - WNN, "Pakistan, China Agree to Build Chashma 5", 23 November 2017, see <https://www.world-nuclear-news.org/Articles/Pakistan,-China-agree-to-build-Chashma-5>, accessed 7 May 2022; and China Atomic Energy Authority, "Third HPR 1000 Unit to Build Overseas", 30 November 2017, see <https://www.caea.gov.cn/english/n6759361/n6759362/c6798288/content.html>, accessed 17 June 2025.

²⁰⁴² - *The Independent*, "Construction of Chashma Nuclear Power Plant Unit 5 Commences.", 30 December 2024, see <https://www.daillyindependent.com.pk/2024/12/30/construction-of-chashma-nuclear-power-plant-unit-5-commences/>, accessed 2 January 2025; and PNRA, "PNRA Issued Construction License to Chashma Nuclear Power Plant Unit 5", Pakistan Nuclear Regulatory Authority, 26 December 2024, see <https://www.pnra.org/C5.html>, accessed 29 December 2024.

construction “reflected the strength of Pakistan-China cooperation.”²⁰⁴³ It is also China’s only ongoing nuclear newbuild project abroad and represents the first non-Russian construction start anywhere in the world in the past five years.

In January 2025, the National Electric Power Regulatory Authority (NEPRA) published an estimated overnight cost of PKR966 billion (US\$3.4 billion) for the Chasma-5 (CHASNUPP-5 or C-5) project and total cost (including financing and other costs) at PKR1,125 billion (US\$4 billion).²⁰⁴⁴ The majority of the cost is planned to be covered by credit from China.²⁰⁴⁵ As construction started, the reactor was reportedly projected to start producing power by 2030, which echoed earlier official announcements.²⁰⁴⁶ The project has been criticized for its high cost of power, and shelving renewable energy projects to make way for it.²⁰⁴⁷

Pakistan’s renewable electricity capacity was 15.2 GW in 2024, up from 14.2 GW in 2023.²⁰⁴⁸ While hydropower, with a total capacity of 11.5 GW, was the most important component of this capacity, solar energy is the fastest growing source of energy. In 2024, the total capacity of solar energy was 1.4 GW, up from 1.2 GW at the end of 2023, while wind constituted 1.8 GW, same as the two previous years. The reported solar energy capacity likely does not reflect the full deployment of the technology in Pakistan, because there are reports of importing 22 GW of solar panels from foreign suppliers.²⁰⁴⁹

Renewable energy sources (including hydro) produced 44.5 TWh net in 2024, comparable to the 2023 figure of 44.4 TWh; wind and solar energy contributed 3.4 TWh and 1.6 TWh respectively in 2024.²⁰⁵⁰

South Korea

See Focus Countries – South Korea Focus.

²⁰⁴³ - *Associated Press of Pakistan*, “Chashma Nuclear Power project unit-5 reflects strong bond of Pakistan-China cooperation: Ahsan Iqbal”, 30 December 2024, see <https://www.app.com.pk/business/chashma-nuclear-power-project-unit-5-reflects-strong-bond-of-pakistan-china-cooperation-ahsan-iqbal/>, accessed 3 January 2025.

²⁰⁴⁴ - NEPRA, “Tariff Petition for Chashma Nuclear Power Plant Unit-5 (C-5)”, Notice of Admission, National Electric Power Regulatory Authority of Pakistan, 4 January 2025, see <https://nepra.org.pk/Admission%20Notices/2025/01%20Jan/C-5.jpg>, accessed 29 August 2025.

²⁰⁴⁵ - Planning Commission, “Schemes Approved by Central Development Working Party (CDWP) and Executive Committee of the National Economic Council (ECNEC)—(1st April 2023 to 15th May 2024)”, Ministry of Planning, Development & Special Initiatives, Government of Pakistan, June 2024, see <https://pc.gov.pk/uploads/downloads/Schemes%20approved%20by%20CDWP%20&%20ECNEC%202024.pdf>; and Ministry of Information and Broadcasting, “Signing of MoU for CHASNUPP-5 to Further Cement Economic Cooperation B/W Pakistan, China: PM”, Government of Pakistan, 20 June 2023, see <https://www.moib.gov.pk/News/54094>; both accessed 17 June 2025.

²⁰⁴⁶ - *Energy Update Magazine*, “Construction of Pakistan’s Largest Nuclear Power Plant Begins Today”, 30 December 2024, see <https://www.energyupdate.com.pk/2024/12/30/construction-of-pakistans-largest-nuclear-power-plant-begins-today/>, accessed 8 June 2025; and Raja Ali Raza Anwar, “National Statement of Pakistan”, Chairman, Pakistan Atomic Energy Commission, 16 September 2024, delivered at 68th Regular Session of the General Conference of the International Atomic Energy Agency, 16–18 September 2024, as released by the IAEA, see <https://www.iaea.org/sites/default/files/24/09/pakistan-gc68.pdf>, accessed 1 May 2025.

²⁰⁴⁷ - Mushtaq Ghumman, “\$5bn Chashma-5 N-Plant to Produce Power at Rs20 per Unit: Country Has Swallowed a Bitter Pill?”, *Business Recorder*, 12 July 2023, see <https://www.brecorder.com/news/40252138>, accessed 29 June 2024.

²⁰⁴⁸ - IRENA, “Renewable Capacity Statistics 2025”, International Renewable Energy Agency, March 2025, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Mar/IRENA_DAT_RE_Capacity_Statistics_2025.pdf, accessed 1 June 2025.

²⁰⁴⁹ - Michael Barnard, “Pakistan’s 22 GW Solar Shock: How a Fragile State Went Full Clean Energy”, *CleanTechnica*, 5 April 2025, see <https://cleantechnica.com/2025/04/04/pakistans-22-gw-solar-shock-how-a-fragile-state-went-full-clean-energy/>, accessed 2 June 2025.

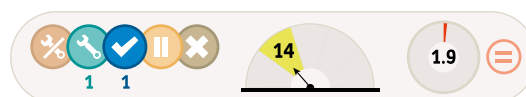
²⁰⁵⁰ - Energy Institute, “Statistical Review of World Energy 2025–Consolidated Dataset”, 2025, op. cit.

Taiwan

See Focus Countries – [Taiwan Focus](#).

MIDDLE EAST

Iran



Iran only operational reactor, Bushehr-1—also spelled Busheer-1—has a net capacity of 915 MW and was connected to the grid in September 2011.²⁰⁵¹ IAEA-PRIS statistics for this reactor shows a record production of 6.4 TWh in 2024. Per the Energy Institute, with 7.3 TWh gross, nuclear covered a stable 1.9 percent of the total electricity generated in the country.

A second unit with a net capacity of 974 MW, also a Pressurized Water Reactor from Rosatom, had been on the IAEA's list as under construction for almost 20 years before vanishing in 2005. It has been relisted as under construction since September 2019 in the IAEA's PRIS database. However, the first pour of concrete for the foundations of the reactor building, the traditional marker for official start of construction, only happened in November 2019 according to the Atomic Energy Organization of Iran (AEOI).²⁰⁵²

The contract for the second unit was signed as part of a two-unit project, Bushehr-2 and -3, by the Nuclear Power Production and Development Company of Iran and Rosatom's subsidiary Atomstroyexport JSC back in November 2014.²⁰⁵³ These two units were to be added “in the short-term”; Rosatom also announced that two more reactors would be built at Bushehr “in the medium-term”, and that it would develop “an entirely new nuclear power plant in the country with four VVER reactors” at a location that was “yet to be announced by the Iranian nuclear authorities.”²⁰⁵⁴

Apart from Bushehr-2, no official construction start has been reported, and WNISR does not consider any other project as under construction. However, Iranian officials routinely talk about “Units 2 and 3” being under construction. In February 2025, for example, the AEOI website featured a press release that announced that Iran's President Dr. M. Pezeshkian, “inspected the progress of the construction of units 2 and 3 of the Bushehr nuclear power plant.”²⁰⁵⁵

²⁰⁵¹ - IAEA-PRIS, “Country Statistics—Bushehr-1”, Updated 28 August 2025, see <https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=310>, accessed 29 August 2025.

²⁰⁵² - AEOI, “Concrete Pouring of the Second Unit of Nuclear Power Plant Held in Bushehr”, Atomic Energy Organization of Iran, 12 November 2019, see <https://aeoi.org.ir/en/portal/home/?news/45799/69280/294254/concrete-pouring-of-the-second-unit-of-nuclear-power-plant-held-in-bushehr>, accessed 22 August 2024.

²⁰⁵³ - Rosatom and Atomstroyexport, “Solemn Ground-Breaking Ceremony for Bushehr-2 NPP Construction in Iran”, Press Release, 6 September 2016, see <https://ase-ec.ru/en/for-journalists/news/2016/sep/news61/>, accessed 24 July 2024.

²⁰⁵⁴ - Rosatom, “Rosatom to Build Eight New Reactors in Iran”, Newsletter #64, November 2014, see <https://rosatomnewsletter.com/2014/11/12/rosatom-to-build-eight-new-reactors-in-iran/>, accessed 24 July 2024.

²⁰⁵⁵ - AEOI, “The President's Visit of the Bushehr Nuclear Power Plant (BNPP)”, Atomic Energy Organization of Iran, 14 February 2025, see [https://www.aeoi.org.ir/en/portal/home/?news/45799/69280/369942/the-president%e2%80%99s-visit-of-the-bushehr-nuclear-power-plant-\(bnpp\)](https://www.aeoi.org.ir/en/portal/home/?news/45799/69280/369942/the-president%e2%80%99s-visit-of-the-bushehr-nuclear-power-plant-(bnpp)), accessed 9 June 2025.

At the end of 2019, these two reactors were expected to be completed in 2024 and 2026, respectively.²⁰⁵⁶ However, in September 2024, at a side event of the IAEA's General Conference, officials were reported as saying that the reactor pressure vessel for Unit 2 was to be installed “30 months later” (namely, in May 2027), and that the “physical start-up” was anticipated to be in 2029.²⁰⁵⁷

Some work is under way, according to the AEOI, for a domestically designed 300-MW reactor, at the Darkhovin or Karun nuclear power plant, in Ahvaz, Khuzestan province²⁰⁵⁸ and for four Russian-designed reactors of 1250 MW each, in Sirik, Hormozgan province.²⁰⁵⁹ Both of these projects were officially announced in 2024. AEOI has also identified Shiraz as another potential location for a nuclear power plant.²⁰⁶⁰ The official goal is to expand nuclear capacity to 20 GW by 2040.²⁰⁶¹

On 9 June 2025, AEOI's President Mohammad Eslami reportedly confirmed that an agreement had been signed with Russia on the construction of eight reactors, it being understood that this includes four units at the Busheer site—only one of which is under construction—and the four units at Darkhovin. Russia is supposed to provide the funding for the projects.²⁰⁶²

Iran is highly reliant on fossil fuels for electricity generation—mainly gas, which accounted for 86 percent of the total gross production—with renewable energy, including hydro, accounting for only 5.3 percent, down from 6.5 percent in 2023.²⁰⁶³ There are plans to increase wind energy capacity by 5.5 times in line with the 7th Development Plan's target of 30 GW by 2028.²⁰⁶⁴ Furthermore, Iran is planning to add 15 GW of solar capacity.²⁰⁶⁵ While no explicit deadline has been set to achieve this target, in April 2023, the Iranian Ministry of Energy announced that 10 GW of renewable energy capacity would be added by August 2025.²⁰⁶⁶

2056 - WNISR, “Iran: Construction Restart of Busheer-2”, 14 November 2019, see <https://www.worldnuclearreport.org/Iran-Construction-Restart-of-Busheer-2>, accessed 17 June 2025.

2057 - WNN, “Iran Outlines Nuclear Energy Plans, Including First Concrete for Busheer 3 This Year”, *World Nuclear News*, 27 September 2024, see <https://world-nuclear-news.org/articles/iran-aims-for-first-concrete-for-busheer-3-by-end-of-year>, accessed 25 November 2024.

2058 - AEOI, “The First Stage of Excavation of Karun 300 MW Nuclear Plant Has Been Accomplished”, Press Release, 28 February 2024, see <https://aeoi.org.ir/en/portal/home/?news/45799/69280/359541/the-first-stage-of-excavation-of-karun-300-mw%C2%A0-nuclear-plant-has-been-accomplished>, accessed 13 March 2024.

2059 - AEOI, “Construction Operation Start of 4 Nuclear Power Plants Units in the Hormozgan Province”, Press Release, 2 February 2024, see <https://aeoi.org.ir/en/portal/home/?news/45799/69280/358720/construction-operation-start-of-4-nuclear-power-plants-units-in-the-hormozgan-province>, accessed 19 April 2024.

2060 - IRNA, “Iran Plan to Build Another Reactor in Shiraz: Eslami”, *The Islamic Republic News Agency*, 12 May 2024, see <https://en.irna.ir/news/85474784/Iran-plans-to-build-new-nuclear-reactor-in-Shiraz-Eslami>, accessed 22 June 2024.

2061 - AEOI, “Statement by Vice President and the AEOI head of I.R.I in the 68th GC of the IAEA”, 16 September 2024, see <https://www.aeoi.org.ir/en/portal/home/?news/45799/69280/365397/statement-by-vice-president-and-the-aeoi-head-of-i.r.i-in-the-68th-gc-of-the-iaea>, accessed 9 June 2025.

2062 - Darrell Proctor, “Russia Has Deal to Build Eight Nuclear Power Plants in Iran”, *POWER Magazine*, 10 June 2025, see <https://www.powermag.com/russia-has-deal-to-build-eight-nuclear-power-plants-in-iran/>, accessed 17 June 2025.

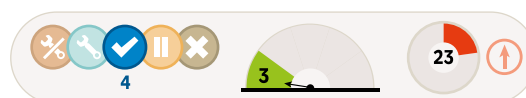
2063 - Energy Institute, “Statistical Review of World Energy 2025—Consolidated Dataset”, June 2025, op. cit.

2064 - IRNA, “Capacity Of Iran's Wind Power Plants to Increase by 5.5 Times”, *The Islamic Republic News Agency*, 12 June 2024, see <https://en.irna.ir/news/85506434/Capacity-of-Iran-s-wind-power-plants-to-increase-by-5-5-times>, 30 June 2024.

2065 - IRNA, “Iran Finalizes Plan for Construction of 15 GW Solar Power Plants”, *The Islamic Republic News Agency*, 4 October 2023, see <https://en.irna.ir/news/85247625/Iran-finalizes-plan-for-construction-of-15-GW-solar-power-plants>, accessed 30 June 2024.

2066 - Enterprise Climate, “Iran Breaks Ground on the Second Phase of the Busheer Nuclear Power Plant”, 10 October 2023, see <https://climate.enterprise.press/stories/2023/10/10/iran-breaks-ground-on-the-second-phase-of-the-busheer-nuclear-power-plant-102883/>; and *Tehran Times*, “Capacity of Iran's Renewable Power Plants Rises 0.9% in a Month”, 17 April 2023, see <https://www.tehrantimes.com/news/483751/Capacity-of-Iran-s-renewable-power-plants-rises-0-9-in-a-month>; both accessed 9 August 2024.

United Arab Emirates



The United Arab Emirates (UAE) operates four South Korean APR-1400 reactors at the Barakah nuclear project with a total (net) capacity of 5.3 GW. The last of these reactors was connected to the grid on 23 March 2024,²⁰⁶⁷ and entered commercial operation in September 2024²⁰⁶⁸. The earlier three units were declared entering commercial operation in April 2021, March 2022, and February 2023 respectively.²⁰⁶⁹ Each of these was about four years delayed compared to the timeline projected by the Emirates Nuclear Energy Corporation (ENEC) in 2014.²⁰⁷⁰

As reported in **WNISR2024**, ENEC is considering building more nuclear reactors, and launched the so-called ADVANCE program in late 2023 to “evaluate Small Modular Reactors (SMRs) and so-called Advanced Reactor technologies for both domestic and international investment and development.”²⁰⁷¹ In May 2025, it signed an MoU with General Electric Vernova Hitachi to “evaluate the deployment of the BWRX-300 Small Modular Reactor (SMR) technology internationally.”²⁰⁷² This follows an earlier agreement signed with GE-Hitachi, as well as five other SMR vendors, on the sidelines of the 28th Conference of the Parties of the UN Framework Convention on Climate Change (COP28) in 2023.²⁰⁷³ In addition, in early 2025, ENEC signed an agreement with Newcleo “to explore opportunities to work together to support the advancement of LFR [lead cooled fast reactor] projects.”²⁰⁷⁴ All of these are non-binding agreements.

In 2024, nuclear reactors contributed 38.6 TWh (net) of electricity to the UAE’s grid, or 22.9 percent of the total electricity generation (gross). The corresponding figures for 2023 are 32.7 TWh and 20.6 percent. Natural gas remains the main source of electricity generation in

²⁰⁶⁷ - ENEC, “Unit 4 of Barakah Nuclear Energy Plant Successfully Connected to UAE Grid”, Press Release, Emirates Nuclear Energy Corporation, 23 March 2024, see <https://www.enec.gov.ae/news/latest-news/unit-4-of-barakah-nuclear-energy-plant-successfully-connected-to-uae-grid/>, accessed 25 March 2024.

²⁰⁶⁸ - ENEC, “UAE Celebrates Historic Milestone as Unit 4 of the Barakah Plant Commences Commercial Operation: Delivering Full-fleet Operations”, Press Release, 5 September 2024, see <https://www.enec.gov.ae/news/latest-news/uae-celebrates-historic-milestone-as-unit-4-of-the-barakah-plant-commences-commercial-operation/>, accessed 19 June 2025.

²⁰⁶⁹ - ENEC, “The UAE’s Sustainable Powerhouse: Barakah Nuclear Energy Plant Doubles Clean Electricity Generation with Start of Commercial Operations at Unit 2”, 24 March 2022, see <https://www.enec.gov.ae/news/latest-news/barakah-plant-doubles-clean-electricity-generation-with-start-of-commercial-operations-at-unit-2/>; and ENEC, “In the Year of Sustainability UAE Takes Significant Leap Towards Net Zero 2050 as Unit 3 of Barakah Nuclear Energy Plant Starts Commercial Operations”, Press Release, 24 February 2024, see <https://www.enec.gov.ae/news/latest-news/uae-takes-leap-towards-net-zero-2050-as-unit-3-plant-starts-commercial-operations/>; both accessed 28 August 2024.

²⁰⁷⁰ - ENEC, “Unit 1 of Power Plant More Than 57% Complete”, Press Release, 17 September 2014, see <https://www.enec.gov.ae/news/latest-news/unit-1-of-enecs-barakah-power-plant-now-more-than-57-complete/>, accessed 10 June 2022.

²⁰⁷¹ - ENEC, “Next Phase of UAE Civil Nuclear Energy Development”, 29 January 2025, see <https://www.enec.gov.ae/news/announcements/next-phase-of-uae-civil-nuclear-energy-development/>, accessed 19 June 2025.

²⁰⁷² - GE Vernova, “ENEC and GE Vernova Hitachi Sign Small Modular Reactor Deployment Evaluation MoU During World Utilities Congress”, Press Release, 27 May 2025, see <https://www.gevernova.com/news/press-releases/enec-ge-vernova-hitachi-sign-small-modular-reactor-deployment-evaluation-mou-during-world-utilities-congress>, accessed 29 May 2025.

²⁰⁷³ - NEI Magazine, “COP28: ENEC Signs Three More SMR Agreements”, 12 December 2023, see <https://www.neimagazine.com/news/newscop28-enec-signs-three-more-smr-agreements-11365120>, accessed 13 January 2024; and ENEC, “Latest News—2023”, 2023, see <https://www.enec.gov.ae/news/latest-news/2023/>, accessed 19 June 2025.

²⁰⁷⁴ - Newcleo, “ENEC and Newcleo Sign Memorandum of Strategic Cooperation to Explore Developing Nuclear Projects Globally”, Press Release, 25 February 2025, see <https://www.newcleo.com/news-insights/enec-and-newcleo-sign-memorandum-of-strategic-cooperation-to-explore>, accessed 30 April 2025.

the country, contributing over 68 percent of the total.²⁰⁷⁵ Renewables contributed 15.5 TWh net, or 8.8 percent of all electricity supplied to UAE's grid.²⁰⁷⁶

When compared to earlier years, installed capacity of renewables grew relatively slowly, by less than 1 percent, in 2024 to a total of 6.14 GW; in comparison, the capacity in 2022 was only 3.6 GW.²⁰⁷⁷ Solar energy dominates with 6 GW, including photovoltaics (5.4 GW) and concentrated solar power (600 MW). According to the 2023 update of its energy strategy, by 2030, the UAE plans to triple the capacity of renewable energy compared to 2022 and generate 32 percent of its power by nuclear and renewables.²⁰⁷⁸

EUROPEAN UNION (EU27)



The EU27 member states have gone through three nuclear construction waves (see Figure 80)—two small ones in the 1960s and the 1970s and a larger one in the 1980s (mainly in France). Over the past 30 years, 1995–2024, only 13 reactors were connected to the grid in current EU27 Member States, six of them in Western Europe—five in France and one in Finland—and seven in Eastern and Central Europe—three in Slovakia, and two each in the Czech Republic and Romania. Only four reactors started up in the past 20 years, 2005–2024: after Cernavoda-2 was connected to the grid in Romania in 2007, it took another 15 years, until the following reactor, Olkiluto-3 in Finland, produced its first kilowatt-hours in March 2022; Mochovce-3 in Slovakia, where construction first started in 1985, was finally connected to the grid in January 2023; and Flamanville-3 in France started up in December 2024.

As Figure 81 shows, 100 reactors are operating in the EU27 as of mid-2025, 36 less than the historic maximum in 1989, a drop by over one quarter. Eighty percent of the operating plants are located in six of the western countries—with 57 units in France alone—and only 20 in six newer member states.

²⁰⁷⁵ - Energy Institute, “Statistical Review of World Energy 2025—Consolidated Dataset”, June 2025, op. cit.

²⁰⁷⁶ - Ibidem.

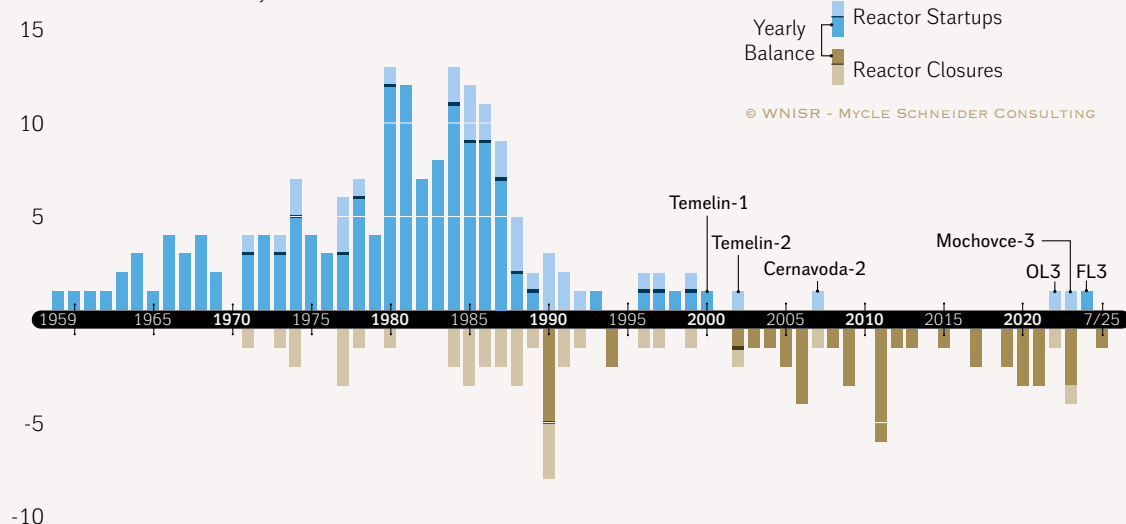
²⁰⁷⁷ - IRENA, “Renewable Capacity Statistics 2025”, International Renewable Energy Agency, March 2025, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Mar/IRENA_DAT_RE_Capacity_Statistics_2025.pdf, accessed 1 June 2025.

²⁰⁷⁸ - Ministry of Energy & Infrastructure, “UAE Energy Strategy 2050”, United Arab Emirates Government, 14 August 2023, see <https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/uae-energy-strategy-2050>, accessed 27 August 2023.

Figure 80 · Nuclear Reactors Startups and Closures in the EU27, 1959–1 July 2025

Reactor Startups and Closures in the EU27

in Units, from 1959 to 1 July 2025



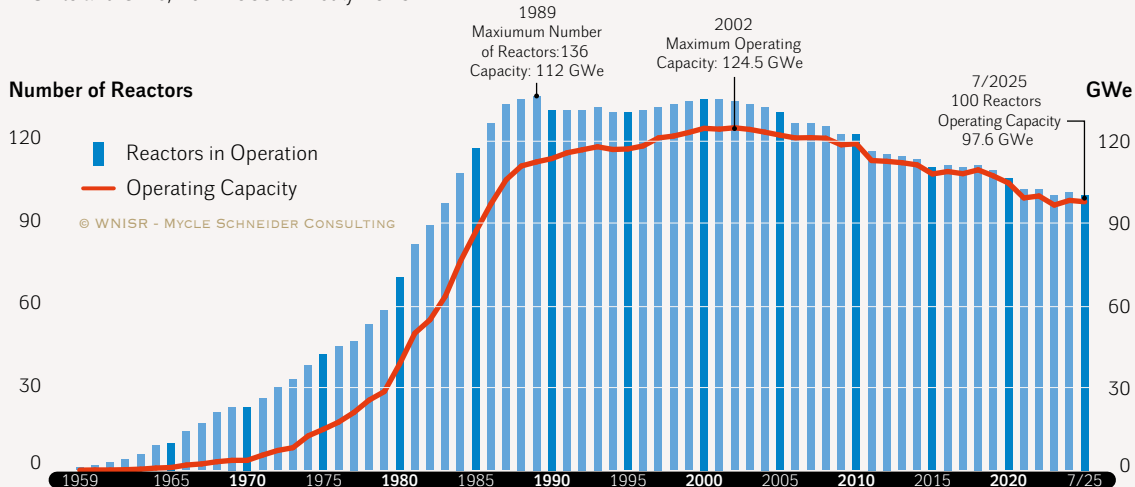
Sources: WNISR with IAEA-PRIS, 2025

The closures of Tihange-2 and Doel-1 in Belgium in February 2023 and February 2025 respectively, and Emsland, Isar-2, and Neckarwestheim-2 in Germany in April 2023, brought the number of permanently closed reactors in the EU27 to 78 (69 in Western Europe, over half of which in Germany). Thirty-six units were closed over the past 20 years from 2005 to mid-2025.

Figure 81 · Nuclear Reactors and Net Operating Capacity in the EU27

Nuclear Reactors and Net Operating Capacity in the EU 27

in Units and GWe, from 1959 to 1 July 2025



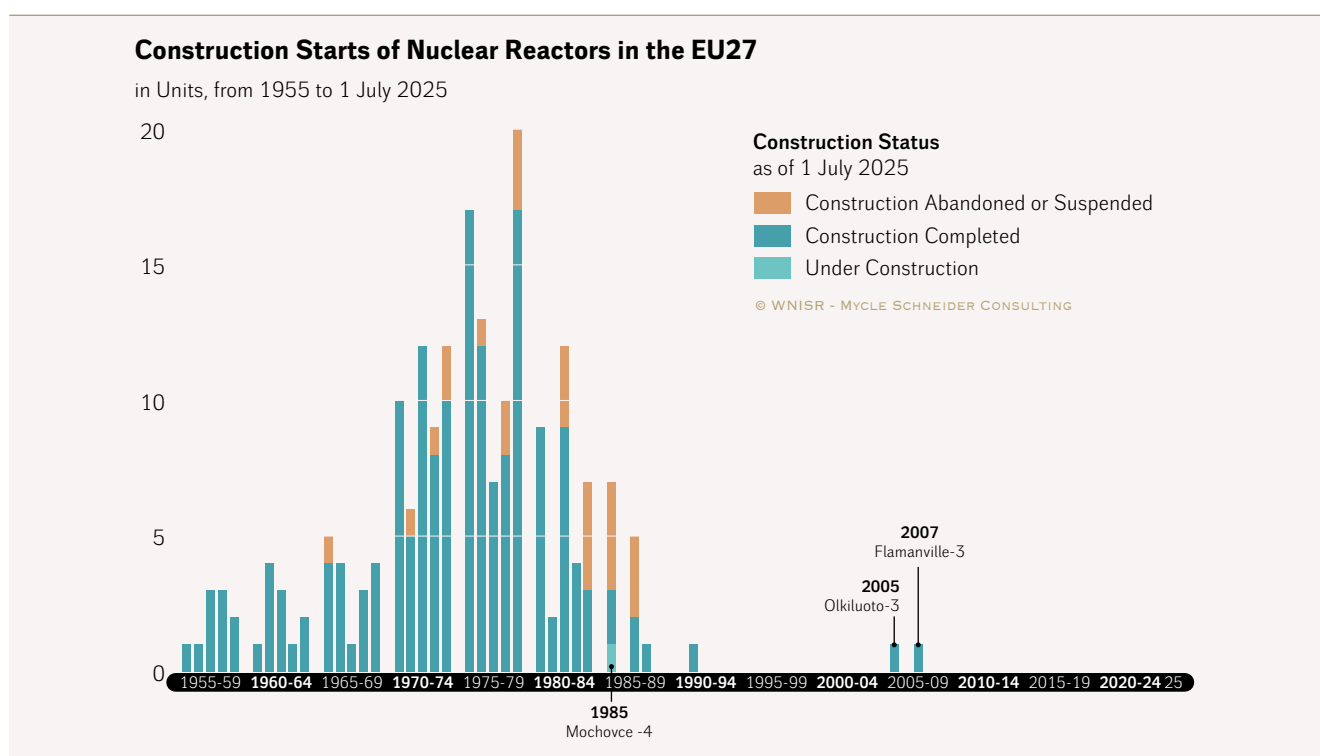
Sources: WNISR with IAEA-PRIS, 2025

In 2024, nuclear plants generated 617 TWh net in the EU27, an increase of almost 5 percent compared to the previous year; production had increased by almost 2 percent in 2023, following a plunge of 17 percent in 2022. Consequently, the nuclear share in gross power generation had dropped to 21.7 percent in 2022, slightly increasing to 22.6 percent and 23.2 percent in 2023 and 2024 respectively.

In the absence of any significant delivering newbuild program (see Figure 82), the average age of nuclear power plants has increased since the mid-80s and at mid-2025 is 38.7 years (see Figure 83 and Figure 84). Following grid connection of Olkiluoto-3, Mochovce-3, and Flamanville-3, only one reactor remains under construction in the EU27, Mochovce-4, in Slovakia, where construction originally began 40 years ago, in 1985.

When the last unit has finally been connected to the grid, in late 2025 or early 2026 (?), in view of the long lead times of nuclear construction projects, there will be no new nuclear power reactors starting up in the EU27 for years to come. In other words, the current nuclear fleet will continue aging and shrinking at least in the medium term.

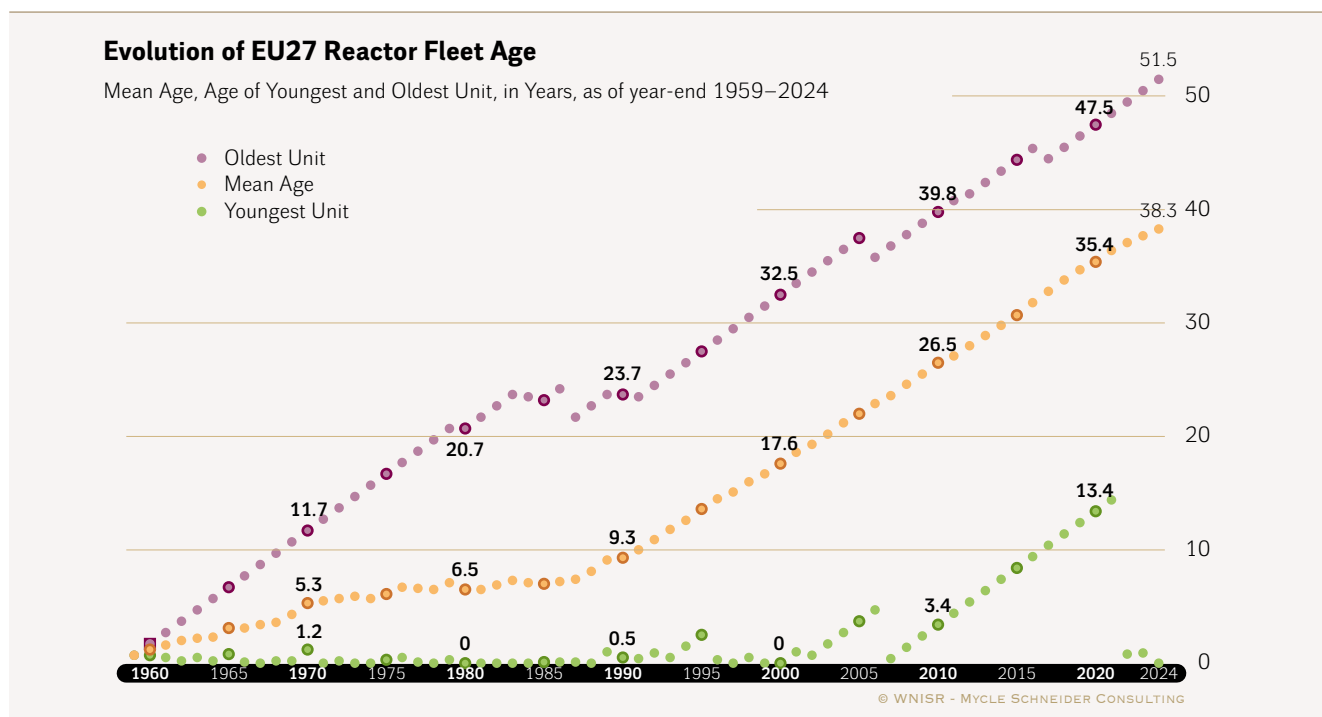
Figure 82 · Construction Starts of Nuclear Reactors in the EU27



Sources: WNISR with IAEA-PRIS, 2025

Note: Construction start of Mochovce-3 and -4 was first introduced as of 1985 in IAEA-PRIS, "Nuclear Power Reactors in the World – April 1986 Edition", 1986. Their construction was later suspended. See section on Slovakia.

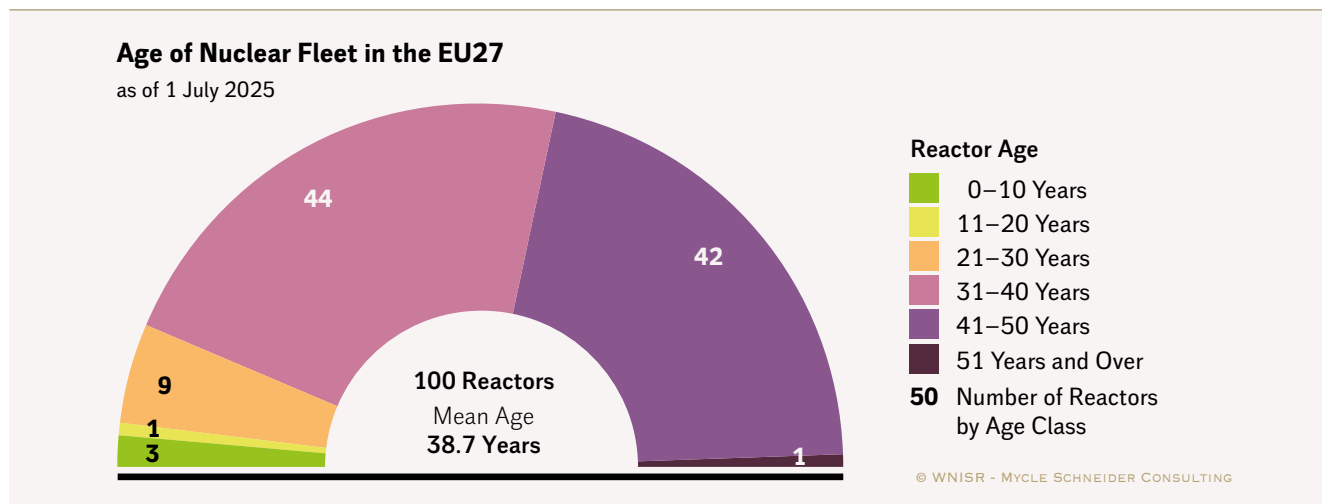
Figure 83 · Age Evolution of EU27 Reactor Fleet, 1959–2024



Sources: WNISR with IAEA-PRIS, 2025

The age distribution shows that now almost nine in ten (87) of the E.U.'s operating nuclear reactors have been in operation for 31 years and beyond of which 42 have been on the grid for 41 years and more. One reactor, Borssele in the Netherlands, the oldest in the E.U., reached 51 years of operation in July 2024. The then second oldest reactor, Doel-1, was closed after just over 50 years of operation in early 2025.

Figure 84 · Age Distribution of the EU27 Reactor Fleet



Sources: WNISR with IAEA-PRIS, 2025

In June 2025, the European Commission has published the long-awaited Nuclear Illustrative Program (PIN). It estimates that “Delivering Member States’ plans regarding nuclear energy

will require significant investments, of around €241 billion (US\$274 billion) until 2050, both for lifetime extensions of existing reactors and the construction of new large-scale reactors,” not including SMRs or other types of “advanced reactors”. The report projects installed nuclear capacity across the E.U. is to grow “from 98 GWe in 2025 to 109 around GWe by 2050”.²⁰⁷⁹ In other words, to hardly grow over the 25-year period. However, previously, the Commission envisaged nuclear capacity to continue the declining trend.

The European Commission does not carry out any feasibility assessment: “It aggregates Member States’ plans for nuclear energy as declared in their National Energy and Climate Plans (NECPs) and derives the evolution of installed generation capacity from large-scale reactors, as well as the associated investment needs.” The Commission also states in a “Working Document” distributed alongside the communication on PINC—wrongly—that besides the Mohovce-4 unit, two reactors would be under construction at the Paks site in Hungary although none of the units have achieved the milestone of concreting the base slab of the reactor building, the official construction start.

The Commission nevertheless carried out a sensitivity analysis of potential delays judging an upper limit of 10 years delay credible. Such delays “could shift the installed capacity in 2050 by more than 20 GWe”, which could drop to 85 GWe by 2050. The Commission recognizes that

The EU’s nuclear industry is facing significant challenges in responding to current and future nuclear development trends across the segments including new builds and lifetime extensions, (as well as decommissioning and waste management). Therefore, the industry has to undergo a substantial transformation to increase its capacity, effectiveness, and competitiveness.²⁰⁸⁰

and surprisingly bluntly describes the nuclear industry’s attractiveness issue:

[The] Nuclear sector has an image problem and is not attractive to young people, often not even considered as an option.

WESTERN EUROPE

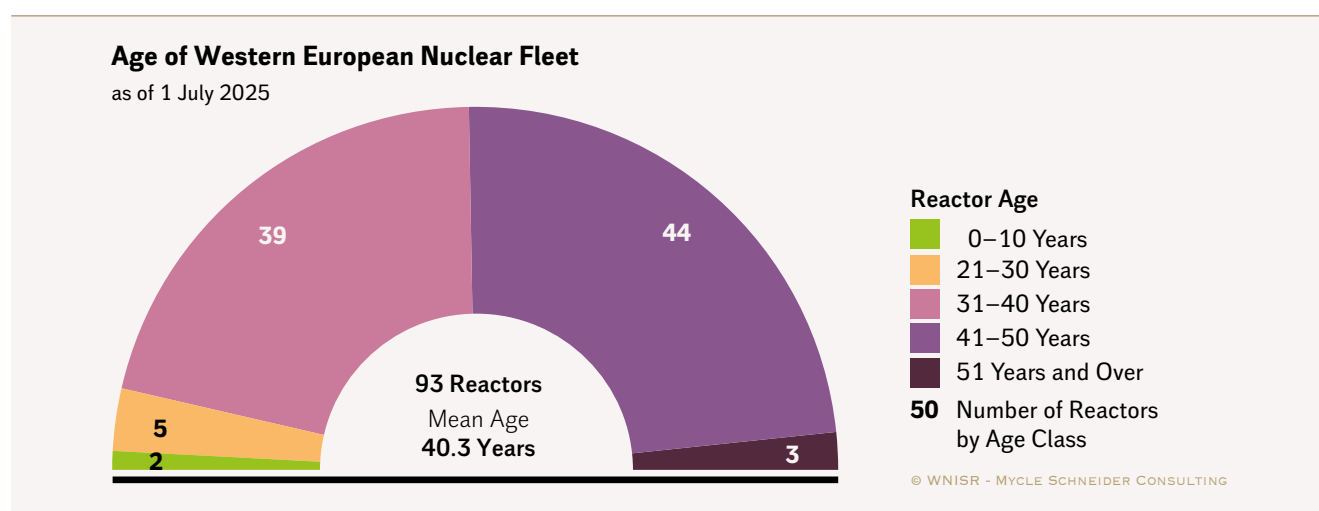
As of mid-2025, 93 nuclear power reactors operated in Western Europe (western E.U. member states, U.K., and Switzerland), 67 fewer units than in the peak years 1988–89, a 42-percent decline. Over the year, Flamanville-3 started up and Doel-1 closed.

With Switzerland operating two reactors for over 50 years—Beznau-1 at 56, and Beznau-2 at almost 54—the average age of operating reactors in Western Europe reaches 40.3 years (see Figure 85).

²⁰⁷⁹ - European Commission, “Commission Assesses Nuclear Investment Needs by 2050 in View of Decarbonisation and Competitiveness Goals”, Press Release, 13 June 2025.

²⁰⁸⁰ - European Commission, “Commission Staff Working Document Accompanying the document Communication from the Commission Nuclear Illustrative Programme presented under Article 40 of the Euratom Treaty for the opinion of the European Economic and Social Committee”, COM(2025) 315 final, 13 June 2025.

Figure 85 · Age Distribution of the Western European Reactor Fleet (incl. Switzerland and the U.K.)



Sources: WNISR with IAEA-PRIS, 2025

The only remaining active construction project is implemented by French utility EDF at Hinkley Point in the U.K., where two European Pressurized Water Reactors (EPR), Hinkley Point C-1 and C-2, have been under construction since 2018 and 2019 respectively. As previous EPR projects in Finland and France, both units are billions over budget, years behind schedule, and are currently not expected to be commissioned before around 2030 or later (see [United Kingdom Focus](#)).

The mean-age evolution of the nuclear reactor fleet in Western Europe follows the same pattern as the EU27, constantly increasing since the middle of the 1980s. The eventual startup of the two reactors currently under construction will have little impact on the aging aspect of an otherwise shrinking fleet.

Belgium



From an original fleet of seven reactors, as of 1 July 2025, four reactors (two at Doel and two at Tihange) totaling 3.5 GW remained connected to the Belgian grid. The 445-MW PWR Doel-1 was closed on 15 February 2025 in line with a nuclear power plant phaseout plan that had come into effect in 2003 (see [Table 21](#)). This legislation limited the operational lifetime of Belgian commercial power plants to 40 years and prohibited the construction of additional reactors.²⁰⁸¹ In 2021, the government of Alexander De Croo confirmed the final closure year for all Belgian reactors as 2025.²⁰⁸² But in 2022, following the Russian invasion of Ukraine and subsequent energy supply challenges, the government initiated preparatory steps to extend the lifetimes

²⁰⁸¹ - Government of Belgium, “Loi sur la sortie progressive de l’énergie nucléaire à des fins de production industrielle d’électricité”, Federal Public Service Economy, SMEs, Self-employed and Energy, enacted 31 January 2003, promulgated 28 February 2003, see <https://faolex.fao.org/docs/pdf/bel147415.pdf>, accessed 16 May 2025.

²⁰⁸² - Federal Public Service Economy, “Base légale de la sortie du nucléaire en Belgique”, 5 February 2024, see <https://economie.fgov.be/fr/themes/energie/sources-et-vecteurs-denergie/nucleaire/base-legale-de-la-sortie-du>, accessed 23 May 2025.

of the youngest, 40-year-old units Doel-4 and Tihange-3 beyond the 2025 closure date.²⁰⁸³ The current average age of the four units is 45 years.

Negotiations are ongoing between operator Electrabel, owned by French Engie, and the Belgian government on the details of the conditions for lifetime extensions. In mid-2023, the parties signed an interim agreement to extend the lifetimes of Doel-4 and Tihange-3 by ten years. For this, the Belgian state would become equal co-owner of the plants with Engie and implement a “contract for difference model with incentives for the industrial operator to achieve [favorable] technical and economic performance at the plants.” The state would also receive a €15 billion (US\$₂₀₂₂ 15.8 billion) lump sum payment from Engie, ridding the company of all “future costs related to the treatment of nuclear waste” not only for the two lifetime-extended units but for all seven Belgian power reactors, both operational and closed.²⁰⁸⁴ Additionally, according to the deal, the Belgian state and Electrabel will provide 89.807 percent of the €2–2.5 billion (US\$2.3–2.8 billion) total capital contribution to fund the cost of the lifetime extension backfitting and upgrading work; the remainder will be covered by Electricité de France (EDF) subsidiary Luminus that owns shares of the Doel plant. As of February 2025, the exact composition of the funding, i.e., the distribution of shareholder loans and equity injection, was yet to be decided.²⁰⁸⁵ The new law allowing for the lifetime extension of Doel-4 and Tihange-3 was enacted on 26 April 2024 and promulgated on 5 June 2024.²⁰⁸⁶ See *Belgium Focus* in *WNISR2024* for further details on the procedure.

The European Commission approved the deal on 21 February 2025 after having carried out an investigation, launched in July 2024, “to assess whether public support that Belgium plans to grant for the lifetime extension of two nuclear reactors (Doel 4 and Tihange 3) is in line with EU State aid rules.”²⁰⁸⁷

The government and Engie officially signed the deal on 14 March 2025, paving the way for the remaining preparatory steps to operate Doel-4 and Tihange-3 until 2035 (see *Figure 86*). For the operator, these include organizing fuel deliveries, receiving a final approval (expected in June 2025) from the Belgian nuclear regulatory agency FANC/AFCN,²⁰⁸⁸ and completing

²⁰⁸³ - Prime Minister of Belgium, “Prolongation de la durée de vie des centrales Doel 4 et Tihange 3”, Press Release, *News Belgium*, 18 March 2022, see <https://news.belgium.be/fr/prolongation-de-la-duree-de-vie-des-centrales-doel-4-et-tihange-3>, accessed 23 May 2025.

²⁰⁸⁴ - ENGIE, “ENGIE Signs an Agreement with the Belgian Government on the Extension of Tihange 3 and Doel 4 Nuclear Reactors and All Obligations Related to Nuclear Waste”, Press Release, 29 June 2023, see <https://corporate.engie.be/en/press/release/engie-signs-agreement-belgian-government-extension-tihange-3-and-doel-4-nuclear>, accessed 21 July 2023.

²⁰⁸⁵ - European Commission, “Commission Decision of 21.2.2025 on the State Aid Measure SA.106107 (2024/N) Which Belgium Is Planning to Implement for the Lifetime Extension of Two Nuclear Reactors (Doel 4 And Tihange 3)”, 21 February 2025, see https://ec.europa.eu/competition/state_aid/cases1/202520/SA_106107_316.pdf, accessed 14 May 2025.

²⁰⁸⁶ - Federal Public Service Economy, SMEs, Self-employed and Energy, “26 avril 2024. - Loi modifiant la loi du 31 janvier 2003 sur la sortie progressive de l’énergie nucléaire à des fins de production industrielle d’électricité”, *Moniteur Belge*, Federal Public Service Justice, promulgated 5 June 2024, see <http://www.ejustice.just.fgov.be/eli/loi/2024/04/26/2024003971/moniteur>, accessed 20 August 2024.

²⁰⁸⁷ - European Commission, “Commission Decision of 21.2.2025 on the State Aid Measure SA.106107 (2024/N) Which Belgium Is Planning to Implement for the Lifetime Extension of Two Nuclear Reactors (Doel 4 And Tihange 3)”, 21 February 2025, op. cit.; and European Commission, “Commission Opens In-Depth State Aid Investigation into Belgian Support for Lifetime Extension of Two Nuclear Reactors”, Press Release, 22 July 2024, see https://ec.europa.eu/commission/presscorner/detail/en/IP_24_3901, accessed 20 August 2024.

²⁰⁸⁸ - On 1 July 2025, the Federal Agency for Nuclear Control (FANC) did approve the “action plan for Tihange LTO”, and on 3 July it okayed the restart and operation of Tihange-3 until 2035; a similar process is required for Doel-4 which is expected to restart at the latest by 1 November 2025; see FANC, “Exploitation à long terme (LTO) de Doel 4 et Tihange 3 jusqu’en 2035”, Updated 11 July 2025, see <https://afcn.fgov.be/fr/dossiers/centrales-nucleaires-en-belgique/exploitation-long-terme-lto-de-doel-4-et-tihange-3-jusqu'en>, accessed 12 July 2025.

engineering tasks during the scheduled temporary shutdown of the reactors—from April to July and from July to October 2025 at Tihange-3 and Doel-4, respectively.²⁰⁸⁹ The first installment of €₂₀₂₂ 11.5 billion (US\$₂₀₂₂ 12 billion) was subsequently paid to the specially set-up agency Hedera. The remainder of the lump sum payment is expected to be transferred once both reactors have returned to operations in November 2025.²⁰⁹⁰

The Belgian electricity mix is still dominated by nuclear power. In 2024, the nuclear fleet produced 31.4 TWh gross, down by 1.5 TWh compared to 2023, and corresponding to 41.9 percent of Belgian electricity. The remainder was provided by natural gas (18.7 percent), solar (11.9 percent), wind (18.7 percent—offshore 9.6 percent and onshore 9.1 percent), bioenergy (4.7 percent), and hydro (0.6 percent).²⁰⁹¹ The historic maximum nuclear share was 67.1 percent in 1986.

Table 21 · Belgian Nuclear Fleet (as of 1 July 2025)

Reactor	Net Capacity (MW)	Grid Connection	Operating Age (as of 1 July 2025) / Age at Closure	End of License (Planned or Actual Closure Date)
Doel-1	433	28/08/1974	50.5	15 February 2025 (Closed on 14 February 2025)
Doel-2	433	21/08/1975	49.9	10-year lifetime extension to 1 December 2025
Doel-3	1 006	23/06/1982	40.3	1 October 2022 (Closed on 23 September 2022)
Doel-4	1 038	08/04/1985	40.2	10-year lifetime extension (Closure date 2035–2037)
Tihange-1	962	07/03/1975	50.3	10-year lifetime extension to 1 October 2025
Tihange-2	1 008	13/10/1982	40.3	1 February 2023 (Closed on 31 January 2023)
Tihange-3	1 038	15/06/1985	40.0	10-year lifetime extension (Closure date 2035–2037)

Sources: Various, compiled by WNISR with Belgian Laws of 28 June 2015²⁰⁹² and 26 April 2024²⁰⁹³

With the closure of Doel-1 in February 2025 and the expected closures of Tihange-1 and Doel-2 in October and December 2025, respectively,²⁰⁹⁴ nuclear power production is bound

²⁰⁸⁹ - ENGIE, “Closing of the Agreement between ENGIE and the Belgian Government”, Press Release, 14 March 2025, see <https://corporate.engie.be/en/press/release/closing-agreement-between-engie-and-belgian-government>, accessed 16 May 2025.

²⁰⁹⁰ - Engie, “Universal Registration Document 2024—Including Annual Financial Report”, March 2025, see https://www.engie.com/sites/default/files/assets/documents/2025-03/ENGIE_DEU_2024_US_PDF_MEL_v3.pdf, accessed 23 May 2025; and Luc Joris, “Engie Leaves Door Open for Expanding Belgium’s Nuclear Energy”, *Newmobility.news*, 17 March 2025, see <https://newmobility.news/2025/03/17/engie-leaves-door-open-for-expanding-belgiums-nuclear-energy/>, accessed 16 May 2025.

²⁰⁹¹ - EMBER, “Yearly Electricity Data”, 2025, see <https://ember-energy.org/data/yearly-electricity-data>, accessed 28 June 2025.

²⁰⁹² - *Moniteur Belge*, “Loi modifiant la loi du 31 janvier 2003 sur la sortie progressive de l’énergie nucléaire à des fins de production industrielle d’électricité afin de garantir la sécurité d’approvisionnement sur le plan énergétique”, N.174, Second Edition, 6 July 2015, see http://www.ejustice.just.fgov.be/mopdf/2015/07/06_2.pdf.

- For Doel-1&-2, see Electrabel, GDF Suez/Engie, “Note de Presse—Sécurité d’approvisionnement et transition énergétique—Accord sur la prolongation de Doel 1 et Doel 2”, Press Release, 1 December 2015; and Engie Electrabel, “Doel Nuclear Power Plant—Profile of the 4 Units”, Updated 7 August 2017, see <http://corporate.engie-electrabel.be/local-player/nuclear-3/doel/>;

- For Tihange-1, see Engie Electrabel, “Tihange”, Undated, see <http://corporate.engie-electrabel.be/local-player/nuclear-3/tihange/>; all accessed 23 June 2019.

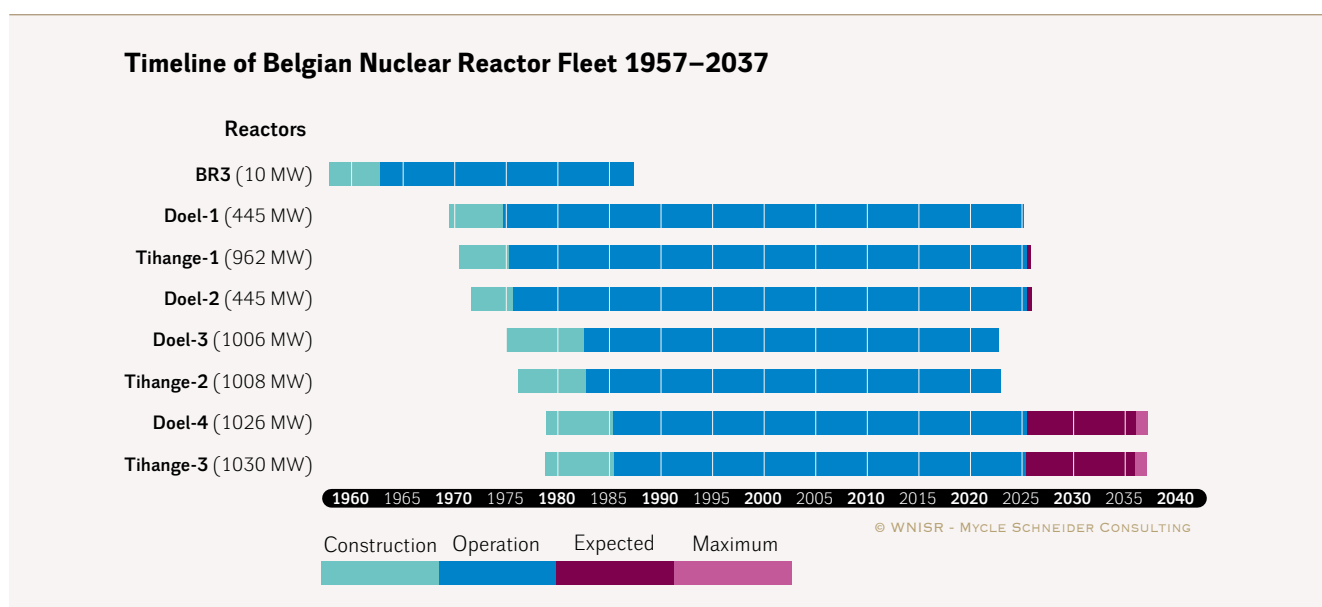
²⁰⁹³ - Federal Public Service Justice, “26 avril 2024. - Loi modifiant la loi du 31 janvier 2003 sur la sortie progressive de l’énergie nucléaire à des fins de production industrielle d’électricité”, *Moniteur Belge*, 5 June 2024, op. cit.

²⁰⁹⁴ - FANC, “Cessation des activités et démantèlement des centrales nucléaires belges”, 14 February 2025, see <https://afcn.fgov.be/fr/dossiers/centrales-nucleaires-en-belgique/cessation-des-activites-et-demanterement-des-centrales>, accessed 15 April 2025.

to decrease. Most recent Belgian energy policy envisioned carbon neutrality by 2050, to be achieved mostly through ambitious renewables expansion targets, including large offshore wind projects. Belgium missed the June 2024 deadline to submit its final updated National Energy and Climate Plan (NECP) to the European Commission, which in turn launched an infringement procedure against the country in October 2024.²⁰⁹⁵

Federal elections held in June 2024 resulted in a new government, dubbed the “Arizona coalition”, that comprises five partners and is led by Flemish nationalist Bart De Wever, who was sworn into office on 4 February 2025.²⁰⁹⁶ As of 30 June 2025, the government had still not provided a final updated National Energy and Climate Plan (NECP), initially due in June 2024.²⁰⁹⁷

Figure 86 · 80-Year Histogram of Belgian Nuclear Program



Sources: WNISR with IAEA-PRIS and Belgian Law of 26 April 2024, 2025

Note: According to the Belgian law of 26 April 2024, Doel-4 and Tihange-3 can operate for an additional period of 10 years from the restart date, on the understanding that nuclear power plants will be deactivated at the end of this period and no later than 31 December 2037.

The resulting February 2025 coalition agreement promises “enormous transformations” of Belgium’s energy landscape involving numerous ambitions for the nuclear sector, including by securing 4 GW of “existing” nuclear in the short term, and “striv[ing] to remove all obstacles, and to facilitate and accelerate the construction of new nuclear reactors.” The agreement includes the following:

²⁰⁹⁵ - Henrique Morgado Simões and Gregor Erbach, “Belgium’s Climate Action Strategy”, European Parliamentary Research Service, December 2024, see [https://www.europarl.europa.eu/RegData/etudes/BRIE/2024/767175/EPRS_BRI\(2024\)767175_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/BRIE/2024/767175/EPRS_BRI(2024)767175_EN.pdf), accessed 16 May 2025.

²⁰⁹⁶ - Raf Casert, “Belgium Has a New Prime Minister, One Who Long Tried to Gut the Nation and Seek Regional Autonomy”, AP News, 3 February 2025, see <https://apnews.com/article/belgium-government-nationalism-eu-de-wever-56f491df936173918dfe488b461f5b16>, accessed 16 May 2025.

²⁰⁹⁷ - European Commission, “National Energy and Climate Plans”, Undated, see https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en, accessed 30 June 2025.

- ➔ “in the very short term, the government will take all necessary measures to extend the operating life of existing units that meet safety standards and will begin discussions with the nuclear operator and owners to this effect”—it is somewhat unclear which units this refers to, the ones still operating, the ones already slated for lifetime extension, or the ones already closed
- ➔ “the government will launch an ambitious program in the short term to relaunch the nuclear industry in Belgium and build new nuclear reactors”
- ➔ the government will lift all legal dispositions relative to the nuclear phaseout and the prohibition of the construction of new reactors
- ➔ concerning Doel-4 and Tihange-3, “the government opts for a minimum additional lifetime extension of 10 years”
- ➔ concerning SMRs, the government recommends “the introduction of a standard certificate at European level and the shortening of licensing procedures.”²⁰⁹⁸

In March 2025, the newly appointed Energy Minister Mathieu Bihet explained in an interview with the newspaper *De Tijd* that the new coalition’s energy policy was “based on two pillars: nuclear energy and renewable energy.”²⁰⁹⁹ In an energy policy brief, Bihet announced that “taking into account [...] sustainability, safety, and cost optimization, the government [aimed] to integrate a capacity of 4 GW of nuclear energy in the electricity mix” without providing a target year or any further detail.²¹⁰⁰

The Belgian nuclear operator has a different view of the potential options. In January 2025, the CEO of Engie Belgium, Vincent Verbeke, told Belgian news agency VRT NWS that further extending the lifetimes of Doel-4 and Tihange-3 was “unthinkable” and that nuclear was no longer part of Engie’s “strategic ambition.”²¹⁰¹

The political shift towards nuclear power culminated in a parliamentary vote after which the phaseout legislation was scrapped and the ban on constructing new nuclear power plants was lifted.²¹⁰² On 15 May 2025, the legislation passed with a large majority (102 in favor, eight against (Ecolo-Groen), and 31 abstentions (Socialist Party and far-left Worker’s Party PTB).²¹⁰³ The current Arizona coalition has only 80 seats.²¹⁰⁴

²⁰⁹⁸ - Federal Government of Belgium, “Accord de coalition fédérale 2024-2029”, February 2025, see https://www.belgium.be/sites/default/files/resources/publication/files/Accord_gouvernemental-Bart_De_Wever_fr.pdf, accessed 23 May 2025.

²⁰⁹⁹ - Tobe Steel, “Minister van Energie Mathieu Bihet: ‘Zonder kerncentrales zaten we komende winter in de problemen’”, interview with Mathieu Bihet, Minister of Energy, Federal Government of Belgium, in *De Tijd*, 22 March 2025, see <https://www.tijd.be/dossiers/regering-de-wever/minister-van-energie-mathieu-bihet-zonder-kerncentrales-zaten-we-komende-winter-in-de-problemen/10599242.html>, accessed 16 May 2025.

²¹⁰⁰ - Chamber of Representatives, “Beleidsverklaring Energie / Exposé d’Orientation Politique Énergie”, Parliament of Belgium, 14 March 2025, see <https://www.lachambre.be/FLWB/PDF/56/0767/56Ko767040.pdf>, accessed 9 July 2025.

²¹⁰¹ - Rik Arnoudt, “Bijkomende verlenging Doel 4 en Tihange 3 ondenkbaar”, zegt Engie, Kamerfractie MR niet blij”, VRT NWS, 24 January 2025, see <https://www.vrt.be/vrtnws/nl/2025/01/24/bijkomende-verlenging-doe-4-en-tihange-3-ondenkbaar-zegt-eng/>, accessed 16 May 2025.

²¹⁰² - David Dalton, “Belgium Parliament Votes To Abandon Nuclear Phaseout Plans”, *NucNet*, 16 May 2025, see <https://www.nucnet.org/news/belgium-parliament-votes-to-abandon-nuclear-phaseout-plans-5-5-2025>, accessed 16 May 2025.

²¹⁰³ - Chamber of Representatives, “Vote propositions de projets et proposition de loi – séance plénière du jeudi 15 mai 2025”, Weekly Newsletter 56/030, Parliament of Belgium, May 2025, see https://www.lachambre.be/kvvcr/pdf_sections/newsletter/0000025097/56-030-vote-propositions.pdf, accessed 23 May 2025.

²¹⁰⁴ - Chamber of Representatives, “Halfron - Hémicycle”, Parliament of Belgium, 20 March 2025, see https://www.lachambre.be/kvvcr/pdf_sections/depute/hemi_56.pdf, accessed 2 July 2025.

Now that legislative hurdles have been removed, the government has to concretize its plans and convince the Belgian nuclear operator for nuclear power's relaunch in the country. How this pans out, and whether new nuclear power plants will be seriously pursued, remains to be seen. As of May 2025, there were conflicting statements and reports regarding Engie's enthusiasm towards new nuclear or further lifetime extensions.²¹⁰⁵ Luminus, majority owned by EDF (68.6 percent), is a shareholder in the Belgian reactors Doel-4 and Tihange-3 (10.2 percent of each), while EDF Belgium, a full EDF subsidiary, co-owns Tihange-1 with Electrabel (50 percent each).²¹⁰⁶ In March 2025, Luminus CEO Grégoire Dallemagne expressed the company's interest in cooperating with the Belgian government on the expansion plans, with the company also planning to invest up to €4 billion (US\$4.71 billion) into energy projects, including renewables and batteries, by 2030.²¹⁰⁷

Meanwhile, Belgian renewables capacities have substantially increased over the past decade. From 2015 to 2024, onshore wind capacity grew from 1.5 GW to 3.3 GW, offshore wind more than tripled from 712 MW to an estimated 2.26 GW, and solar PV grew by a factor of 3.1 to over 9.7 GW of installed capacity. However, year-on-year onshore wind power capacity expansion was only 145 MW, from approximately 3.2 GW in 2023 to just above 3.3 GW in 2024, while offshore capacities have remained stagnant at 2.26 GW since 2020.²¹⁰⁸ Plans for substantial offshore wind capacity expansion in the "Princess Elisabeth" zone, about 45 km off the Belgian coast, are advancing with the first 700-MW tender launched at the end of 2024. As of November 2024, Belgium planned a total of 5.8 GW of offshore capacity on its grid by 2030.²¹⁰⁹

Finland



Nuclear reactors supplied 31.1 TWh of electricity in Finland in 2024, down 5.2 percent from 2023. This represented a 39.2 percent share in the electricity mix, a significant drop from the peak of 42.1 percent in 2023.

Finland has adopted different nuclear technologies from various suppliers. Two of its operating reactors are modified VVER-V-213 units (507 MW each) built by Russian contractors at Loviisa and two others are AAIH BWR-2500 models (890 MW each) built by Asea Brown Boveri (ABB) at Olkiluoto. These four units were built in the 1970s.

²¹⁰⁵ - Luc Joris, "Engie Leaves Door Open for Expanding Belgium's Nuclear Energy", *Newmobility.news*, 17 March 2025, see <https://newmobility.news/2025/03/17/engie-leaves-door-open-for-expanding-belgiums-nuclear-energy/>, accessed 16 May 2025; and Bernard Padoan, "Prolongation du nucléaire : la porte reste finalement ouverte chez Engie", *Le Soir*, 14 March 2025, see <https://www.lesoir.be/661727/article/2025-03-14/prolongation-du-nucleaire-la-porte-reste-finalement-ouverte-chez-engie>, accessed 23 May 2025.

²¹⁰⁶ - EDF, "2024 Facts & Figures", April 2025, see <https://www.edf.fr/sites/groupe/files/2025-04/annual-results-2024-facts-and-figures-en-2025-04-09.pdf>, accessed 23 May 2025.

²¹⁰⁷ - David Adriaen, "Luminus-CEO: 'Wij willen praten over bouw nieuwe kerncentrales in België'", *De Tijd*, 14 March 2025, see <https://www.tijd.be/ondernemen/milieu-energie/luminus-ceo-wij-willen-praten-over-bouw-nieuwe-kerncentrales-in-belgie/10597861.html>, accessed 14 March 2025.

²¹⁰⁸ - IRENA, "Renewable Capacity Statistics 2025", March 2025, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Mar/IRENA_DAT_RE_Capacity_Statistics_2025.pdf, accessed 26 March 2025.

²¹⁰⁹ - Adnan Memija, "Belgium Kicks Off Tender for 700 MW Offshore Wind Farm in North Sea", *Offshore Wind*, 26 November 2024, see <https://www.offshorewind.biz/2024/11/26/belgium-kicks-off-tender-for-700-mw-offshore-wind-farm-in-north-sea/>, accessed 19 May 2025.

With the deployment of the 1575-MW European Pressurized Water Reactor (EPR) Olkiluoto-3 (OL3), a third generation (Gen III) technology was added to the fleet. The project was completed with a 13-year delay by French-German consortium Areva-Siemens in 2022 and provided electricity at full capacity for the first time on 16 April 2023, 17.5 years after construction began.²¹¹⁰ The full operational transfer, and with it the cessation of joint liabilities between operator Teollisuuden Voima Oyj (TVO) and Areva-Siemens, was completed in June 2025.²¹¹¹ Refer to [previous WNISR editions](#) for detailed accounts of the OL3 construction project.

Fluctuating Nuclear Production

In 2024, with 96 percent of electricity demand covered by domestic production,²¹¹² Finnish electricity generation fell just short of the government-envisioned target of electrical self-sufficiency, partially due to several unplanned and extended outages at its nuclear power plants.²¹¹³ The outages were not quite compensated for by a record year of wind production with over 20 TWh.²¹¹⁴ The high share of domestic electricity production helped stabilize the Finnish grid²¹¹⁵ which had to operate with reduced interconnection capacity since the EstLink 2 line that links Estonia to Finland was damaged on 25 December 2024 possibly by a tanker anchor, after having returned to service only in September 2024 following an outage of over seven months.²¹¹⁶ The transmission line was returned to operations in June 2025.²¹¹⁷

Lower-than-planned output from OL3 was caused in part by delays in the first annual maintenance outage from which the plant returned five weeks late in May 2024, taking twice as long as planned “as a result of technical problems identified during maintenance activities” per the operator TVO.²¹¹⁸ Unexpected outages and capacity reductions continued throughout the year. For example, in October 2024, the reactor operated at a reduced power level after a control rod was “unexpectedly dropped into the reactor,”²¹¹⁹ and in November 2024, a turbine

²¹¹⁰ - TVO, “Regular electricity production has started at Olkiluoto 3 EPR”, Press Release, Teollisuuden Voima Oyj, 16 April 2023, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2023/regular-electricity-production-has-started-at-olkiluoto3-epr.html>, accessed 27 July 2023.

²¹¹¹ - TVO, “Final Takeover of Olkiluoto 3 Plant Unit Accepted”, Press Release, 19 June 2025, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2025/final-takeover-of-olkiluoto3-plant-unit-accepted.html>, accessed 16 August 2025.

²¹¹² - State Treasury of Finland, “Energy Transition”, Undated, see <https://www.treasuryfinland.fi/investor-relations/sustainability-and-finnish-government-bonds/data-and-facts-energy-transition/>, accessed 2 July 2025.

²¹¹³ - YLE News, “Finland fails to achieve electricity self-sufficiency in 2024”, 1 January 2025, see <https://yle.fi/a/74-20134373>, accessed 20 May 2025.

²¹¹⁴ - EMBER, “Electricity Data Explorer”, 2025, see <https://ember-energy.org/data/electricity-data-explorer>, accessed 7 June 2025.

²¹¹⁵ - YLE News, “NBI Finds Up to 100km-Long Trail Carved into Seabed”, 30 December 2024, see <https://yle.fi/a/74-20133952>, accessed 20 May 2025.

²¹¹⁶ - Findgrid, “The EstLink 2 Electricity Interconnector between Finland and Estonia Returns to Commercial Operation”, Press Release, 3 September 2024, see <https://www.findgrid.fi/en/news/news/2024/the-estlink-2-electricity-interconnector-between-finland-and-estonia-returns-to-commercial-operation/>, accessed 20 May 2025.

²¹¹⁷ - Findgrid, “EstLink 2 Electricity Transmission Link Returns to Commercial Use”, Press Release, 18 June 2025, see <https://www.findgrid.fi/en/news/news/2025/estlink-2-electricity-transmission-link-returns-to-commercial-use/>, accessed 3 July 2025.

²¹¹⁸ - TVO, “Olkiluoto 3 Annual Outage Completed”, Press Release, 16 May 2024, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2024/4824555.html>, accessed 20 May 2025.

²¹¹⁹ - TVO, “Olkiluoto 3 Unit Operating at Low Power Level Due to a Disturbance”, Press Release, 9 October 2024, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2024/olkiluoto3-unit-operating-at-approximately-half-power-due-to-a-disturbance.html>, accessed 20 May 2025.

malfunction interrupted electricity generation,²¹²⁰ which caused a massive frequency loss in the Nordic power grid.²¹²¹ In a LinkedIn post listing OL3's malfunctions that caused substantial frequency changes in the grid in 2024, the Danish battery service provider Hybrid Greentech provocatively stated that "Olkiluoto is starting to compete with the Swedish nuclear power plant Forsmark for being the leading cause of major (loss of generation) disturbances in the Nordic power system" (see *Sweden* in Annex 1).²¹²²

Furthermore, since the start of its operations, OL3, as a participant in the Nordic electricity regulation market, had to reduce its output on several occasions due to high wind generation²¹²³ and grid constraints (lack of reserve capacity).²¹²⁴ In 2025, the annual maintenance outage was completed in just under 60 days instead of the planned 63 days, with operator TVO hoping that past malfunctions and unreliability had resulted from an initial lack of experience.²¹²⁵ Nevertheless, during the outage, the improper closure of a hatch—attributed to human error—resulted in about 100 cubic meter of coolant flowing into "containment rooms closed to the environment and into the floor drain system of the containment." TVO stated that "the incident did not pose any risk to the personnel, the environment, or nuclear safety."²¹²⁶

OL2 was taken off the grid in early September 2024, when concerning moisture levels were detected in the plant's generator. A fault in one of the rotors of this water-cooled generator was identified as the cause.²¹²⁷ The faulty equipment was replaced with a spare rotor. After 28 days, OL2 was reconnected to the grid, albeit at reduced capacity—725 MW instead of 890 MW (net)—to "prevent further damage and due to a shortage of spare parts," according to a subsequent statement from TVO.²¹²⁸ Nevertheless, in April 2025, while in the process of bringing the unit back to full power—apparently made possible by "the arrival of a replacement rotor at Olkiluoto"—the same issue reemerged, and the reactor was shut down again on 15 April

2120 - TVO, "Electricity Production at Olkiluoto 3 Was Interrupted", 20 November 2025, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2024/electricityproductionatolkiluoto3wasinterrupted.html>, accessed 24 May 2025.

2121 - Giles Parkinson, "Big Batteries and Evs to the Rescue Again As Faults with New Nuclear Plant Cause Chaos on Nordic Grids", *RenewEconomy*, 19 November 2024, see <https://reneweconomy.com.au/big-batteries-and-evs-to-the-rescue-again-as-faults-with-new-nuclear-plant-cause-chaos-on-nordic-grids/>, accessed 20 May 2025.

2122 - Hybrid Greentech, LinkedIn Post, 2024, see https://www.linkedin.com/posts/hybridgreentech_the-finish-nuclear-power-plant-olkiluoto-activity-7264352376675835905-TDCA/, accessed 20 May 2025.

2123 - YLE News, "Finland Sees New Record in Wind Power Production", 28 October 2024, see <https://yle.fi/a/74-20120582>, accessed 20 May 2025.

2124 - TVO, "The Energy Agency Issued a Decision on the Main Grid Protection System for Olkiluoto 3", Press Release, 12 January 2024, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2024/4724050.html>, accessed 3 July 2025.

2125 - TVO, "Annual Outage at Olkiluoto 3 Completed After Smooth Implementation – Electricity Production Resumed", Press Release, 29 April 2025, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2025/annualoutageatolkiluoto3completedaftermoothimplementation-electricityproductionresumed.html>, accessed 24 May 2025.

2126 - TVO, "Radioactive Coolant Leakage Into Containment Areas Closed to Environment During Annual Outage at Olkiluoto 3", Press Release, 10 March 2025, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2025/radioactivecoolantleakageintocontainmentareasclosedtoenvironmentduringannualoutageatolkiluoto3.html>, accessed 31 May 2025.

2127 - TVO, "The Cause of the Olkiluoto 2 Generator Fault Has Been Identified – The Plant Will Return to Production at the End of September", Press Release, 12 September 2024, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2024/4898264.html>, accessed 24 May 2025.

2128 - TVO, "Olkiluoto 2 to Return to Full Power Output", Press Release, 12 April 2025, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2025/olkiluoto2returntofullpoweroutput.html>, accessed 24 May 2025; and TVO, "Olkiluoto 2 Returns to Electricity Production", Press Release, 6 October 2024, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2024/olkiluoto2returntoelectricityproduction.html>, accessed 20 May 2025.

2025.²¹²⁹ The replacement rotor was subsequently installed. It was a refurbished spare part, of which there were none left in TVO's inventory. The unit was eventually reconnected to the grid in early May 2025, a few days ahead of the initial schedule.²¹³⁰ OL2 will operate at reduced capacity (735 MW) until its next annual outage in May–June 2026.²¹³¹

At OL1, operations continued as scheduled until 21 May 2025, when a malfunction at the turbine island disrupted ramp-up operations following the unit's annual maintenance outage. The reactor returned to the grid on 24 May 2025.²¹³²

At the Loviisa plant, both reactors underwent annual planned maintenance. At Unit 1, an extensive outage, which takes place every four years, was extended by nine days for additional maintenance work, and at Unit 2, the shorter yearly outage concluded two days later than planned.²¹³³ Technical issues with the cooling system of the reactor's control rod drive mechanisms at Loviisa-2 led to an unexpected shutdown on 18 November 2024, the same week OL3 experienced an unplanned production outage (see above).²¹³⁴ Loviisa-2 was reconnected to the grid four days later.²¹³⁵ The same unit's output was halved for a few days in May 2025 when a hydrogen leak was detected at one of the steam generators.²¹³⁶

Finnish Reactor Lifetime Extension Plans

As of mid-2025, the average age of the four reactors subject to lifetime extensions (OL1, OL2, Loviisa-1, and -2) was 46.3 years. In 2018, OL1 and OL2 (connected to the grid in 1978 and 1980, respectively) were approved to operate until 2038, allowing for up to 60 years of operation.²¹³⁷ In December 2024, operator TVO submitted an Environmental Impact Assessment (EIA) report evaluating the potential consequences of further power uprating at OL1 and OL2—by about eight percent, to 970 MW each—and extending the reactors' operating licenses to 2048 or even 2058. According to TVO documentation, an application for the uprating and potential

²¹²⁹ - TVO, "Electricity production at OL2 suspended due to generator fault", Press Release, 15 April 2025, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2025/electricityproductionatol2suspendedduetogeneratorfault.html>, accessed 24 May 2025.

²¹³⁰ - TVO, "Replacement of Olkiluoto 2 Generator Rotor Progressing Well – Return to Electricity Production Ahead of Schedule", Press Release, 2 May 2025, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2025/replacementofolkiluoto2generatorrotorprogressingwell-returntoelectricityproductionaheadofschedule.html>, accessed 20 May 2025.

²¹³¹ - TVO, "Olkiluoto 2 to Resume Electricity Production in May – After Generator Rotor Replacement, Production Will Continue at a Lower Power Level", Press Release, 17 April 2025, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2025/olkiluoto2toresumeelectricityproductioninmay-aftergeneratorrotorreplacementproductionwillcontinueatalowerpowerlevel.html>, accessed 24 May 2025.

²¹³² - TVO, "Output of Olkiluoto 1 Restricted Due to Malfunction", Press Release, 22 May 2025, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2025/outputofolkiluoto1restrictedduetomalfunction.html>, accessed 24 May 2025; and TVO, "Electricity Production at Olkiluoto 1 to Resume Tomorrow Night", Press Release, 23 May 2025, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2025/electricityproductionatolkiluoto1toresumetomorrownight.html>, accessed 25 May 2025.

²¹³³ - Fortum, "Fortum's Loviisa Nuclear Power Plant Annual Outage 2024 Completed", Press Release, 10 October 2024, see <https://www.fortum.com/media/2024/10/fortums-loviisa-nuclear-power-plant-annual-outage-2024-completed>, accessed 25 May 2025.

²¹³⁴ - Fortum, "Fortumin Loviisan ydinvoimalaitoksen kakkosyksiköllä tuotantokatkos (päivitetty 22.11. klo 22:15)", Updated 22 November 2024, see <https://www.fortum.com/fi/media/2024/11/fortumin-loviisan-ydinvoimalaitoksen-kakkosyksikolla-tuotantokatkos-paivitetty-2211-klo-2215>, accessed 25 May 2025.

²¹³⁵ - Ibidem.

²¹³⁶ - Fortum, "Loviisan voimalaitoksen kakkosyksikkö ajetaan puolelle teholle generaattorin lämmönvaihtimen korjaustöitä varten (päivitys 9.5.2025)", Updated 9 May 2025, see <https://www.fortum.com/fi/media/2025/05/loviisan-voimalaitoksen-kakkosyksikko-ajetaan-puolelle-teholle-generaattorin-lammonvaihtimen-korjaustoitavarten-paivitys-952025>, accessed 25 May 2025.

²¹³⁷ - TVO, "Finnish Government Approves Extension of Operating Licences for OL1 and OL2 Plant Units", Press Release, 20 September 2018, see <https://www.tvo.fi/news/2043>, accessed 25 October 2018.

lifetime extensions would have to be submitted to the Finnish regulator STUK before the end of 2028 if the EIA report is deemed appropriate by the Ministry of Economic Affairs and Employment.²¹³⁸

In April 2025, the Ministry concluded that the report conformed with current legislation,²¹³⁹ prompting TVO to take on a €75 million (US\$81 million) loan from the Nordic Investment Bank. The “considerable” investment project is presented as primarily “aimed at maintaining and improving safety measures”, through the replacement at both units of the Instrumentation & Control (I&C) and monitoring systems and modernization of the steam separators. However, possible lifetime extensions and uprates—for which TVO says it is preparing a “decision-making process”—have explicitly “been accounted for in the investment plans.”²¹⁴⁰

In February 2023, both 507-MW Russian-built reactors at the Loviisa plant were granted operational lifetime extensions until the end of 2050, resulting in 73 and 70 years of planned operation for Loviisa-1 and -2, respectively.²¹⁴¹ Beginning in 2026, work on the modernization of the low-pressure turbines shall increase the total plant capacity by around 38 MW.²¹⁴² In February 2023, the company indicated that after having already invested €300 million (US\$₂₀₂₃ 324 million) into refurbishment over the previous five years,²¹⁴³ it estimates that by 2050 a total of €1 billion (US\$₂₀₂₃ 1.1 billion) will have to be invested to continue operation. The company reiterated the estimate in 2024 and early 2025.²¹⁴⁴

²¹³⁸ - TVO, “Extending the Service Life of the Olkiluoto 1 and Olkiluoto 2 Plant Units”, December 2024, see https://tem.fi/documents/1410877/227837088/English_FINAL.pdf/e40codd4-0330-1f4d-37c0-17c1a0a70c7a/English_FINAL.pdf?version=1.0&t=1733829915354, accessed 20 May 2025.

²¹³⁹ - Ministry of Economic Affairs and Employment, “The Ministry of Economic Affairs and Employment’s Reasoned Conclusion about the Environmental Impact Assessment Report on Extending the Service Life of the Olkiluoto 1 And Olkiluoto 2 Plant Units and Uprating their Thermal Power”, Government of Finland, April 2025, see <https://tem.fi/documents/1410877/227837088/Coordinating+authoritys+reasoned+conclusion.pdf/f929bba2-9085-55a5-14ea-4bda3ad24b8d/Coordinating+authoritys+reasoned+conclusion.pdf?version=1.0&t=1747037020173>, accessed 20 May 2025.

²¹⁴⁰ - Nordic Investment Bank, “NIB Finances TVO’s Safety Investments in Nuclear Power in Olkiluoto, Finland”, Press Release, 29 April 2025, see <https://www.nib.int/news/nib-finances-tvos-safety-investments-in-nuclear-power-in-olkiluoto-finland/>, accessed 25 May 2025; and TVO, “Considerable Investment in Development of OL1 and OL2 Plant Units in Olkiluoto”, Press Release, 29 April 2025, see <https://www.tvo.fi/en/index/news/pressreleasesstockexchangerelases/2025/considerableinvestmentindevelopmentofoliandol2plantunitsinolkiluoto.html>, accessed 24 May 2025.

²¹⁴¹ - Ministry of Economic Affairs and Employment, “Fortum Granted Licence to Operate Loviisa Power Plant Units Until End of 2050”, Press Release, Government of Finland, 16 February 2023, see <https://valtioneuvosto.fi/en/-/1410877/fortum-granted-licence-to-operate-loviisa-power-plant-units-until-end-of-2050>, accessed 16 June 2024; and Government of Finland, “Decision”, Record No. VN/7906/2022, adopted 16 February 2023, see [https://tem.fi/documents/1410877/113721784/Loviisa%2BNPP%2BOperating%2BLicence%2B\(1\).pdf/87b7d85a-80a8-8d22-de09-39b10d650064/Loviisa%2BNPP%2BOperating%2BLicence%2B\(1\).pdf](https://tem.fi/documents/1410877/113721784/Loviisa%2BNPP%2BOperating%2BLicence%2B(1).pdf/87b7d85a-80a8-8d22-de09-39b10d650064/Loviisa%2BNPP%2BOperating%2BLicence%2B(1).pdf), accessed 16 August 2025.

²¹⁴² - Fortum, “Fortum’s Loviisa Nuclear Power Plant Low-Pressure Turbines To Be Modernised, Increasing Capacity by Approximately 38 MW”, Press Release, 29 May 2024, see <https://www.fortum.com/media/2024/05/fortums-loviisa-nuclear-power-plant-low-pressure-turbines-be-modernised-increasing-capacity-approximately-38-mw>, accessed 25 May 2025.

²¹⁴³ - Fortum, “The Finnish Government Has Granted a New Operating Licence for Fortum’s Loviisa Nuclear Power Plant”, 16 February 2023, see <https://www.fortum.com/media/2023/02/finnish-government-has-granted-new-operating-licence-fortums-loviisa-nuclear-power-plant>, accessed 27 July 2023.

²¹⁴⁴ - Fortum, “Fortum’s Loviisa Nuclear Power Plant Low-Pressure Turbines To Be Modernised, Increasing Capacity by Approximately 38 MW”, Press Release, 29 May 2024, op. cit.; and Fortum, “Financials 2024”, February 2025, see <https://www.fortum.com/files/fortum-financials-2024>, accessed 25 May 2025.

Fuel Supply Diversification

The Loviisa operator, Fortum, is diversifying its fuel supply away from Russian supplier TVEL and loaded the first batch of Westinghouse-manufactured fuel into Loviisa-2 in August 2024.²¹⁴⁵ More fuel is expected to be delivered in 2025 by Spanish fuel rod manufacturer Enusa, which signed a ten-year cooperation deal with Westinghouse earlier this year.²¹⁴⁶

New Nuclear Projects and Current Power Mix

In May 2025, Russian state-owned vendor Rosatom filed a US\$2.8 billion lawsuit in Moscow against Fortum and steel manufacturer Outokumpu, who, together with SSAB and other Finnish companies, had held two thirds of the Fennovoima project company (one-third held by Rosatom) that was set up to manage the Hanhikivi power plant project in 2013. The project was canceled unilaterally by the Finnish contractors in the wake of the Russian invasion of Ukraine in 2022. Refer to [previous WNISR editions](#) for details on the Hanhikivi project and its cancellation.

Since then, several litigation claims have been made by all parties that are mostly under confidential arbitration at international courts. Outokumpu dismissed Rosatom's most recent reported filing by stating that Moscow was "not the appropriate venue to address the related disputes."²¹⁴⁷ In another instance, the Finnish customs agency commenced an investigation against an "operator of a nuclear power plant construction project" who allegedly attempted to export archival material of the project to Russia, which is currently forbidden under E.U. sanctions.²¹⁴⁸

Despite the challenges of the OL3 construction project and the cancellation of the Hanhikivi plant, some Finnish utilities are envisioning further nuclear power expansion. This is supported by the government, with Juho Kortenien, Head of the Energy Department's Nuclear Energy Unit at the Ministry of Economics, stating that the "road is [...] open for new projects [...]." However, perhaps preemptively excluding Russian vendors, he added that the "applicant's background [must be] acceptable from the point of view of national security."²¹⁴⁹

²¹⁴⁵ - Fortum, "First Batch of Westinghouse Fuel Loaded at Fortum's Loviisa Nuclear Power Plant", Press Release, 2 September 2024, see <https://www.fortum.com/media/2024/09/first-batch-westinghouse-fuel-loaded-fortums-loviisa-nuclear-power-plant>, accessed 26 September 2024.

²¹⁴⁶ - Enusa, "Westinghouse y Enusa celebran 50 años de exitosa colaboración con un nuevo acuerdo tecnológico", Press Release, 13 March 2025, see <https://www.enusa.es/en/westinghouse-y-enusa-celebran-50-anos-de-exitosa-colaboracion-con-un-nuevo-acuerdo-tecnologico/>, accessed 20 May 2025.

²¹⁴⁷ - Anastasiya Lyrchikova, Anne Kauranen and Gleb Stolyarov, "Rosatom Sues Finnish Firms \$2.8B Over Nuclear Plant Contract", *Reuters* as published by *Mining.com*, 5 May 2025, see <https://www.mining.com/web/rosatom-sues-finnish-firms-2-8b-over-nuclear-plant-contract/>, accessed 20 May 2025; and Outokumpu Corporation, "Outokumpu's Position Regarding the News on the Process Initiated by Rosatom in Moscow", 6 May 2025, see <https://www.outokumpu.com/en/news/2025/outokumpu>, accessed 25 May 2025.

²¹⁴⁸ - TULLI, "Finnish Customs Suspects the Operator of a Nuclear Power Plant Construction Project of a Regulation Offence", Finnish Customs, 17 April 2025, see <https://tulli.fi/en/-/finnish-customs-suspects-the-operator-of-a-nuclear-power-plant-construction-project-of-a-regulation-offence>, accessed 3 July 2025.

²¹⁴⁹ - Juho Kortenien, "Reforming the Utilisation and Regulation of Nuclear Energy", Ministry of Economic Affairs and Employment, Finnish Government, 31 August 2023, see <https://valtioneuvosto.fi/en/-/1410877/reforming-the-utilisation-and-regulation-of-nuclear-energy>, accessed 20 May 2025.

In January 2025, then-Environment Minister Kai Mykkänen²¹⁵⁰ said that “the Finnish state should invest in a new, large nuclear power plant” because of the expected doubling of Finnish electricity demand in the coming years.²¹⁵¹

Plans for Small Modular Reactors (SMRs)

From 2022 to 2024, a flurry of studies on SMRs were initiated and numerous MoUs signed (see [section on Finland](#) in [WNISR2023](#) and [WNISR2024](#)). MoUs are not binding, and the timing of potential investment decisions has not been specified.

The most advanced project seems to be that of Finnish vendor Steady Energy, which signed a letter of intent with utility Helen in October 2023 to work towards a multipurpose agreement, ultimately enabling the commissioning of up to ten SMRs.²¹⁵² Helen launched a “nuclear energy program” in September 2024 to evaluate potential partners, suppliers, sites, and SMR designs for heat and power generation. The company stated that it hoped to operate its first SMR for district heating in Helsinki by the early 2030s.²¹⁵³

In early 2024, nuclear operator Fortum launched a pre-licensing dialogue with the Finnish nuclear safety authority while reviewing the potential of several sites for new nuclear capacity, both “small and large”. However, Fortum Vice-President Laurent Leveugle pointed out that the company was “unlikely to embark on a first-of-a-kind facility.”²¹⁵⁴ This statement clarified there was little, if any, expectation on Finnish SMR construction for commercial power production to begin anytime soon, especially since most companies with whom MoUs have been signed remain far from building their first reactors and none have any operational experience or even a certified SMR design (see [chapter on SMRs](#)).

In March 2025, the results of Fortum’s two-year feasibility study on new nuclear in Finland and Sweden—the company co-owns four Swedish reactors—were presented.²¹⁵⁵ In a nutshell, Fortum concludes that for new nuclear projects, lead times of ten years or more are required and that the company will not be able to fund any projects itself; thus it would require some form of risk-sharing with respective states, and capital investment sharing with potential project partners, before an investment decision can be taken towards the end of the decade. In short, the company does not expect new nuclear to deliver any power in Finland before the second half of the 2030s.

²¹⁵⁰ - Kai Mykkänen has since resigned as Environment Minister to become the Mayor of Espoo, Finland’s second largest city, in February 2025; see City of Espoo, “Mykkänen is Espoo’s new mayor”, 21 October 2024, see <https://www.espoo.fi/en/news/2024/10/kai-mykkanen-espoo-new-mayor>, accessed 26 May 2025.

²¹⁵¹ - YLE News, “Environment Minister: Finland Should Invest in New Nuclear Power Plant”, 14 January 2025, see <https://yle.fi/a/74-20136905>, accessed 20 May 2025.

²¹⁵² - Helen, “Helen and Steady Energy Aim to Introduce Nuclear Heat Production in Finland”, 3 October 2023, see <https://www.helen.fi/en/news/2023/helen-and-steady-energy-aim-to-introduce-nuclear-heat-production-in-finland>, accessed 26 May 2025.

²¹⁵³ - Helen, “Helen Proceeds Towards Non-Combustion by Launching a Nuclear Energy Programme”, 9 September 2024, see <https://www.helen.fi/en/news/2024/helen-proceeds-towards-non-combustion-by-launching-a-nuclear-energy-programme>, accessed 26 May 2025.

²¹⁵⁴ - Anne Kauranen, “Fortum Considers Nordic Sites for New Nuclear Power”, *Reuters*, 22 January 2024, see <https://www.reuters.com/business/energy/fortum-considers-nordic-sites-new-nuclear-power-2024-01-22/>, accessed 1 February 2024.

²¹⁵⁵ - Fortum, “Fortum Concludes New Nuclear Feasibility Study – Continues to Develop Nuclear as a Future Option”, Press Release, 24 March 2025, see <https://www.fortum.com/media/2025/03/fortum-concludes-new-nuclear-feasibility-study-continues-develop-nuclear-future-option>, accessed 16 April 2025.

Notably, Fortum concludes that for an effective project execution, they must select a “proven technology”, “[build] more than one reactor”, and “rely on competent owners with nuclear experience.” As a result, Fortum says it will “deepen collaboration” with three potential vendors: Westinghouse, EDF, and GE-Hitachi (GEH).²¹⁵⁶ For Westinghouse and EDF, it remains uncertain whether the cited large reactor designs, i.e., AP-1000 and EPR, will be built again by the vendors, given disastrous experiences at past projects. Indeed, according to the *Wall Street Journal*, Westinghouse signaled in 2024 that it “no longer takes on reactor construction,”²¹⁵⁷ while EDF is working to incorporate the lessons of said experiences to develop an improved (but yet unproven) design, the EPR2, and GEH’s BWRX-300 has not received a general design certification by any regulator yet, but did receive a construction license in Canada (see [chapter on SMRs](#)).

Energy Policy Outlook

According to global energy think tank EMBER, Finland produced 84.27 TWh (gross) of electricity in 2024. Nuclear power had the highest share at 43.6 percent,²¹⁵⁸ followed by onshore wind (26.8 percent), hydro (19.1 percent), biomass (13.8 percent), coal (1.8 percent), and other fossil fuels (4.4 percent). Solar provided 1.6 percent of the power mix, while gas provided 0.9 percent.²¹⁵⁹ The only Finnish offshore wind farm near Pori²¹⁶⁰ provided 0.4 percent of the country’s electricity.²¹⁶¹

Finland is committed to fully decarbonize its electricity system by 2035.²¹⁶² Over the past decade, renewable capacities have grown substantially. Wind grew thirteenfold in the decade from 2014 to 2024, from 627 MW to 8.4 GW, driven mostly by onshore wind expansion. In 2024, solar PV capacity reached a modest 1.2 GW.²¹⁶³

According to the Finnish National Energy and Climate Plan, submitted in June 2024, by 2035 wind power generation is to increase to over 46 TWh and solar generation to roughly 7 TWh from a negligible level today. For 2040, the plan envisions a nuclear share of around 30 percent, with absolute electricity generation increasing to around 37 TWh in 2025 and then remaining roughly stable. Wind power shall contribute approximately 40 percent by 2040 while Biomass

²¹⁵⁶ - Laurent Leveugle, “Fortum New Nuclear Feasibility Study - Key Conclusions and Next Steps” in “Fortum Develops New Nuclear Power as an Option to Meet Future Customer Demand”, Fortum, 24 March 2025, see <https://cms.fortum.com/files/press-conference-materials-fortums-news-nuclear-study-24th-march-2025>, accessed 20 May 2025.

²¹⁵⁷ - Kim Mackrael, James Marson, Nikita Nikolaenko and Jennifer Hiller, “The American Company Trying to Keep Ukraine’s Nuclear Reactors Online”, *The Wall Street Journal*, 7 June 2024, see <https://www.wsj.com/world/the-american-company-trying-to-keep-ukraines-nuclear-reactors-online-e636917a>, accessed 7 June 2024.

²¹⁵⁸ - The 39.1 percent share number in the first paragraph of the chapter is based on net production and is from a different source, i.e., IAEA-PRIS rather than EMBER.

²¹⁵⁹ - EMBER, “Yearly Electricity Data”, 2025, see <https://ember-energy.org/data/yearly-electricity-data>, accessed 15 May 2025.

²¹⁶⁰ - Suomen uusiutuv ry, “Offshore Wind Power in Finland”, Undated, see <https://suomenuusiutuvat.fi/en/wind-power/offshore-wind-power/>, accessed 20 May 2025.

²¹⁶¹ - EMBER, “Yearly Electricity Data”, 2025, op. cit.

²¹⁶² - Ministry of Economic Affairs and Employment, “Finland’s Integrated National Energy and Climate Plan Update”, Government of Finland, June 2024, see https://commission.europa.eu/document/download/069886e9-7a50-4df1-b523-9eb7bf7308c3_en?filename=FI_FINAL%20UPDATED%20NECP%202021-2030%20%28English%29.pdf, accessed 2 July 2024.

²¹⁶³ - IRENA, “Renewable Energy Statistics 2025”, International Renewable Energy Agency, March 2025, see <https://www.irena.org/Publications/2025/Mar/Renewable-capacity-statistics-2025>, accessed 21 May 2025.

and hydro shall account for 10 percent and 12 percent, respectively; the remainder is to be covered mainly through solar PV.²¹⁶⁴

In August 2024, the Ministry for Economic Affairs and Employment published a 17-point action plan to promote the expansion of offshore wind power capacities. The report notes that there were inquiries for offshore grid connections adding up to 90 GW (albeit with a partial overlap), and that Fingrid identified five potential connection areas for wind farms off the Finnish coast with up to 1.3 GW grid capacity each.²¹⁶⁵ In their latest update published in November 2024, Fingrid expanded their potential sites by two, bringing the potential offshore grid connection capacity to 9 GW in the 2030s.²¹⁶⁶

France

See Focus Countries – [France Focus](#).

The Netherlands



The Netherlands operates a single, over 50-year-old 482-MW PWR at Borssele—the oldest in the E.U.—that provided 3.4 TWh of electricity in 2024, a 10 percent decline over 2023. This corresponded to a stable 2.9 percent of the country’s electricity, compared to the historic maximum of 6.2 percent in 1986, when the country also operated a 60-MW BWR at Dodewaard. This reactor operated from 1968 to 1997. All the spent fuel had been removed by April 2003, and the site entered a 40-year “safe enclosure period” in June 2005, after which the plant is to be dismantled²¹⁶⁷ (see [Decommissioning Status Report](#)). Refer to [Netherlands Focus](#) in [WNISR2024](#) for a detailed description of the changes in the Dutch nuclear power policy in recent years.

Lifetime extension plans for the Borssele plant for up to twenty years beyond 2033, potentially allowing the reactor to operate for 80 years, seem to be advancing, but a final decision has yet to be made. The government’s multi-year 2026 Climate Fund Plan, released in April 2025, notes that the government will be “investigating the safe and efficient extension of the lifespan of the nuclear power plant in Borssele.”²¹⁶⁸ In November 2024, the IAEA conducted a pre-SALTO (Safety Aspects of Long Term Operation) mission to the plant and indicated 15 issues that would have to be addressed to bring the plant up to “the level of IAEA safety standards and

²¹⁶⁴ - Ministry of Economic Affairs and Employment, “Finland’s Integrated National Energy and Climate Plan Update—Annex 1—Reporting of used parameters and variables included in Annex 1, part 2, of the Energy Union Governance as agreed in trilogue”, Government of Finland, 2024, see https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/165742/Annex_02_Finland_NECP_2024_parameters.xlsx?sequence=3&isAllowed=y, accessed 2 July 2024.

²¹⁶⁵ - Ministry of Economic Affairs and Employment, “Merituulivoiman edistämisen toimenpidesuunnitelma”, Government of Finland, August 2024, see <https://julkaisut.valtioneuvosto.fi/handle/10024/165776>, accessed 20 May 2025.

²¹⁶⁶ - Fingrid, “Fingrid’s Final Report Refines the Preliminary Connection Possibilities for Offshore Wind Power”, Press Release, 21 November 2024, see <https://www.fingrid.fi/en/news/news/2024/fingrids-final-report-refines-the-preliminary-connection-possibilities-for-offshore-wind-power/>, accessed 31 May 2025.

²¹⁶⁷ - IAEA, “Country Nuclear Power Profiles—2022 Edition—The Netherlands”, Updated 2022, see <https://www-pub.iaea.org/MTCD/publications/PDF/cnpp2022/countryprofiles/Netherlands/Netherlands.htm>, accessed 15 June 2024.

²¹⁶⁸ - Ministry of Climate Policy and Green Growth, “Ontwerp-Meerjarenprogramma Klimaatfonds 2026”, Government of the Netherlands, 25 April 2025, see <https://www.rijksoverheid.nl/documenten/rapporten/2025/04/25/ontwerp-meerjarenprogramma-2026-klimaatfonds>, accessed 19 June 2025.

international best practices.” This includes the finalization of “aging management [programs] for mechanical and electrical components” as well as civil structures and ensuring that skilled personnel is available for long term operation.²¹⁶⁹

The plant is operated by Elektriciteits-Produktie maatschappij Zuid-Nederland (EPZ). Seventy percent of the plant’s shares are owned by Zeeuwse Energie Houdster maatschappij (ZEH), which is in turn owned by the province of Zeeland and several municipalities in the same province. German utility RWE owns the remaining shares.²¹⁷⁰ The lifetime extension requires amendments to the so-called Borssele covenant, an agreement that was introduced for the previous lifetime extension to 2033, as well as to the Nuclear Energy Act, among other legislative changes.²¹⁷¹

In an interview with news agency *Omroep Zeeland*, EPZ manager Tom Keij said that EPZ would need to know by 2029 whether Borssele shall operate beyond 2033, or whether it shall be decommissioned.²¹⁷² The interview was the subject of a written inquiry to the Dutch Parliament that was answered in May 2025 by Sophie Hermans, now-acting Climate and Energy Minister. The government hoped to pass necessary regulatory amendments by 2026 so that EPZ could submit its application to the regulatory agency in 2027.²¹⁷³ However, in June 2025, the Schoof Government collapsed, and snap elections were called for 29 October 2025.²¹⁷⁴ Additionally, the lifetime extension remains subject to a shareholder vote, expected in 2029. EPZ’s shareholders have indicated that they would only agree to the project if the state took over most of the financial risk.²¹⁷⁵ Thus, it remains to be seen whether the new government will pursue the lifetime extension, and if so, whether Dutch regulators will approve.

In recent years, despite governmental advisory committee warnings of potential overcapacities in the grid,²¹⁷⁶ Dutch energy policy has shifted towards nuclear newbuild (see *Netherlands Focus* in *WNISR2024* for details). The previous government had suggested deciding on whether to pursue the construction of two new nuclear reactors in the Netherlands by the end

²¹⁶⁹ - Division of Nuclear Installation Safety, “Report of the Pre-Safety Aspects of Long Term Operation Mission (pre-SALTO) to the Borssele Nuclear Power Plant Borssele, Netherlands”, International Atomic Energy Agency, May 2025, see <https://www.autoriteitnvs.nl/documenten/rapporten/2025/05/02/iaea-rapport-pre-salto-missie-kerncentrale-borssele>, accessed 27 May 2025.

²¹⁷⁰ - WNN, “Dutch State Could Buy Share in Borssele Plant”, 5 June 2024, see <https://www.world-nuclear-news.org/Articles/Dutch-state-could-buy-share-in-Borssele-plant>, accessed 5 June 2024; and RWE, “Annual Report 2024”, 20 March 2025.

²¹⁷¹ - Authority for Nuclear Safety and Radiation Protection, “Borssele: Possible Extension of Nuclear Power Plant’s Operating Life”, Undated, see <https://english.autoriteitnvs.nl/topics/borssele-possible-extension-of-nuclear-power-plant-s-operating-life>, accessed 20 June 2025.

²¹⁷² - Pim van den Berge, “EPZ wil snel duidelijkheid over de toekomst van de kerncentrale: Slopen of doorgaan?”, *Omroep Zeeland*, 2 May 2025, see <https://www.omroepzeeland.nl/nieuws/17433389/epz-wil-snel-duidelijkheid-over-de-toekomst-van-de-kerncentrale-slopen-of-doorgaan>, accessed 27 May 2025.

²¹⁷³ - Ministry of Climate Policy and Green Growth, “Beantwoording Kamervragen over duidelijkheid toekomst kerncentrale Borssele”, Government of the Netherlands, Answer to Parliamentary Question 2025Z08789, 26 May 2025, see <https://open.overheid.nl/documenten/a094db21-56bd-45e5-852e-83d33d398980/file>, accessed 20 June 2025.

²¹⁷⁴ - ANP, “New Parliamentary Elections Confirmed for October 29”, *NL Times*, 6 June 2025, see <https://nltimes.nl/2025/06/06/new-parliamentary-elections-confirmed-october-29>, accessed 3 July 2025.

²¹⁷⁵ - Ministry of Climate Policy and Green Growth, “Beantwoording Kamervragen over duidelijkheid toekomst kerncentrale Borssele”, Government of the Netherlands, Answer to Parliamentary Question 2025Z08789, 26 May 2025, op. cit.

²¹⁷⁶ - Expertteam Energiesysteem 2050, “Energie door perspectief: rechtvaardig, robuust en duurzaam naar 2050”, 12 April 2023, see <https://etes2050.nl/publicaties/outlookenergiesysteem2050/HandlerDownloadFiles.ashx?idnv=2448181>, accessed 22 August 2023.

of 2024.²¹⁷⁷ After the 2023 election, in its coalition agreement (2024), the incoming right-wing government expanded the target to four new reactors—as did a motion passed by Parliament in February 2024—and pledged a total of €14 billion (US\$15.2 billion) to the nuclear program until 2035.²¹⁷⁸ These funds were set aside in the 2026 Climate Fund Plan, but have been deemed “likely insufficient” to build all four reactors.²¹⁷⁹ Answering a written parliamentary question in February 2025, Energy Minister Sophie Hermans said that the plan to select a series of potentially suitable locations for newbuild, including the current Borssele site, by 2025 would not be possible and concluded that “it does not seem realistic anymore to have the first plant in operation by 2035.”²¹⁸⁰ The choice of the Borssele site would likely require substantial grid expansion investments to cope in parallel with the high generation from nearby wind power,²¹⁸¹ and another potential site in the province of Groningen is facing local opposition from city councils and the province.²¹⁸²

In many of the cited references, the Dutch words “kerncentrale” and “kernreactor” are used seemingly interchangeably, sometimes even in the same document.²¹⁸³ They translate to “nuclear power plant” and “nuclear reactor”, respectively. There are substantial differences regarding cost as well as siting, licensing, and construction procedures between building four reactors in total and four power plants in different locations, with potentially more than one reactor per site. Until the government announces concrete capacity targets, WNISR considers the expansion plans to relate to four reactors. The committed government funding for the entire nuclear program is very limited whatever the final target definition would be.

In another progress report to the Tweede Kamer (House of Representatives), published in May 2025, Minister Hermans warned that the earmarked sum of €14 billion would not suffice (even for two reactors) and that €20–30 billion (US\$22.7–34 billion) would be required to fund two reactors. She added that the Dutch government would have to finance the projects during the “first phases of construction”, and even then it would be challenging to attract private

²¹⁷⁷ - Ibidem; and *NL Times*, “Cabinet Moving Forward with Nuclear Plant Plans, Despite Experts Seeing ‘Limited Role’”, 12 April 2023, see <https://nltimes.nl/2023/04/12/cabinet-moving-forward-nuclear-plant-plans-despite-experts-seeing-limited-role>, accessed 31 July 2023.

²¹⁷⁸ - Party for Freedom, People’s Party for Freedom and Democracy, New Social Contract and Farmer-Citizen Movement, “HOOP, LEF EN TROTS—Hoofdlijnenakkoord 2024 – 2028 van PVV, VVD, NSC en BBB” and “Budgettaire bijlage hoofdlijnenakkoord”, May 2024.

²¹⁷⁹ - Ministry of Climate Policy and Green Growth, “Ontwerp-Meerjarenprogramma Klimaatfonds 2026”, Government of the Netherlands, 25 April 2025, op. cit.

²¹⁸⁰ - Ministry of Climate Policy and Green Growth, “Antwoord op vragen van het lid Erkens over vertraging bouw kerncentrales”, Government of the Netherlands, submitted to Tweede Kamer, 11 February 2025, see <https://www.tweedekamer.nl/downloads/document?id=2025Do5631>, accessed 20 June 2025.

²¹⁸¹ - Expertteam Energiesysteem 2050, “Energie door perspectief: rechtvaardig, robuust en duurzaam naar 2050”, April 2023, op. cit.

²¹⁸² - Emma van Bergeijk, “Nieuwe kerncentrales komen jaren later en vallen veel duurder uit”, *NU*, 16 May 2025, see <https://www.nu.nl/klimaat/6355960/nieuwe-kerncentrales-komen-jaren-later-en-vallen-veel-duurder-uit.html>, accessed 26 May 2025; and Province of Groningen, “Geen kerncentrale in de Eemshaven”, 22 November 2024, see <https://www.provinciegroningen.nl/actueel/nieuws/nieuwsartikel/geen-kerncentrale-in-de-eemshaven/>, accessed 20 June 2025.

²¹⁸³ - Ministry of Climate Policy and Green Growth, “Ontwerp-Meerjarenprogramma Klimaatfonds 2026”, 25 April 2025, op. cit.

investors into the project.²¹⁸⁴ In mid-2024, the Dutch pension fund floated the idea of investing in the projects.²¹⁸⁵

Meanwhile, in November 2024, engineering firm Amentum was tasked by the Dutch Authority for Nuclear Safety and Radiation Protection (ANVS) to evaluate the potential of constructing two new PWRs by 2035 from three vendors, Westinghouse, KHNP, and EDF, based on feasibility studies carried out by the vendors.²¹⁸⁶ In late March 2025, ANVS concluded from the Amentum report that, from a safety perspective, all three designs “seem suitable for construction in the Netherlands,” though the review “does not guarantee that we [ANVS] will be able to issue a license.” A detailed assessment of the design, depending on the chosen site, would be necessary before a definitive permit could be granted.²¹⁸⁷ By mid-March 2025, KHNP had already announced it would no longer pursue the project of building a reactor in the Netherlands, leaving only Westinghouse and EDF as potential vendors.²¹⁸⁸

In March 2025, a preliminary study by NRG Pallas, the operator of a medical isotope facility at Petten, on the integration of SMRs, commissioned by the Province of Gelderland, identified “four areas” as “potentially suitable for the construction of an SMR.”²¹⁸⁹ Reportedly, representatives of the province said that they were going to “do follow-up research and enter into concrete discussions on the “arrival of SMRs.”²¹⁹⁰ The ambition is to designate two locations by 2027 and to deploy a first unit between 2035–2040.²¹⁹¹

In October 2024, a joint report of NRG Pallas with the Dutch Agency for Applied Research TNO on SMR deployment in the Netherlands concluded that the construction of “two to more than 13 SMRs”, supplying both electricity and heat, would be viable by 2050.²¹⁹² The report also stated:

²¹⁸⁴ - Sophie Hermans, “Voortgangsbrieff nieuwbouw kernenergie mei 2025”, Ministry of Climate Policy and Green Growth, Government of the Netherlands, submitted to Parliament, 16 May 2025, see <https://open.overheid.nl/documenten/52194d47-a35a-4d7c-86bd-3a4d310b200b/file>, accessed 26 May 2025.

²¹⁸⁵ - NOS Nieuws, “Pensioenfonds PME wil investeren in kernenergie, roept andere partijen op te volgen”, *Nederlandse Omroep Stichting*, 25 July 2024, see <https://nos.nl/nieuwsuur/artikel/2530256-pensioenfonds-pme-wil-investeren-in-kernenergie-roept-andere-partijen-op-te-volgen>, accessed 29 May 2025.

²¹⁸⁶ - Amentum, “Amentum Selected to Evaluate Nuclear New Build Options for the Netherlands”, Press Release, 20 November 2024, see <https://www.amentum.com/news/amentum-selected-to-evaluate-nuclear-new-build-options-for-the-netherlands/>, accessed 29 May 2025.

²¹⁸⁷ - ANVS, “ANVS Shares Assessment of Feasibility Studies for New Nuclear Power Plants”, Autoriteit Nucleaire Veiligheid en Stralingsbescherming/Dutch Authority for Nuclear Safety and Radiation Protection, 25 March 2025, see <https://english.autoriteitnvs.nl/latest/news/2025/03/25/anvs-shares-assessment-of-feasibility-studies-for-new-nuclear-power-plants>, accessed 21 April 2025.

²¹⁸⁸ - Ministry of Climate Policy and Green Growth, “Brief van de Minister van Klimaat en Groene Groei”, Letter Nr. 139, addressed to Dutch Parliament, 17 March 2025, see https://www.tweedekamer.nl/kamerstukken/brieven_regering/detail?id=2025Z04898&did=2025D11359, accessed 22 June 2025.

²¹⁸⁹ - NRG Pallas, “Verkenning SMR-inpassing provincie Gelderland”, March 2025, see <https:// gelderland.stateninformatie.nl/document/15152537/1/Bijlage+-NRG+onderzoek+naar+ruimtelijke+mogelijkheden+voor+kleine+modulaire+kernreactoren+%28SMR%29>, accessed 2 June 2025; and NRG Pallas, “Research for the Province of Gelderland on the Possibilities for Integrating SMRs”, 13 March 2025, see <https://www.nrg.eu/en/news/research-for-the-province-of-gelderland-on-the-possibilities-for-integrating-smrs>, accessed 20 June 2025.

²¹⁹⁰ - WNN, “Dutch Province Considers SMR Deployment”, 13 March 2025, see <https://world-nuclear-news.org/articles/dutch-province-considers-smr-deployment>, accessed 2 June 2025.

²¹⁹¹ - Province of Gelderland, “Kernenergie (SMR)”, 12 February 2025, see <https://www.gelderland.nl/themas/duurzaamheid/energietransitie/energie-opwek/kernenergie>, accessed 20 June 2025.

²¹⁹² - Cornelis Zandt, Juan Giraldo Chavarriaga, and Martin Scheepers, “Small Modular Reactors in the Dutch Energy System—Combined Heat and Power Production in Industry”, TNO 2024 P11768, TNO and NRG Pallas, October 2024, see <https://publications.tno.nl/publication/34643320/eXPuDLgv/TNO-2024-P11768.pdf>, accessed 2 June 2025.

On the other hand, with delayed introduction of SMRs or no nuclear at all, a carbon neutral energy system in 2050 is possible as well (...).

Nevertheless, it can be concluded that SMRs are an important option for decarbonization of the industry by supplying process heat.

However, apart from several non-binding agreements (see [previous WNISR editions](#)), there have been no commitments to SMRs in the Netherlands, and the central administration seems to be focused on high-capacity reactors.

Today's electricity mix in the Netherlands is dominated by natural gas, but the situation is changing fast. In 2024, renewables combined generated 50.9 percent of total power—up from 26.8 percent in 2020—that is more than all fossil fuels and nuclear combined at 49 percent, with wind energy contributing 27.3 percent, solar 18.1 percent, and bioenergy 5.5 percent compared to natural gas providing 35.8 percent, coal 7 percent, “other fossil fuels” 3.3 percent, and nuclear 2.9 percent.²¹⁹³

Renewable capacities continue to grow, with over 200 MW of onshore and 770 MW of offshore wind capacities added in 2024, in addition to a remarkable 2.4 GW of new solar.²¹⁹⁴ According to REN21, the Netherlands has the highest installed photovoltaics capacity per capita in the world.²¹⁹⁵ Nevertheless, in a November 2024 report, the Environmental Agency noted that additional policy changes were necessary to ensure that the 2030 emission reduction targets were met.²¹⁹⁶

Spain



As of 1 July 2025, Spain operates seven reactors totaling 7.1 GW capacity that provided 51.9 TWh in 2024, representing a 4 percent decrease year-on-year and 19.1 percent of the country's electricity generation—far below the historic maximum of 38.2 percent in 1989. Spain's reactors have a mean operating age of 40.4 years as of mid-2025.

Spanish nuclear ownership is concentrated with the utilities Iberdrola and Endesa. Both utilities share ownership of Ascó-2 and Vandellós-2, Almaraz-1 and -2 with Naturgy, and Trillo with Naturgy and EDP. Endesa is the sole owner of Ascó-1, and Iberdrola fully owns Cofrentes.²¹⁹⁷

In January 2019, Spain's coalition government agreed on a nuclear phaseout plan with utilities Endesa, Iberdrola, and Naturgy as part of the overall Integrated National Energy and Climate

²¹⁹³ - EMBER, “Electricity Data Explorer—Netherlands electricity generation by source”, 2024, see <https://ember-climate.org/data/data-tools/data-explorer/>, accessed 5 June 2024.

²¹⁹⁴ - Statistics Netherlands, “Renewable Electricity; Production and Capacity”, Centraal Bureau voor de Statistiek, Updated 6 June 2025, see <https://www.cbs.nl/en-gb/figures/detail/82610ENG>, accessed 20 June 2025.

²¹⁹⁵ - REN21, “Renewables 2025 Global Status Report: Global Overview”, 20 June 2025, see <https://www.ren21.net/renewables-2025-global-status-report-global-overview/>, accessed 24 June 2025.

²¹⁹⁶ - Netherlands Environmental Assessment Agency, “Climate and Energy Outlook of the Netherlands 2024”, English summary, 18 November 2024, see https://www.pbl.nl/system/files/document/2025-01/pbl-2024-climate-and-energy-outlook-of-the-netherlands-2024_5278.pdf, accessed 2 June 2025.

²¹⁹⁷ - Foro Nuclear, “Nuclear power in Spain”, Undated, see <https://www.foronuclear.org/en/nuclear-power/nuclear-power-in-spain/>, accessed 6 August 2025.

Plan (INECP).²¹⁹⁸ All of Spain’s reactors are scheduled to be closed by 2035. However, the policy also secured the possibility for all reactors to apply for lifetime extensions beyond 40 years, in contrast to the previously governing Socialist Party’s (PSOE) policy allowing for a limited seven-year deferral of the plants’ closures initially scheduled for 2024–2028.²¹⁹⁹ This plan was confirmed in the final version of the country’s NECP, published in September 2024.²²⁰⁰

Operating licenses were extended beyond 40 years for all the Spanish reactors within the past five years (see [previous WNISR editions](#)). As shown in [Table 22](#), Almaraz-1 and -2 are the next reactors to close in November 2027 and October 2028, respectively. As the current operating licenses for Ascó-2, Vandellós-2, and Trillo expire prior to their planned delayed closure, they will have to be extended if the reactors are to operate according to the latest schedule.

Table 22 · Status of the Spanish Nuclear Fleet (as of 1 July 2025)

Reactor	Net Capacity (MW) ^(a)	Grid Connection	License Expiration ^(b)	Expected Closure ^(c)
Almaraz-1	1 011	01/05/1981	November 2027	November 2027
Almaraz-2	1 006	08/10/1983	October 2028	October 2028
Ascó-1	995	13/08/1983	October 2030	October 2030
Cofrentes	1 064	14/10/1984	November 2030	November 2030
Ascó-2	997	23/10/1985	October 2031	September 2032
Vandellós-2	1 047	12/12/1987	July 2030	February 2035
Trillo-1	1 003	23/05/1988	November 2034	May 2035

Sources: Various, compiled by WNISR, 2025

Notes:

a - Reference Unit Power from IAEA-PRIS as of 1 July 2025.

b - Individual reactor pages on Spanish Nuclear Safety Council’s website.²²⁰¹

c - Nuclear Safety Council, Eighth and Ninth Report to the Convention on Nuclear Safety.²²⁰²

In recent years, the Spanish electricity market has seen an increase in both the absolute number and the duration of periods with very low or even negative electricity prices.²²⁰³ For example,

²¹⁹⁸ - Government of Spain, “Integrated National Energy and Climate Plan 2021-2030”, 20 January 2020, see https://energy.ec.europa.eu/system/files/2020-06/es_final_necp_main_en_o.pdf, accessed 22 July 2025.

²¹⁹⁹ - Henrique Mariño, “La ministra Ribera afirma que es necesario prolongar la vida de las centrales nucleares”, *Público*, 3 March 2019, see <https://www.publico.es/politica/energia-nuclear-prolonga-vida-centrales-nucleares.html>, accessed 8 July 2021.

²²⁰⁰ - Government of Spain, “Integrated National Energy and Climate Plan—Update 2023-2030”, September 2024, see https://commission.europa.eu/document/download/211d83b7-b6d9-4bb8-b084-4a3bfb4cad3e_en?filename=ES%20-%20FINAL%20UPDATED%20NECP%202021-2030%20%28English%29.pdf, accessed 28 April 2025.

²²⁰¹ - CSN, “Almaraz—Información general”, Consejo de Seguridad Nuclear/Spanish Nuclear Safety Council, Undated, see <https://www.csn.es/central-nuclear/almaraz/informacion-general>; and CSN, “Ascó—Información general”, Undated, see <https://www.csn.es/centrales-nucleares-de-espana/asco>; also CSN, “Cofrentes—Información general”, Undated, see <https://www.csn.es/centrales-nucleares-de-espana/cofrentes>; and CSN, “Vandellós II—Información general”, Undated, see <https://www.csn.es/centrales-nucleares-de-espana/vandellos-ii>; also CSN, “Trillo—Información general”, see <https://www.csn.es/centrales-nucleares-de-espana/trillo>; all accessed 28 June 2025.

²²⁰² - CSN, “Convention on Nuclear Safety—Eighth and Ninth National Report”, August 2022, see https://www.iaea.org/sites/default/files/23/11/spain_cns_national_report_joint_8th-9th_review_meeting.pdf, accessed 28 June 2025.

²²⁰³ - *Europa Press*, “El precio del mercado mayorista de la luz toca mínimos en mayo por los precios negativos en horas solares”, 19 May 2025, see <https://www.europapress.es/economia/energia-00341/noticia-precio-mercado-mayorista-luz-toca-minimos-mayo-precios-negativos-horas-solares-20250519130759.html>, accessed 24 June 2025; and IEA, “Electricity 2025—Analysis and Forecast to 2027”, International Energy Agency, Revised February 2025, see <https://iea.blob.core.windows.net/assets/0fo28d5f-26b1-47ca-ad2a-5ca3103d070a/Electricity2025.pdf>, accessed 20 February 2025; also Jean-Paul Harreman, “Free Power: Spain Tops European League Table”, *Montel*, 29 October 2024, see <https://montel.energy/commentary/free-power-spain-tops-european-league-table>, accessed 24 June 2025.

during the Easter holidays in March 2024, the temporary reduction of nuclear capacities to only 3.6 GW was attributed partially to a “prolonged renewable output,” during which Spanish wholesale electricity prices were at less than €0.6 per MWh (US\$₂₀₂₄ 0.65/MWh).²²⁰⁴ The pattern repeated in 2025, when Almaraz-1 and -2, Ascó-1, and Cofrentes were disconnected from the grid due to low electricity prices induced by increased supply from wind and hydro, pushing wholesale prices to less than €12.14 per MWh (US\$13.8/MWh) in early April 2025.²²⁰⁵

Spanish nuclear operators and lobby group Foro Nuclear blame a “disproportionate tax burden”, which increases operating costs and forces the plants to shut down temporarily for economic reasons.²²⁰⁶ Indeed, the levy for nuclear waste management and decommissioning activities was raised from €7.98/MWh to €10.36/MWh (US\$9.1 to US\$11.8/MWh) in June 2024 due to “rising storage and disposal costs”, estimated at €20.2 billion (US\$₂₀₂₃ 21.8 billion) in the latest General Plan for Nuclear Waste Management approved in December 2023. This tax increase is subject to a legal challenge submitted to the Supreme Court by Foro Nuclear, which has been lamenting the tax burden weighing on nuclear operators for years (see past WNISR editions).²²⁰⁷ Iberdrola and Endesa have both filed appeals contesting the General Plan and the derived fee revision, arguing it constitutes a breach of the 2019 phaseout protocol, and claim a combined €778 million (US\$883.5 million) in compensation.²²⁰⁸

Attempts to Reverse Spanish Nuclear Phaseout Policy

The Spanish plans to end operations of their nuclear power plants have been facing increasing opposition in recent years (refer to [previous WNISR editions](#)). The 2023 elections led to conservative party, Partido Popular (PP), winning the majority of seats in the Spanish Parliament. However, after they failed to form a government, incumbent socialist Prime Minister Pedro Sánchez formed a government, which remains in power as of mid-2025, despite

²²⁰⁴ - Gianluca Baratti, “Spanish Nuclear Output Halves After Three Plants Halt”, S&P Global Commodity Insights, 11 March 2024, see <https://www.spglobal.com/commodity-insights/en/news-research/latest-news/electric-power/031124-spanish-nuclear-output-halves-after-three-plants-halt>, accessed 23 June 2025.

²²⁰⁵ - Xavier Grau del Cerro, “El insólito apagón nuclear en España por las tormentas”, ARA, 16 April 2025, see https://es.ara.cat/economia/energia/insolito-apagon-nuclear-espana-tormentas_1_5350102.html, accessed 24 June 2025.

²²⁰⁶ - Foro Nuclear, “Información sobre la parada de las centrales nucleares por mercado eléctrico”, Press Release, 16 April 2025, see <https://www.foronuclear.org/sala-de-prensa/notas-de-prensa/informacion-sobre-la-parada-de-las-centrales-nucleares-por-mercado-electrico/>; and CNAT, “Información sobre la central nuclear de almaraz”, Press Release, Centrales Nucleares Almaraz-Trillo, 15 April 2025, see <https://www.cnat.es/notpdf/NI%20Informaci%C3%B3n%20sobre%20CN%20Almaraz.pdf>; both accessed 7 August 2025.

²²⁰⁷ - Ministry for the Ecological Transition and Demographic Challenge, “El Gobierno actualiza la prestación patrimonial que financia el servicio de Enresa a las centrales nucleares en explotación”, Press Release, Government of Spain, 25 June 2025, see https://www.miteco.gob.es/content/dam/miteco/es/prensa/24_06_25_NdP_El_Gobierno_actualiza_la_prestaci%C3%B3n_patrimonial_que.pdf, accessed 7 August 2025; and Pietro Lombardi, “Spain’s Nuclear Waste Levy Hike Faces Legal Challenges”, *Reuters*, 4 October 2024, see <https://www.reuters.com/business/energy/spains-nuclear-waste-levy-hike-faces-legal-challenges-2024-10-04/>, accessed 24 June 2025; also Ministry for Ecological Transition and Demographic Challenge, “El Gobierno aprueba el Séptimo Plan General de Residuos Radiactivos”, Government of Spain, 27 December 2023, see <https://www.miteco.gob.es/es/prensa/ultimas-noticias/2023/12/el-gobierno-aprueba-el-septimo-plan-general-de-residuos-radiacti.html>, accessed 25 July 2024.

²²⁰⁸ - *La Vanguardia*, “Endesa se suma a Iberdrola y reclama 454 millones por la tasa a las nucleares”, 8 July 2025, see <https://www.lavanguardia.com/economia/20250708/10870501/endesa-suma-iberdrola-reclama-454-millones-tasa-nucleares.html>, accessed 7 August 2025.

mounting pressure due to ongoing investigations into corruption allegations against senior officials in his government and party, as well as family members.²²⁰⁹

The PP had run its election campaign on reversing the nuclear phaseout plan,²²¹⁰ and in February 2025, it passed a non-binding law proposal in the lower house of the Spanish Parliament to “extend the useful life of existing nuclear power plants in our country” and to

facilitate the economic sustainability of nuclear facilities in a way that reflects the fundamental role of this technology in ensuring a secure and stable electricity supply, and in its contribution to reducing electricity market prices and greenhouse gas emissions.²²¹¹

The vote showed the divide among Spanish political parties, with 171 votes in favor from PP, far-right party Vox, and the Navarrese People’s Union (Unión del Pueblo Navarro or UPN), against 164 votes from left-wing and supporting parties, and 14 abstentions from Catalan separatist parties.²²¹²

Industry demands to extend the reactors’ lifetimes beyond 2035, which had been ongoing for several years, were intensified after the vote.²²¹³ A few days after the parliamentary vote, six companies from the nuclear industry—with the support of 35 companies from other sectors—signed a manifesto calling for “dialogue and renegotiation of the 2019 agreement” and a revision to “the National Integrated Energy and Climate Plan to incorporate measures ensuring the continuity of nuclear energy,” among other demands.²²¹⁴

Also in February 2025, and regularly thereafter, a number of organizations and prominent stakeholders called for the extension of operating lifetimes. These included María Guardiola, president of Extremadura (the region bordering Portugal in which the Almaraz plant is located), who also suggested that the Spanish state should take over the operations of the plant

²²⁰⁹ - Aitor Hernández-Morales, “Corruption Scandals Put Spain’s Sánchez Under Pressure to Call Snap Elections”, *Político*, 17 June 2025, see <https://www.politico.eu/article/spain-corruption-scandal-socialist-pedro-sanchez-snap-election-santos-cerdan/>, accessed 24 June 2025; and Guy Hedgecoe, “Pedro Sánchez’s Nightmare Before Christmas”, *Político*, 24 December 2024, see <https://www.politico.eu/article/pedro-sanchez-corruption-probes-socialists-peoples-party/>; also Carmen Muela, “Spanish Judge Charges Pedro Sánchez’s Wife with Embezzlement”, *The Financial Times*, 19 August 2025, see <https://www.ft.com/content/1cab8767-aa24-4460-8b12-3b287745905d>; both accessed 22 August 2025.

²²¹⁰ - Pietro Lombardi, “Spain’s Election Frontrunners Plan U-Turn in Nuclear Power Phase-Out”, *Reuters*, 26 June 2023, see <https://www.reuters.com/world/europe/spains-election-frontrunners-plan-u-turn-nuclear-power-phase-out-2023-06-26/>, accessed 27 June 2023.

²²¹¹ - Congreso de los Diputados, “Proposición no de Ley sobre el cierre programado de la generación nuclear en España. (162/000359)”, adopted 12 February 2025, Parliament of Spain, see https://www.congreso.es/es/busqueda-de-iniciativas?p_p_id=iniciativas&p_p_lifecycle=o&p_p_state=normal&p_p_mode=view&_iniciativas_mode=mostrarDetalle&_iniciativas_legislatura=XV&_iniciativas_id=162/000359, accessed 7 August 2025.

²²¹² - Congreso de los Diputados, “-Proposición no de Ley del Grupo Parlamentario Popular en el Congreso, sobre el cierre programado de la generación nuclear en España—Resultado de la Votación”, 12 February 2025, see https://www.congreso.es/webpublica/pendata/votaciones/Leg15/Sesion091/20250212/Votacion001/VOT_20250212154035.pdf, accessed 7 August 2025.

²²¹³ - Pietro Lombardi, “Spain’s Business Lobby Calls for Extension of Nuclear Power”, *Reuters*, 3 November 2023, see <https://www.reuters.com/business/energy/spains-business-lobby-calls-extension-nuclear-power-2023-11-03/>, accessed 6 June 2024.

²²¹⁴ - Foro Nuclear, “Leading Nuclear Companies Present a Manifesto for the Continuation of Nuclear Power in Spain”, 25 February 2025, see <https://www.foronuclear.org/en/updates/news/leading-nuclear-companies-present-a-manifesto-for-the-continuation-of-nuclear-power/>; and Empresarios Agrupados – GHESA, Framatome, GD Energy Services, GEV Hitachi Nuclear Energy, IDOM and Westinghouse Electric Spain, “Manifiesto de la Industria Auxiliar del Sector Eléctrico en Favor de la Extensión de Vida de las Centrales Nucleares Españolas”, February 2025, see <https://www.foronuclear.org/wp-content/uploads/2025/02/Manifiesto-industria-auxiliar-nuclear.pdf?x44548>; both accessed 7 August 2025.

if the taxes were not reduced.²²¹⁵ Co-signing a declaration with María Guardiola to reverse the Almaraz closure decision, the president of the Community of Madrid, Isabel Díaz Ayuso, described the nuclear plant as “essential” to guarantee the stability of the national electricity system and regional economic development.²²¹⁶

Additionally, in March 2025, Iberdrola’s president, Ignacio Sánchez Galán, claimed that the phaseout would increase Spanish wholesale electricity prices by up to 30 percent and have a detrimental impact on grid reliability. He further questioned, “Can we as Europeans be in a position to renounce those natural energy resources, just because of ideology? Or do we have to be pragmatic, like the Americans?”, referring to lifetime extensions and recommissioning of closed reactors in the U.S.,²²¹⁷ and affirmed that nuclear was “absolutely necessary to keep the lights on”.²²¹⁸

Effects of the Iberian Blackout on 28 April 2025

On 28 April 2025, the Iberian Peninsula experienced the worst power blackout in its recent history, affecting mainland Spain and Portugal. Minor power cuts were also experienced in French border towns and in Andorra.²²¹⁹ Power was lost shortly after 12:30 a.m. and restored throughout the next day with help from neighboring grid connections in France and Morocco, as well as hydro-electric and pumped storage plants and combined-cycle gas plants.²²²⁰

Despite the Spanish government asking for patience until the cause for the blackout was identified, and grid operator Red Eléctrica narrowing the potential causes down to two substations that had failed in the southwest of Spain, the high share of renewables in the electricity mix at the time of the blackout—solar and wind were providing about 70 percent of power—fueled calls for the reversal of the phaseout policy.²²²¹ The search for the cause of the blackout began shortly after the incident, and cyberattacks were quickly ruled out. Despite this

²²¹⁵ - *El Confidencial*, “María Guardiola propone a Sánchez que el Estado asuma la gestión de las centrales nucleares”, 3 February 2025, see https://www.elconfidencial.com/espana/2025-02-03/maria-guardiola-propone-sanchez-estado-gestion-central-nucleares_4056529/, accessed 24 June 2025; and Junta de Extremadura, “María Guardiola urge a una reforma del sistema de financiación autonómica frente a la condonación y exige la continuidad de la Central Nuclear de Almaraz”, 6 June 2025, see <https://www.juntaex.es/w/conferencia-presidentes-barcelona>, accessed 7 August 2025.

²²¹⁶ - Comunidad de Madrid, “Díaz Ayuso pide en Extremadura la ampliación de la vida útil de Almaraz: ‘No podemos permitir que el Gobierno apague el futuro de España’”, 24 February 2025, see <https://www.comunidad.madrid/noticias/2025/02/24/diaz-ayuso-pide-extremadura-ampliacion-vida-util-almaraz-no-podemos-permitir-gobierno-apague-futuro-espana>, accessed 7 August 2025.

²²¹⁷ - Jamie Smyth, Barney Jopson and Laura Pitel, “Iberdrola Warns Energy Prices Will Soar if Spain Shuts Nuclear Plants”, *The Financial Times*, 20 March 2025, see <https://www.ft.com/content/4224da9e-dbc5-4aec-85b3-1ce793228086>, accessed 7 August 2025.

²²¹⁸ - *Agence France-Presse*, “Spain Under Pressure to Abort Nuclear Energy Phase-Out”, as published by *France 24*, 7 March 2025, see <https://www.france24.com/en/live-news/20250307-spain-under-pressure-to-abort-nuclear-energy-phase-out>, accessed 24 June 2025.

²²¹⁹ - Cecilia Castelló Llantada and Álvaro Sánchez, “Massive Power Blackout Hits Spain and Portugal”, *EL PAÍS English*, 28 April 2025, see <https://english.elpais.com/international/2025-04-28/massive-power-outages-cause-blackouts-in-spain-and-portugal.html>, accessed 24 June 2025; and Molly Lempriere, Daisy Dunne and Josh Gabbatiss, “Q&A: What We Do – And Do Not – Know About the Blackout in Spain and Portugal”, *Carbon Brief*, 30 April 2025.

²²²⁰ - Paul Kirby, “How Spain Powered Back to Life from Unprecedented National Blackout”, *BBC*, 29 April 2025, see <https://www.bbc.com/news/articles/c175ykvjxyeo>, accessed 24 June 2025; and ENTSO-E, “28 April Blackout in Spain and Portugal: Expert Panel Releases New Information”, European Network of Transmission System Operators for Electricity, Updated 16 July 2025, see <https://www.entsoe.eu/news/2025/07/16/28-april-blackout-in-spain-and-portugal-expert-panel-releases-new-information/>, accessed 27 July 2025.

²²²¹ - Manuel Planelles, “Massive Blackout Reignites Culture War Over the Future of Nuclear Energy in Spain”, *EL PAÍS English*, 30 April 2025, see <https://english.elpais.com/climate/2025-04-30/massive-blackout-in-spain-reignites-culture-war-over-the-future-of-nuclear-energy.html>; and Suman Naishadham, “After Spain’s Blackout, Questions About Renewable Energy Are Back”, *The Associated Press*, 9 May 2025, see <https://apnews.com/article/renewables-nuclear-spain-portugal-energy-power-outage-climate-change-c62fbb73e982365d10402323e4fcfc6>; both accessed 24 June 2025.

uncertainty, the high share of renewables in power production continued to be blamed, with commentators confusing correlation with causation.²²²²

On 17 June 2025, the Spanish government reported the conclusion of the investigation carried out by a specially tasked committee.²²²³ A full report with individual retracted sections was published on the same day.²²²⁴ According to the analysis, a series of individual events triggered a chain reaction within the system.²²²⁵ These events include power plants capable of stabilizing the grid not behaving as had been planned by the grid operator, an unexpectedly slow response of these plants after being called to stabilize the grid when renewable production steadily increased on the morning of the 28 April, and so-called “rhythmic oscillations” as well as “premature disconnections” from the grid that led to a loss of capacity that was too fast for the grid to keep up with.²²²⁶

The Minister for the Ecological Transition, Sara Aagesen, concluded in her presentation of the report that grid-operator Red Eléctrica had “miscalculated the power capacity needs for that day,” failing to bring additional thermal capacity to the grid, and she blamed private operators who “were supposed to control voltage—[and] were paid to do just that—did not absorb all the voltage they were supposed to.” The companies were not named.²²²⁷ The report does acknowledge that “vulnerabilities and deficiencies” exist in the Spanish and Portuguese grids and advocates for improved supervision of operators, an increase in the country’s overall power capacity, and the expansion of interconnections to neighboring countries.

On 24 June 2025, only one week after the publication of the inquiry report, the Spanish government adopted a set of “urgent measures” to strengthen the electricity system in three areas:

- ➔ strengthening the monitoring, verification, compliance, and transfer capacities of the system
- ➔ enhancing the storage and flexibility of the system

²²²² - *Euronews*, “Did Wind and Solar Really Make Spain’s Power Grid More Vulnerable?”, 30 April 2025, see <https://www.euronews.com/green/2025/04/29/did-renewable-energy-cause-spain-and-portugals-mass-blackout-experts-weigh-in>; and Jan D. Walter, “Fact Check: Did Solar Power Cause the Iberian Blackout?”, *Deutsche Welle*, 2 May 2025, see <https://www.dw.com/en/fact-check-was-the-iberian-blackout-caused-by-too-much-solar-power/a-72415376>; both accessed 24 June 2025.

²²²³ - Ministry for the Ecological Transition and the Demographic Challenge, “Se Presenta El Informe Del Comité De Análisis De La Crisis Eléctrica Del 28 De Abril”, Government of Spain, 17 June 2025, see <https://www.miteco.gob.es/es/prensa/ultimas-noticias/2025/junio/se-presenta-el-informe-del-comite-de-analisis-de-la-crisis-elect.html>, accessed 18 June 2025.

²²²⁴ - The Committee for the Analysis of Circumstances that concurred in the Electricity Crisis of April 28, 2025, and National Security Council, “Versión no confidencial del informe del comité para el análisis de las circunstancias que concurrieron en la crisis de electricidad del 28 de abril de 2025”, Government of Spain, June 2025, see <https://www.lamoncloa.gob.es/consejodeministros/resumenes/Documents/2025/Informe-no-confidencial-Comite-de-analisis-28A.pdf>, accessed 18 June 2025.

²²²⁵ - System Operation Division, “Blackout in Spanish Peninsular Electrical System the 28th of April 2025”, Red Eléctrica, 18 June 2025, see https://d1n1o4zeyfu21r.cloudfront.net/WEB_Incident_%2028A_SpanishPeninsularElectricalSystem_18june25.pdf, accessed 24 June 2025.

²²²⁶ - The Committee for the Analysis of Circumstances that concurred in the Electricity Crisis of April 28, 2025, and National Security Council, “Versión no confidencial del informe del comité para el análisis de las circunstancias que concurrieron en la crisis de electricidad del 28 de abril de 2025”, Government of Spain, June 2025, op. cit.

²²²⁷ - Guy Hedgcock, “Spain’s Government Blames Huge Blackout on Grid Regulator and Private Firms”, *BBC News*, 17 June 2025, see <https://www.bbc.com/news/articles/c62d8k8edgxo>, accessed 24 June 2025, and La Moncloa, “El Gobierno presenta el informe sobre las causas del apagón, que se debió a una sobretensión de origen ‘multifactorial’”, President and Council of Ministers, Government of Spain, 17 June 2025, see <https://www.lamoncloa.gob.es/consejodeministros/resumenes/paginas/2025/170625-rueda-de-prensa-ministros.aspx>, accessed 7 August 2025.

- advancing electrification, facilitating the integration of industrial demand, transport, and renewable generation²²²⁸

One day prior to the release of the task force report, the European Investment Bank (EIB) announced funding of €1.6 billion (US\$1.8 billion) to increase the power exchange capacity between Spain and France from 2.8 GW to 5 GW,²²²⁹ and in May 2025, the Spanish government launched a €700-million (US\$795 million) support scheme to fund up to 3.5 GW for “innovative” energy storage projects.²²³⁰ Obviously, both projects had been in the pipeline for several years.

Meanwhile, the Spanish government remains committed to its target of becoming climate neutral by 2050 and reaching 81 percent of renewable electricity supply by 2030.²²³¹ In 2024, 7.3 GW of renewable capacity was added to the grid, of which 6 GW were solar PV and 1.3 GW were onshore wind. Over the past decade, renewable capacities grew by 37 GW to over 85 GW in 2024 consisting of solar, wind, hydro, as well as marginal capacities of bioenergy and other technologies, such as geothermal.²²³² The electricity mix (gross) in 2024 comprised 22.4 percent onshore wind, 20.9 percent solar, 19.6 percent nuclear, 18.7 percent natural gas, 11.6 percent hydro, followed by “other fossil” (3.6 percent), bioenergy (2.2 percent), and coal (0.9 percent).²²³³

Sweden



Sweden’s nuclear fleet of six reactors generated 48.1 TWh in 2024, a 4.4 percent increase compared to the previous year. Nuclear accounted for 29.4 percent of the country’s total electricity production. The share of nuclear power in the country’s electricity mix peaked in 1996 at 52.8 percent when 12 reactors were operating, while the fleet reached its highest output of over 75 TWh in 2004 with 11 units still on the grid. Refer to **Sweden Focus** in **WNISR2024** for details on the Swedish nuclear energy policy and past developments.

Lifetime Extensions for Aging Swedish Fleet?

The mean age of the Swedish fleet is 43 years, with four reactors over 41 years (see **Figure 87**).

²²²⁸ - Government of Spain, “El Gobierno refuerza la supervisión y la innovación del sistema eléctrico”, 24 June 2025, see <https://www.lamoncloa.gob.es/consejodeministros/resumenes/paginas/2025/240625-rueda-de-prensa-ministros.aspx>, accessed 7 August 2025.

²²²⁹ - *Le Monde*, “Spain Blames ‘Overvoltage’ for Huge April Blackout”, with *Agence France-Presse*, 17 June 2025, see https://www.lemonde.fr/en/energies/article/2025/06/17/spain-blames-overvoltage-for-huge-april-blackout_6742433_98.html, accessed 24 June 2025; and European Investment Bank, “EIB Supports with €1.6 Bn the Strategic Bay of Biscay Electricity Interconnection between Spain and France”, 16 June 2025, see <https://www.eib.org/en/press/all/2025-241-eib-supports-with-eur1-6-bn-the-strategic-bay-of-biscay-electricity-interconnection-between-spain-and-france>, accessed 7 August 2025.

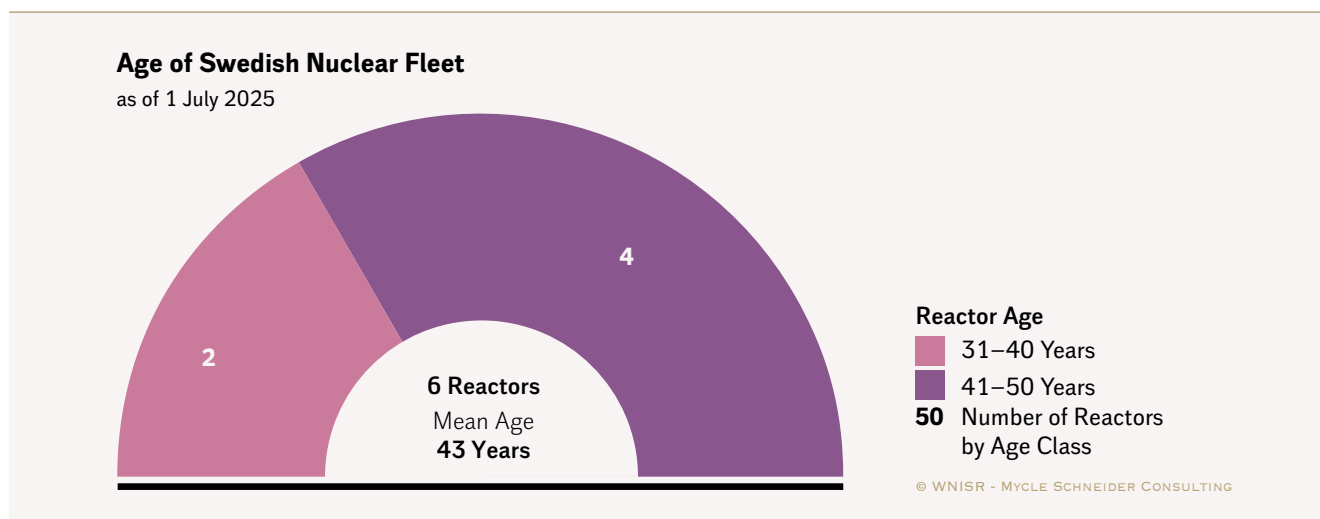
²²³⁰ - Pilar Sánchez Molina, “Lanzada la convocatoria de 700 millones en ayudas para almacenamiento energético a gran escala”, *PV Magazine España*, 30 May 2025, see <https://www.pv-magazine.es/2025/05/30/lanzada-la-convocatoria-de-700-millones-en-ayudas-para-almacenamiento-energetico-a-gran-escala/>, accessed 24 June 2025.

²²³¹ - Government of Spain, “Integrated National Energy and Climate Plan—Update 2023-2030”, September 2024, op. cit.; and José María Camarero, “El Gobierno mantendrá su plan energético tal y como estaba a pesar del apagón”, *ABC*, 30 April 2025.

²²³² - Red Eléctrica, “Informe del Sistema Eléctrico - Informe resumen de energías renovables 2024”, March 2025, see https://www.sistemaelectrico-ree.es/sites/default/files/2025-03/Informe_Renovables_2024.pdf, accessed 24 June 2025.

²²³³ - EMBER, “Yearly Electricity Data”, 2025, see <https://ember-energy.org/data/yearly-electricity-data>, accessed 15 May 2025.

Figure 87 · Age Distribution of the Swedish Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2025

In June 2024, Vattenfall, the majority-owner-operator of the three Boiling Water Reactors (BWRs) at Forsmark and the two Pressurized Water Reactors (PWRs) at Ringhals (that were connected to the grid between 1980 and 1985), announced that it had “taken a directional decision to extend the operating lifetime of the plants’ reactors from 60 to 80 years,” and therefore was awaiting an “in-depth investigation”.²²³⁴ This would push their closure dates into the 2060s. The investigation is planned to conclude in 2026, after which an investment decision is expected.²²³⁵ In September, the owners of Oskarshamn-3, Uniper and Fortum, declared the launch of a study to investigate the reactor’s operation beyond its current expected lifetime, 2045, “well into the mid 2060s.”²²³⁶

Independent of the outcome of the investigations and the decisions in principle to extend operating lifetimes, all of the reactors have to pass decennial safety reviews by the regulator.

In recent years, the operations of Swedish nuclear power reactors have been plagued by a series of unplanned and extended outages (see [past WNISR editions](#)). While the operations at the Ringhals site appear to be under control following major challenges in 2022,²²³⁷ Forsmark-3 was shut down on 1 September 2024 for a revision that was scheduled to conclude by mid-October of the same year.²²³⁸ In November, it was announced that the outage would be extended until 27 January 2025 due to extensive repairs on cracks affecting two low-pressure turbines, but

²²³⁴ - Vattenfall, “Forsmark and Ringhals Nuclear Power Plants Aim for 80 Years of Operation of Existing Reactors”, Press Release, 17 June 2024, see <https://group.vattenfall.com/press-and-media/pressreleases/2024/forsmark-and-ringhals-nuclear-power-plants-aim-for-80-years-of-operation-of-existing-reactors>, accessed 17 June 2024.

²²³⁵ - Vattenfall, “Annual and Sustainability Report 2024”, June 2024, see <https://group.vattenfall.com/globalassets/com/sustainability/vattenfall-annual-and-sustainability-report-2024.pdf>, accessed 17 June 2024.

²²³⁶ - Fortum, “Owners of Oskarshamn Nuclear Power Plant in Sweden Investigate Lifetime Extension”, 18 September 2024, see <https://www.fortum.com/media/2024/09/owners-oskarshamn-nuclear-power-plant-sweden-investigate-lifetime-extension>; and Uniper, “80 blir det nya 60 – för kärnkraften”, 24 September 2024, see <https://www.uniper.energy/sverige/nyheter/80-blir-det-nya-60-for-karnkraften/>, both accessed 7 August 2025.

²²³⁷ - Nora Buli, Anna Ringstrom and Anne Kauranen, “Sweden’s Ringhals 4 Nuclear Outage Extends into Winter Months”, Reuters, 13 September 2022, see <https://www.reuters.com/business/energy/swedens-ringhals-4-nuclear-outage-extends-into-winter-months-2022-09-13/>, accessed 13 June 2023.

²²³⁸ - Vattenfall, “Revisionen avslutad - Forsmark 3 har fasat”, Press Release, 3 February 2025, see <https://group.vattenfall.com/se/nyheter-och-press/nyheter/2025/revisiionen-avslutad-forsmark-3-har-fasat>, accessed 17 June 2025.

that the annual closure planned for March 2025 would be combined with the audit scheduled for 2026, reducing the total planned outage of Forsmark-3 by 15 days for 2025 and 2026 combined.²²³⁹ The plant came back online during the first weekend of February 2025.²²⁴⁰ Only a few days later, on 4 February, the reactor went offline again due to a faulty valve and returned to the grid three days later.²²⁴¹

On 28 March 2025, after achieving its longest run of consecutive days generating power per OKG, Oskarshamn-3 was taken off the grid for refueling and maintenance planned to last “just under three weeks.”²²⁴² In April 2025, cracks were discovered in several critical pipes, leading to an extension of the outage until 15 June. By May, this had been further extended until mid-August,²²⁴³ and on 26 June restart was again delayed, to early September 2025 this time.²²⁴⁴

Swedish Nuclear Policy Reversal—Embracing Newbuild

In changing its target definition for electricity production by 2040 from “100% renewable” to “100% fossil-free” in June 2023, Sweden paved the way for nuclear newbuild in the country.²²⁴⁵ Current plans envision 2.5 GW of new nuclear on the grid by 2035 and the equivalent of ten new large reactors by 2045.²²⁴⁶

In January 2024, a “nuclear power coordinator” was appointed, tasked with identifying necessary measures, removing regulatory hurdles, coordinating with all stakeholders, and promoting new nuclear development. The final report is scheduled for end-2026.²²⁴⁷ In the second interim report, the coordinator lists several completed, ongoing, and planned promotional measures to support Swedish nuclear newbuild, for example, the potential financing of pilot and demonstration plants by the Swedish Energy Agency or the development of a financing model for new nuclear plants by the Ministry of Finance.

²²³⁹ - Terje Solsvik, “Sweden Cancels Planned 2025 Maintenance at Forsmark 3 Nuclear Reactor”, *Reuters*, 25 November 2024, see <https://www.reuters.com/business/energy/sweden-cancels-planned-2025-maintenance-forsmark-3-nuclear-reactor-2024-11-25/>, accessed 17 June 2025; and Vattenfall, “Revisionen på Forsmark 3 utgår 2025”, 25 November 2024, see <https://group.vattenfall.com/se/nyheter-och-press/nyheter/2024/revisionen-pa-forsmark-3-utgar-2025>, accessed 7 August 2025.

²²⁴⁰ - Vattenfall, “Revisionen avslutad - Forsmark 3 har fasat”, Press Release, 3 February 2025, op cit.

²²⁴¹ - Vattenfall, “Forsmark 3 åtgärdar ventil”, Press Release, Updated 7 February 2025, see <https://group.vattenfall.com/se/nyheter-och-press/nyheter/2025/forsmark-3-atgardar-ventil>, accessed 17 June 2025.

²²⁴² - OKG, “Efter 325 dagar – nu pausas O3 för revision”, Press Release, 28 March 2025, see <https://www.mynewsdesk.com/se/okg/pressreleases/efter-325-dagar-nu-pausas-o3-foer-revision-3378063>, accessed 17 June 2025.

²²⁴³ - Linn Kolar, “40 år och stopp – Sveriges största reaktor pausas”, *Dagens PS*, 6 May 2025, see <https://www.dagensps.se/teknik/energi/40-ar-och-stopp-sveriges-storsta-reaktor-pausas/>, accessed 17 June 2025.

²²⁴⁴ - OKG Aktiebolag, “Unavailability of Electricity Facilities : Production—Oskarshamn 3 – G3”, UMM Platform, Nord Pool, 26 June 2025, see <https://umm.nordpoolgroup.com/#/messages/6e67cd67-66eb-4525-8473-eac8114e55bf/7>, accessed 8 August 2025.

²²⁴⁵ - Simon Johnson, “Swedish Parliament Passes New Energy Target, Easing Way for New Nuclear Power”, *Reuters*, 20 June 2023, see <https://www.reuters.com/sustainability/climate-energy/swedish-parliament-passes-new-energy-target-easing-way-new-nuclear-power-2023-06-20/>, accessed 8 September 2023.

²²⁴⁶ - Ministry of Climate and Enterprise, “Sweden’s Updated National Energy and Climate Plan 2021-2030”, Government Offices of Sweden, June 2024, see https://commission.europa.eu/document/download/26d2c93e-641d-489f-a160-a7052fde58bb_en?filename=SE_FINAL%20UPDATED%20NECP%202021-2030%20%28English%29.pdf, accessed 2 July 2024.

²²⁴⁷ - Regeringskansliet, “Carl Berglöf utses till nationell kärnkraftssamordnare”, Press Release, Government Offices of Sweden, 4 January 2024, see <https://www.regeringen.se/pressmeddelanden/2024/01/carl-bergl-of-utses-till-nationell-karnkraftssamordnare/>, accessed 28 July 2024; and David Dalton, “Sweden / Gov’t Appoints Nuclear Coordinator As Plans to Deploy New Reactors Gather Pace”, *NucNet*, 5 January 2024, see <https://www.nucnet.org/news/gov-t-appoints-nuclear-coordinator-as-plans-to-deploy-new-reactors-gather-pace-1-5-2024>, accessed 10 June 2024.

The coordinator notes that from a regulatory perspective, the acceleration of the licensing process for up to 2.5 GW of new nuclear is necessary and is “the most challenging aspect”. His report elaborates that the newly proposed permitting process is estimated to take 10 years from application to grid connection but acknowledges that “there are some uncertainties about the efficiency of the process when it is used for the first few times.” The report concludes, therefore, that parallel expansion projects involving “at least two sites” is the strategy most likely to achieve the targeted 2.5 GW deployment by 2035.²²⁴⁸

In its 2025 budget proposal adopted in late 2024, the government earmarked SEK1 billion (US\$104 million) to fund fossil-free electricity generation. This included SEK100 million (US\$10.4 million) to “support pilot and demonstration projects in the nuclear field”, SEK2.5 million (US\$261,000) in increased funding to the Swedish Environmental Protection Agency for consultancy on developing new nuclear permitting processes, and SEK30 million (US\$3.1 million) for further activities towards creating favorable conditions for new nuclear.²²⁴⁹

A report by the Swedish Energy Agency highlights another looming challenge: the potential future lack of competent staff, not limited to nuclear but also affecting the electrification of Sweden’s entire energy supply system. For nuclear, the report points out that, in the short-term, current plant staff members are nearing retirement age, while there is growing demand for expertise in project planning, construction, and operation of a potential new fleet. It notes that other countries likely experiencing a growing need for skilled staff at the same time, due to their own nuclear expansion plans and/or maintenance requirements, will cause fierce competition in the future and thus pose a major challenge needing to be addressed. Consequently, to account for necessary training and education times, the report calls for an assessment of future demand and supply for a nuclear-trained workforce.²²⁵⁰

Regarding the planned newbuild program’s financing, a commission tasked with developing models through which the government could help shoulder the associated risks concluded its work in August 2024.²²⁵¹ A financing scheme based on the commission’s recommendations

²²⁴⁸ - Carl Berglöf, “Interim Report 2: Report on the National Nuclear New-Build Coordinator’s Mission Regarding the Expansion of Nuclear Power in Sweden”, National Nuclear New-build Coordinator, January 2025, see <https://www.government.se/contentassets/980730753890483c8f7323af6d2b5dce/interim-report-2-report-on-the-national-nuclear-new-build-coordinators-mission-regarding-the-expansion-of-nuclear-power-in-sweden-january-2025/>, accessed 17 June 2025.

²²⁴⁹ - WNN, “Sweden Budgets for Nuclear New Build”, 11 September 2024, see <https://world-nuclear-news.org/articles/sweden-budgets-for-nuclear-new-build>, accessed 17 June 2025; and Government of Sweden, “Satsningar på elektrifiering och grön omställning”, Press Release, 9 September 2024, see <https://www.regeringen.se/pressmeddelanden/2024/09/satsningar-pa-elektrifiering-och-gron-omstallning>, accessed 7 August 2025.

²²⁵⁰ - Energimyndigheten, “Kompetens för samhällets elektrifiering—Slutrapportering av regeringsuppdrag att samordna en nationell kraftsamling”, Swedish Energy Agency, November 2024, see <https://www.energimyndigheten.se/4ad6b4/globalassets/nyheter/2024/slutrapport-kompetens-for-samhallets-elektrifiering.pdf>, accessed 17 June 2025.

²²⁵¹ - Simon Johnson, “Price Tag for New Nuclear Power in Sweden \$38 Billion, Commission Says”, *Reuters*, 12 August 2024, see <https://www.reuters.com/business/energy/price-tag-new-nuclear-power-sweden-38-bln-commission-says-2024-08-12/>, accessed 17 June 2025; and Finance Department, “Promemoria Finansiering och riskdelning vid investeringar i ny kärnkraft”, Government of Sweden, August 2024, see <https://www.regeringen.se/contentassets/785ee941726840229ed69135ca8f890c/finansiering-och-riskdelning-vid-investeringar-i-ny-karnkraft.pdf>, accessed 22 August 2024.

was proposed to the Riksdag, Sweden's parliament, by the government in March 2025. The corresponding legislation was passed in May and will enter into force in August 2025.²²⁵²

Recognizing the private sector's reluctance to take on the risk of nuclear newbuild, the new legislation allows the Swedish state to fund up to 75 percent of a project's investment cost with government loans, which would correspond to SEK315 billion (US\$32.9 billion) for four reactors.²²⁵³ The government notes that concrete details on funding and financing would be determined once a specific project's costs have been determined—as of now, there is no project. Furthermore, the operator would receive fixed revenues via a symmetrical Contracts-for-Difference scheme capped at SEK0.8 per kWh (US\$0.083/kWh). This is to be funded by a levy on electricity prices to electricity consumers of SEK0.02 per kWh (US\$0.002/kWh).²²⁵⁴ Risks of cost increases are to be shared equally with private investors according to the share structure of the project. The scheme is still subject to approval by the European Commission.²²⁵⁵

In late June 2025, the government approved a new ordinance regulating the application process for state aid to companies seeking to build reactors. On 1 August 2025, the applications portal opened for “companies whose sole activity is the construction and operation of new nuclear power reactors.”²²⁵⁶

In an interview with Swedish newspaper *Dagens Nyheter*, Prime Minister Ulf Kristersson stated that the construction of a new nuclear power plant would commence before the next election, which is scheduled for September 2026.²²⁵⁷ This ambitious plan is described as unrealistic from both sides of the political spectrum, e.g., by former advisor and CEO of conservative think tank Timbro, P. M. Nilsson²²⁵⁸ and by Rolf Lindahl of Greenpeace.²²⁵⁹

The skepticism appears reasonable given that none of the Swedish operators have yet committed themselves to specific projects or vendors. In June 2024, Vattenfall's head of new nuclear

²²⁵² - Ministry of Finance, “Green Light for a New Model for Financing and Risk Sharing for Investments in New Nuclear Power”, Press Release, Government of Sweden, 21 May 2025, see <https://www.government.se/press-releases/2025/05/green-light-for-a-new-model-for-financing-and-risk-sharing-for-investments-in-new-nuclear-power/>, accessed 24 May 2025; and Government of Sweden, “Finansiering och riskdelning vid investeringar i ny kärnkraft—Regeringens proposition 2024/25:150”, 27 March 2025, see <https://www.riksdagen.se/sv/dokument-och-lagar/dokument/proposition/finansiering-och-riskdelning-vid-investeringar-i-hco3150/>, accessed 25 April 2025; also Sveriges Riksdag, “Finansiering och riskdelning vid investeringar i ny kärnkraft (Betänkande 2024/25:NU20 Näringsutskottet)”, Parliament of Sweden, 21 May 2025, see <https://www.riksdagen.se/sv/dokument-och-lagar/dokument/betankande/finansiering-och-riskdelning-vid-investeringar-i-hco1nu20/>, accessed 19 June 2025; and Government of Sweden, “Government Bill 2024/25:150—Financing and Risk-Sharing for Investments in New Nuclear Power”, 27 March 2025, see <https://www.government.se/contentassets/415569456a034f22a31b2c8e16f88726/financing-and-risk-sharing-for-investments-in-new-nuclear-power.pdf>, accessed 8 August 2025.

²²⁵³ - Ibidem.

²²⁵⁴ - Depending on the electricity demand, this could increase electricity bills by SEK60 (flat with no electrical heating, 3,000 kWh) to SEK500 (house with heat pump, 25,000 kWh), i.e., by US\$6.3 and US\$52.2, respectively.

²²⁵⁵ - Government of Sweden, “Regeringens proposition 2024/25:150—Finansiering och riskdelning vid investeringar i ny kärnkraft”, 27 March 2025, see <https://data.riksdagen.se/fil/F01EA497-E7B5-42ED-B2D2-ACB1FED55630>, accessed 17 June 2025.

²²⁵⁶ - Ministry of Climate and Enterprise and Ministry of Finance, “Legislation to Enable Applications for State Aid for Investments in New Nuclear Power”, Press Release, Government of Sweden, 27 June 2025, see <https://www.government.se/press-releases/2025/06/legislation-to-enable-applications-for-state-aid-for-investments-in-new-nuclear-power/>, accessed 8 August 2025.

²²⁵⁷ - Hans Olsson, “Ulf Kristersson: Ny kärnkraft börjar byggas före nästa val”, *Dagens Nyheter*, 26 September 2024, see <https://www.dn.se/verige/kristerssons-besked-om-karnkraften-kommer-borja-byggas-fore-nasta-val/>, accessed 17 June 2025.

²²⁵⁸ - Tomas Nordenskiöld, “Regeringens planer på ny kärnkraft döms ut: ”Sinnessjukt stora belopp””, *Expressen*, 16 December 2024, see <https://www.expressen.se/nyheter/sverige/satsningen-pa-ny-karnkraft-doms-ut/>, accessed 17 June 2025.

²²⁵⁹ - Rolf Lindahl, “Climate Ambition Slammed by Nuclear Populism: The Case of Sweden”, Climate and Energy Campaigner, Greenpeace, *Nuclear Monitor*, 19 December 2024, see <https://www.wiseinternational.org/climate-ambition-slammed-by-nuclear-populism-the-case-of-sweden/>, accessed 18 June 2025.

power, Desirée Comstedt, said that they “[had not] made a choice of reactor technology yet” but that two “potential suppliers of small modular reactors” had been shortlisted. These were Rolls-Royce and GE Hitachi. However, she noted that “Vattenfall will continue to investigate the conditions for building large-scale reactors.” Potential vendors were Westinghouse, EDF, and KHNP.²²⁶⁰

Thus, Vattenfall has not even decided whether to build high-capacity plants or wait for currently unavailable SMR technologies, but made clear it wants to build at a site adjacent to Ringhals.²²⁶¹ It noted in a report from 2024 that it would wait to make an investment decision until a final design of a reactor has been approved (see [chapter on SMRs](#)) and not subject to further modifications.²²⁶² Nevertheless, in April 2025, the company announced it was in the process of setting up Videberg Kraft AB, a project company exclusively for nuclear, in order to be able to apply for the new state aid mechanism.²²⁶³ By that time, only four technology suppliers were still under consideration.

Finnish utility Fortum owns shares of the Oskarshamn-3 reactor. The utility has announced ambitious plans to build new nuclear power plants in Finland and Sweden (see also [section on Finland](#)). In March 2025, the company concluded a two-year feasibility study clarifying that it maintained its interest in new nuclear but did not view it as a viable option in the short term, seeing an opportunity for deployment in the second half of the 2030s at the earliest “if market and regulatory conditions are right.” Its president and CEO commented that “In the next 5-10 years, new demand in the Nordics will be primarily met with new onshore wind and solar power coupled with flexibility and storage solutions as well as lifetime extensions of existing nuclear power plants.” The company said, however, it would now “continue to deepen the collaboration with two conventional reactor technology providers, EDF and Westinghouse-Hyundai, and one SMR developer, GE-Hitachi,” the stated intent being to “mitigate project risks before we would consider an investment.”²²⁶⁴ In June 2025, Fortum reportedly signed an Early Work Agreement with EDF to “continue their collaboration toward the potential development of new nuclear projects in Finland and Sweden.”²²⁶⁵ The exact meaning of this remains unclear.

²²⁶⁰ - Vattenfall, “Vattenfall Takes the Next Step for New Nuclear Power at Ringhals in Sweden”, Press Release, 12 June 2024, see <https://group.vattenfall.com/press-and-media/pressreleases/2024/vattenfall-takes-the-next-step-for-new-nuclear-power-at-ringhals-in-sweden>, accessed 12 June 2024.

²²⁶¹ - On 21 August 2025, Vattenfall announced it had “decided to move forward with the US GE Vernova and UK Rolls-Roy SMR in the process of choosing a final supplier of new nuclear reactors”; see Vattenfall, “Vattenfall Is Proceeding with Nuclear Power Suppliers GE Vernova and Rolls-Royce SMR and Invites to Press Seminar”, Press Release, 21 August 2025, see <https://group.vattenfall.com/se/nyheter-och-press/pressmeddelanden/2025/vattenfall-gar-vidare-med-karnkraftsleverantörerna-ge-vernova-och-rolls-royce-smr-och-bjuder-in-till-presseminarium>, accessed 21 August 2025.

²²⁶² - Vattenfall, “Status of Vattenfall’s Initiative for New Nuclear”, 19 February 2024, see <https://group.vattenfall.com/se/siteassets/documents/vattenfall-plan-for-new-nuclear-20240219.pdf>, accessed 29 July 2024.

²²⁶³ - Vattenfall, “Vattenfall startar nytt kärnkraftsbolag för att möjliggöra ny kärnkraft i Sverige – och förbereder för delägarskap från industrin”, Press Release, 16 April 2025, see <https://group.vattenfall.com/se/nyheter-och-press/pressmeddelanden/2025/vattenfall-startar-nytt-karnkraftsbolag-for-att-mojliggora-ny-karnkraft-i-sverige--och-forbereder-for-delagarskap-fran-industrin>, accessed 8 August 2025.

²²⁶⁴ - Fortum, “Fortum Concludes New Nuclear Feasibility Study – Continues to Develop Nuclear as a Future Option”, Press Release, 24 March 2025, see <https://www.fortum.com/media/2025/03/fortum-concludes-new-nuclear-feasibility-study-continues-develop-nuclear-future-option>, accessed 16 April 2025.

²²⁶⁵ - WNN, “Fortum, EDF Deepen Cooperation on New-Build Projects”, 13 June 2025, see <https://world-nuclear-news.org/articles/fortum-edf-deepen-cooperation-on-new-build-projects>, accessed 18 June 2025.

The Swedish government's nuclear power plant expansion plans are criticized as “energy populism” by Greenpeace campaigner Rolf Lindahl. According to his analysis, the shift from an ambitious (and successful) renewables expansion plan to nuclear might risk Swedish climate targets because the plants will probably not be built—or they might be delayed—and renewables are being neglected.²²⁶⁶ The headwinds for the expansion of renewables is evidenced by only one of sixteen planned onshore wind projects moving along in the permission process in 2024,²²⁶⁷ or the cancellation in late 2024 of 13 offshore wind projects (totaling ~32 GW) because of “unacceptable consequences for Sweden’s military defense.” This, however, might be an effect of Sweden’s particular permit acquisition scheme.²²⁶⁸ Subsidies for solar power and tax credits for small producers were lowered or scrapped altogether in 2025, with the government reportedly arguing that the sharp increase in installations demonstrated that there was no longer a need to subsidize solar power. The country saw a record increase of PV capacities of 1.6 GW, including small and large facilities, in 2023.²²⁶⁹ Another 1 GW of PV, added in 2024, increased the total installed capacity to approximately 5 GW.²²⁷⁰

Consequently, in 2024, 69.5 percent of Swedish gross electricity production, totaling 173.3 TWh, was covered by renewables, i.e., hydro (37.6 percent), wind (23.2 percent), bioenergy (6 percent), solar PV (2.1 percent), and offshore wind (0.3 percent). Nuclear power supplied 29.2 percent, while the remainder was covered by “other fossil” fuels (1.3 percent) and gas (0.1 percent).²²⁷¹

Switzerland



Swiss gross nuclear power production declined slightly by 1.5 percent year-on-year to 23 TWh in 2024. This corresponded to 28.4 percent of gross national power production, which reached a record level of 81 TWh, up 11.4 percent compared to 2023, fueled mainly by a substantial increase in hydro output.²²⁷² The historic maximum nuclear share of 43 percent was achieved in 1996.

²²⁶⁶ - Rolf Lindahl, “Climate Ambition Slammed by Nuclear Populism: The Case of Sweden”, *Nuclear Monitor*, 19 December 2024, op. cit.

²²⁶⁷ - Svensk Vindenergi, “Nästan alla vindkraftsprojekt stoppades första halvåret 2024”, Press Release, 30 August 2024, see <https://svenskvindenergi.org/pressmeddelanden/nastan-alla-vindkraftsprojekt-stoppades-forsta-halvaret-2024>, accessed 18 June 2025.

²²⁶⁸ - Review Energy, “Sweden Halts 13 Offshore Wind Farms in the Baltic Sea Due to National Security Concerns”, 6 November 2024, see <https://www.review-energy.com/eolico/sweden-halts-13-offshore-wind-farms-in-the-baltic-sea-due-to-national-security-concerns>, accessed 18 June 2025.

²²⁶⁹ - Patrick Jowett, “Sweden to Lower Solar Subsidy, Scrap Tax Breaks for Electricity Micro-Production”, *PV Magazine*, 19 September 2024, see <https://www.pv-magazine.com/2024/09/19/sweden-to-lower-solar-subsidy-scrap-tax-breaks-for-electricity-micro-production/>, accessed 18 June 2025; and Sveriges Riksdag, “Betänkande 2024/25:SkU17— Förändrade skattesubventioner för solceller och mikroproduktion av el”, Swedish Parliament, adopted 15 May 2025, see https://www.riksdagen.se/sv/dokument-och-lagar/dokument/betankande/forandrade-skattesubventioner-for-solceller-och_hcoiskui17/, accessed 8 August 2025.

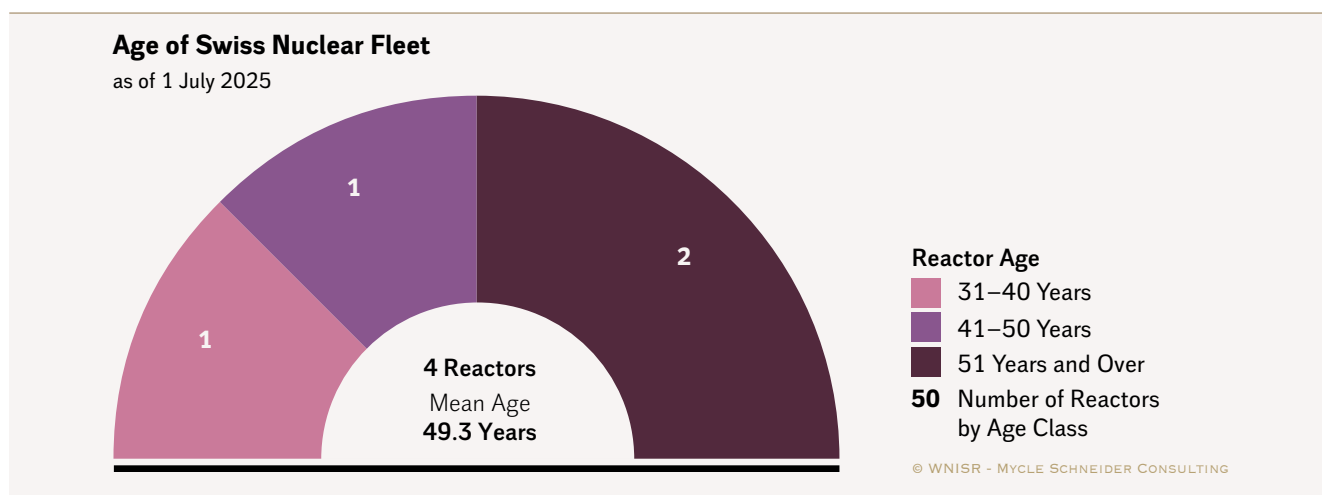
²²⁷⁰ - Patrick Jowett, “Sweden Adds 1 GW of Solar in 2024”, *PV Magazine*, 10 January 2025, see <https://www.pv-magazine.com/2025/01/10/sweden-adds-1-gw-of-solar-in-2024/>, accessed 18 June 2025; and IRENA, “Renewable Capacity Statistics 2025”, March 2025, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Mar/IRENA_DAT_RE_Capacity_Statistics_2025.pdf, accessed 26 March 2025.

²²⁷¹ - EMBER, “Yearly Electricity Data Europe – 2024”, 2025, see https://storage.googleapis.com/emb-prod-bkt-publicdata/public-downloads/europe_yearly_full_release_long_format.csv, accessed 8 August 2025.

²²⁷² - Swiss Federal Office of Energy, “Schweizerische Elektrizitätsstatistik 2024 / Statistique suisse de l’électricité 2024”, Final data as of 19 June 2025, Federal Government of Switzerland, see <https://pubdb.bfe.admin.ch/de/publication/download/5464>, accessed 22 June 2025.

With an average reactor age of 49.3 years (see Figure 88), Switzerland operates the second oldest nuclear fleet in the world (behind the Netherlands that operates only one 52-year old unit), of which Beznau-1, age 56, is the oldest commercially operating reactor in the world. Beznau-2 is almost 54 years old. The reactor at Mühleberg was closed in 2019 and is being decommissioned (see Switzerland in Decommissioning Status Report).

Figure 88 · Age Distribution of the Swiss Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2025

Lifetime Extensions

Swiss nuclear licenses are granted for an indefinite period. They can be revoked if the sites are deemed unsafe by the regulator.²²⁷³ Currently, the operators of all still-running power plants are seeking to operate the plants for at least 60 years,²²⁷⁴ despite controversial reports regarding the operating safety at Beznau-1²²⁷⁵ and Leibstadt²²⁷⁶ (see previous editions of the WNISR for details).

²²⁷³ - Rebekka Bärenbold, “Nuclear Decommissioning Profile Switzerland”, University of Basel, January 2023, see https://fonew.unibas.ch/fileadmin/user_upload/fonew/Reports/2023_01_NucDecom_Switzerland.pdf, accessed 10 November 2023; and Swiss Federal Nuclear Safety Inspectorate, “Laufzeit Schweizer Kernkraftwerke: Die Sicherheit ist entscheidend, nicht das Alter”, 16 February 2012, see <https://ensi.admin.ch/de/2012/02/16/laufzeit-schweizer-kernkraftwerke-die-sicherheit-ist-entscheidend-nicht-das-alter/>, accessed 29 July 2025.

²²⁷⁴ - Axpo Group, “Strengthening Security of Supply: Axpo Is Giving a Clear Yes to the New Electricity Law, Assessing the Potential of Operating Beznau for Longer, and Is Prepared to Construct a Reserve Power Plant”, Press Release, 28 March 2024, see <https://www.axpo.com/group/en/news-and-stories/media-releases.detail.html/news-and-stories/media-releases/2024/strengthening-security-of-supply--axpo-is-giving-a-clear-yes-to-.html>, accessed 28 August 2024; and Swiss Federal Office of Energy, “Aktennotiz Langzeitbetrieb von Kernkraftwerken”, Government of Switzerland, July 2024, see <https://www.bfe.admin.ch/bfe/de/home/versorgung/kernenergie/aufgaben-des-bfe.exturl.html/aHRocHM6Ly9wdWJkYi5iZmUuYWRTaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmVvY2VMTTE4Mzc=.html>, accessed 10 August 2025.

²²⁷⁵ - Kim Wallin, “Assessment of Fractographic Investigation Report and Applicability of the Master Curve Method”, kw-solutions, commissioned by the Swiss Energy Foundation, 14 February 2022, see https://energiestiftung.ch/files/energiestiftung/Studien/2022_Wallin_RDB/KW-2022-01.pdf, accessed 10 September 2023.

²²⁷⁶ - Manfred Mertins, “Studie zu den Sicherheitsdefiziten des Schweizer AKW Leibstadt (Defizit-Studie KKL)”, TH Brandenburg, commissioned by the Swiss Energy Foundation, August 2021, see https://energiestiftung.ch/files/energiestiftung/publikationen/pdf/20210829_Studie%20zu%20den%20Sicherheitsdefiziten%20des%20Schweizer%20AKW%20Leibstadt_final.pdf, accessed 10 September 2023.

A study on “the technical feasibility of operating the Beznau nuclear power plant beyond 60 years” was launched in March 2024.²²⁷⁷ In December 2024, the operator of the plant, Axpo, announced that Unit 1 would close in 2033 and Unit 2 in 2032, which would extend their operations to 64 and 61 years, respectively. Axpo would invest an additional CHF350 million (US\$₂₀₂₄ \$398 million) for safety upgrades after already having invested CHF2.5 billion (US\$₂₀₂₄ 2.8 billion) since the commissioning of the plant.²²⁷⁸

In December 2024, the Swiss Federal Nuclear Safety Inspectorate (ENSI) stated that it took note of the decision by the operator Axpo to operate Beznau up to 2033. The next Periodic Safety Review (PSR) at Beznau is scheduled for 2027, and Axpo must officially submit the corresponding documents to ENSI before the end of 2027.²²⁷⁹ But, according to a knowledgeable source, due to the fact that the decommissioning application must be submitted in 2028 to close the plant in 2033, the documents for the PSR would have to be submitted earlier than 2027.

While conservative National Council member Christian Imark claims that the plant could operate for 100 years, Andreas Pautz of the ETH Lausanne and the Paul-Scherrer Institute says that possibilities to extend operations were limited due to flaws in the steel of the reactor pressure vessel of Beznau-1.²²⁸⁰ These were first discovered in 2015.²²⁸¹

Furthermore, Beznau’s ability to provide a reliable electricity supply for the next few years remains questionable, as the frequency of unplanned outages has reportedly been increasing at the site.²²⁸² For example, in August 2024, Beznau-1 was taken off the grid for a few hours after a valve failure in the “non-nuclear” part of the site.²²⁸³ It was offline again from 28 September to 28 October at first for repairs to a power cable and then due to steel sample results from feedwater tanks requiring “further clarification”, both issues in non-nuclear areas but still impacting operation.²²⁸⁴ According to IAEA-PRIS, Beznau-1’s load factor plunged from 92 percent in 2023 to 76 percent in 2024.

²²⁷⁷ - Axpo Group, “Strengthening Security of Supply: Axpo Is Giving a Clear Yes to the New Electricity Law, Assessing the Potential of Operating Beznau for Longer, and Is Prepared to Construct a Reserve Power Plant”, Press Release, 28 March 2024, op. cit.

²²⁷⁸ - Axpo, “Axpo Will Operate the Beznau Nuclear Power Plant until 2033, Investing a Further CHF 350 Million While Doing So”, Press Release, 5 December 2024, see <https://www.axpo.com/group/en/news-and-stories/media-releases.detail.html/news-and-stories/media-releases/2024/axpo-will-operate-the-beznau-nuclear-power-plant-until-2033--inv.html>, accessed 10 August 2025.

²²⁷⁹ - Swiss Federal Office of Energy, “Aktennotiz Langzeitbetrieb von Kernkraftwerken”, Government of Switzerland, July 2024, op. cit.

²²⁸⁰ - Jannik Belser, “Die Axpo plant die Stilllegung des AKW Beznau bis 2033: Auswirkungen auf die Stromversorgung der Schweiz”, *Neue Zürcher Zeitung*, 12 December 2024, see <https://www.nzz.ch/wirtschaft/axpo-will-kernkraftwerk-beznau-bis-2033-weiter-betreiben-und-dann-vom-netz-nehmen-ld.1860942>, accessed 17 June 2025.

²²⁸¹ - Swiss Federal Nuclear Safety Inspectorate, “ENSI Review of the Axpo Power AG Safety Case for the Reactor Pressure Vessel of the Beznau NPP Unit 1”, ENSI 14/2573, Revision 1, 31 May 2018, see <https://ensi.admin.ch/en/wp-content/uploads/sites/5/2018/03/14H2573-Rev.-1-1.pdf>, accessed 10 August 2025.

²²⁸² - *Aargauer Zeitung*, “AKW Beznau läuft nur noch bis 2033 ++ Axpo-CEO: «Der Entscheid ist unumstösslich» ++ Das sagen Bundesrat Rösti und die Politik”, 5 December 2024, see <https://www.aargauerzeitung.ch/schweiz/akw-newsblog-akw-beznau-laeuft-nur-noch-bis-2033-axpo-ceo-der-entscheid-ist-unumstoesslich-das-sagen-bundesrat-roesti-und-die-politik-ld.2707861>, accessed 17 June 2025.

²²⁸³ - Swiss Federal Nuclear Safety Inspectorate, “Regulatory Oversight Report 2024 Concerning Nuclear Safety in Swiss Nuclear Installations”, June 2025, see https://ensi.admin.ch/en/wp-content/uploads/sites/5/2025/06/ENSI_Aufsichtsbericht_2024.pdf, accessed 10 August 2025.

²²⁸⁴ - Ibidem; and Axpo, “Beznau Nuclear Power Plant: Unit 1 Back on the Grid”, 28 October 2024, see <https://www.axpo.com/group/en/news-and-stories/media-releases/2024/beznau-nuclear-power-plant--unit-1-back-online.html>, accessed 10 August 2025.

Further, during the summers of 2024 and 2025, output at the plant had to be reduced on several occasions due to high temperature levels of the Aare River, e.g. in early July 2025, after operating at half capacity, both units were eventually temporarily shut down.²²⁸⁵

As of July 2024, operators of Gösgen and Leibstadt had not extensively investigated the possibility of operating the two reactors past 60 years, the main holdback being, according to them, the uncertainty over political acceptance.²²⁸⁶ Nevertheless, the companies confirmed at the time that they had been looking into the implications of extended operation—as was known for some time—and that, for planning purposes, an extension would have to be notified 15 years prior to the latest announced closure date. As of 2025, plans still provide for the closure of Gösgen in 2039 and Leibstadt in 2044, corresponding to 60 years of operations.²²⁸⁷ While there have been no official updates, some political actors are already advocating for 80 years of operations.²²⁸⁸

Political Nuclear Newbuild Initiatives

In 2018, the Swiss Energy Strategy 2050 entered into force after passing by referendum in 2017. With this came the ban on building new nuclear power plants in Switzerland.²²⁸⁹ Since the Russian invasion of Ukraine, concerns over energy supply security have resurfaced, and with these, calls for lifting the ban on nuclear newbuild have intensified, too. This culminated in the submission of an initiative (so-called *Volksinitiative* or *Initiative Populaire* that can be brought to referendum by citizens) called “Electricity for all at all times (stop the blackout)” that had gathered the necessary number of at least 100,000 signatures in February 2024.²²⁹⁰

Meanwhile, the rapid expansion of domestic renewable capacities was approved by referendum in June 2024.²²⁹¹ Refer to [previous WNISR editions](#) for more details on Swiss Energy Policy.

In August 2024, the Federal Council formally declined the “Stop the Blackout” initiative to hold a referendum, but signaled its intent to issue a counter-proposal instead with legislative steps designed to deliver on the main demands of the initiative.²²⁹² Consultation on the government’s

²²⁸⁵ - Swiss Federal Nuclear Safety Inspectorate, “Regulatory Oversight Report 2024 Concerning Nuclear Safety in Swiss Nuclear Installations”, June 2025, op. cit.; and Axpo, “Measures to Protect the Aare: Block 2 of the Beznau Nuclear Power Plant Also Shut Down”, Press Release, 3 July 2025, see <https://www.axpo.com/ch/en/newsroom/media-releases/2025/massnahmen-zum-schutz-der-aare.html>, accessed 10 August 2025.

²²⁸⁶ - Swiss Federal Office of Energy, “Aktennotiz—Langzeitbetrieb von Kernkraftwerken”, Federal Department of the Environment, Transport, Energy and Communications, Federal Government of Switzerland, 9 July 2024, see <https://www.bfe.admin.ch/bfe/en/home/versorgung/kernenergie/aufgaben-des-bfe.exturl.html/aHRocHM6Ly9wdWJkYi5iZmUuYWRTaW4uY2gvZGUvcHVibGJjYX/Rpb24vZG93bmxtvYWQvMTE4Mzc=.html>, accessed 10 August 2025.

²²⁸⁷ - Alpiq, “2024 Annual Report”, February 2025, see https://reports.alpiq.com/24/app/uploads/Annual_Report_2024_en.pdf, accessed 10 August 2025.

²²⁸⁸ - *Aargauer Zeitung*, “AKW Beznau läuft nur noch bis 2033 ++ Axpo-CEO: «Der Entscheid ist unumstösslich» ++ Das sagen Bundesrat Rösli und die Politik”, 5 December 2024, op. cit.

²²⁸⁹ - Swiss Federal Office of Energy, “Wichtigste Neuerungen im Energierecht ab 2018”, Federal Department of the Environment, Transport, Energy and Communications, 2 November 2017, see <https://www.news.admin.ch/news/message/attachments/50166.pdf>, accessed 13 July 2018.

²²⁹⁰ - Federal Chancellery, “Eidgenössische Volksinitiative ‘Jederzeit Strom für alle (Blackout stoppen)’”, Government of Switzerland, 24 July 2024, see <https://www.bk.admin.ch/ch/d/pore/vi/vis533.html>, accessed 10 August 2025.

²²⁹¹ - The Federal Council, “Federal Act on a Secure Electricity Supply from Renewable Energy Sources”, Government of Switzerland, Updated 2 June 2025, see <https://www.admin.ch/gov/en/start/documentation/votes/20240609/federal-act-on-a-secure-electricity-supply-from-renewable-energy-sources.html>, accessed 17 June 2025.

²²⁹² - Federal Government of Switzerland, “Initiative «Blackout stoppen»: Bundesrat schlägt indirekten Gegenvorschlag vor”, Press Release, 28 August 2024, see <https://www.news.admin.ch/de/nsb?id=102240>, accessed 10 August 2025.

legislative proposal to repeal the ban on nuclear newbuild from the Nuclear Energy Act ran from December 2024 to April 2025.²²⁹³ The amendments, which are yet to be validated by parliament, gathered support from center-right parties and opposition from Greens and other left-leaning parties.²²⁹⁴ It remains uncertain whether this legislative change will pass, given a stark divide mainly along party lines and between Swiss local (canton) governments.²²⁹⁵ Throughout these efforts, the accelerated deployment of renewable energy sources was still presented as the highest priority. Also, a recent analysis by the Energy Commission of the Swiss Academies of Arts and Sciences concluded that “even in the case of the revocation of the newbuild prohibition, the commissioning of a new nuclear power plant is unlikely before around 2050.”²²⁹⁶

Meanwhile, Swiss electricity production is dominated by hydro, which supplied 48.4 TWh or 59.6 percent of the country’s electricity in 2024, up from 40.8 TWh or 56.1 percent in 2023. Nuclear power supplied 23 TWh in 2024, which corresponded to 28.4 percent. Solar PV output increased from 4.9 TWh (6.8 percent) in 2023 to 6 TWh (7.3 percent) in 2024,²²⁹⁷ with record capacity increases of 1.8 GW in 2024, resulting in over 8 GW of total installed solar capacity by December 2024; the pace of deployment is expected to slightly drop in 2025 and 2026—to 1.5–1.6 GW annual additions—before the impact of new regulations kicking in as of 2027 are expected to reaccelerate buildout.²²⁹⁸ The share of wind power in the Swiss electricity mix is marginal (0.2 percent). As of 2024, only 102 MW of onshore wind energy were connected to the grid.²²⁹⁹ Fossil fuels represented 1.7 percent of the total generation.²³⁰⁰

United Kingdom

See Focus Countries – [United Kingdom Focus](#).

²²⁹³ - Federal Government of Switzerland, “Initiative «Blackout stoppen» – Bundesrat schickt indirekten Gegenvorschlag in die Vernehmlassung”, Press Release, 29 December 2024, see <https://www.news.admin.ch/de/nsb?id=103654>; and Federal Department of the Environment, Transport, Energy and Communications, “Indirekter Gegenvorschlag (Änderung des Kernenergiegesetzes) zur Volksinitiative «Jederzeit Strom für alle (Blackout stoppen) Erläuternder Bericht zur Eröffnung des Vernehmlassungsverfahrens”, 20 December 2024, see <https://www.news.admin.ch/newsd/message/attachments/91232.pdf>; both accessed 10 August 2025.

²²⁹⁴ - SWI, “Swiss Government Proposes Lifting Nuclear Power Ban”, 2 April 2025, see <https://www.swissinfo.ch/eng/swiss-politics/planned-end-to-ban-on-new-nuclear-power-plant-construction-sparks-new-nuclear-debate/89103321>, accessed 17 June 2025.

²²⁹⁵ - Stefan Häne, “Debatte um AKW-Neubau-Verbot: Neue Kernkraftwerke: Bundesrat Röstli erhält Hilfe aus Zürich”, *Tages-Anzeiger*, 12 April 2025, see <https://www.tagesanzeiger.ch/atomkraftwerke-zuercher-regierung-will-neubauverbot-aufheben-587628733379>, accessed 17 June 2025.

²²⁹⁶ - Urs Neu, Jochen Markard et al., “Perspektiven für die Kernenergie in der Schweiz—Kurzfassung”, Swiss Academies of Arts and Sciences, ETH Zurich, Zurich University of Applied Sciences, Paul Scherrer Institute and University of Bern, Swiss Academies Report, Vol. 20, No. 6, 2025, see https://s3.eu-central-2.amazonaws.com/a-plus-cms-statamic/p/assets/publikationen/reports/20-6/report_kernenergie_kurz_d_final_low.pdf, accessed 2 July 2025.

²²⁹⁷ - Swiss Federal Office of Energy, “Schweizerische Gesamtenergie Statistik 2024 - Datentabellen / Statistique Globale Suisse de l’énergie 2024 - Tableaux des données”, Datasets, 7 July 2025, see <https://www.bfe.admin.ch/bfe/en/home/versorgung/statistik-und-geodaten/energiestatistiken/gesamtenergiestatistik.exturl.html/aHRocHM6Ly9wdWJkYi5iZmUuYWRTaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmVxYWQvMTIyMTg=.html>, accessed 18 August 2025.

²²⁹⁸ - Ibidem; and Gwénaëlle Deboutte, “Switzerland Installs 1.78 GW of PV in 2024”, *PV Magazine*, 17 January 2025, see <https://www.pv-magazine.com/2025/01/27/switzerland-installs-1-78-gw-of-pv-in-2024/>, accessed 17 June 2025; and Swissolar, “Baromètre Du Marché Solaire Suisse 2024—Évolution, tendances et perspectives du marché photovoltaïque”, November 2024, see https://www.swissolar.ch/02_markt-politik/solarmonitor-schweiz/solarmonitor_schweiz_2024_fr.pdf, accessed 18 August 2025.

²²⁹⁹ - IRENA, “Renewable Energy Statistics 2025”, July 2025, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jul/IRENA_DAT_RE_Statistics_2025.pdf, accessed 23 July 2025.

²³⁰⁰ - Swiss Federal Office of Energy, “Schweizerische Gesamtenergie Statistik 2024 - Datentabellen / Statistique Globale Suisse de l’énergie 2024 - Tableaux des données”, Datasets, 7 July 2025, op. cit.

CENTRAL AND EASTERN EUROPE

Bulgaria



Bulgaria, like other Eastern European countries, inherited its nuclear reactors from the Soviet Union. The country began its nuclear energy program in the 1970s with the construction of VVER-440 reactors. By the late 1980s, Bulgaria had also successfully completed two VVER-1000 reactors. A project to build four additional VVER-1000 reactors at the Belene site was initiated but ultimately abandoned following the collapse of the Soviet Union in 1991.

Bulgaria's two operating reactors at the Kozloduy nuclear power plant generated 15 TWh of electricity in 2024, a slight decrease from the 15.4 TWh produced in 2023.²³⁰¹ Despite this reduction in electricity output, the share of electricity generated from nuclear power increased from 40.3 percent in 2023 to 41.8 percent in 2024. This was due to a significant decline in electricity production from coal.²³⁰²

The Bulgarian energy sector has historically been heavily dependent on Russian imports, including both fossil fuels and nuclear fuel. However, following Russia's invasion of Ukraine, this dependence has been significantly reduced. Prior to the war, over 90 percent of Bulgaria's natural gas supply came from Russia, but this supply has been completely halted by Russia.²³⁰³

Since 2023, Bulgaria has met its natural gas demand through liquefied natural gas (LNG) terminals in Greece and Türkiye. Additionally, Bulgaria has signed long-term agreements with the Turkish company BOTAŞ, securing access to its LNG terminals and pipeline infrastructure.²³⁰⁴

Despite terminating direct imports of Russian natural gas for its own consumption, Bulgaria continues to serve as a gateway and transit country for Russian gas to Europe via the Balkan Stream pipeline, gas supplies through which reached a historic high in 2024.²³⁰⁵ Operational since January 2021, Balkan Stream is an extension of the TurkStream project and serves as a key conduit for Russian gas exports to southeastern and central Europe, including countries such as Hungary, Serbia, and Romania. However, the project has brought Bulgaria minimal financial benefits, as transit tariffs are heavily subsidized, and the bulk of profits are captured by Russia's Gazprom and intermediaries in other countries.²³⁰⁶

²³⁰¹ - Energy Institute, "Statistical Review of World Energy 2025—Consolidated Dataset", 2025, op. cit.

²³⁰² - EMBER, "Electricity Data Explorer—Electricity Generation in Bulgaria", 2025, see <https://ember-energy.org/data/electricity-data-explorer/?entity=Bulgaria>, accessed 21 July 2025.

²³⁰³ - Andrew Higgins, "Bulgarian Distrust of Russia Simmers Over a Black Sea Oil Terminal", *The New York Times*, 1 May 2024, see <https://www.nytimes.com/2024/05/01/world/europe/bulgaria-russia-oil-ukraine.html>, accessed 28 May 2024.

²³⁰⁴ - Tsvetelia Tsoleva, "Bulgaria Signs Long-Term Gas Deal with Turkey", *Reuters*, 3 January 2023, see <https://www.reuters.com/business/energy/bulgaria-signs-deal-access-turkeys-lng-terminals-gas-network-2023-01-03/>, accessed 31 July 2024.

²³⁰⁵ - Emiliya Milcheva, "Russian Gas Transit Through Bulgaria Hits Record High", *Euractiv*, 14 February 2025, see <https://www.euractiv.com/section/politics/news/russian-gas-transit-through-bulgaria-hits-record-high/>, accessed 25 May 2025.

²³⁰⁶ - Ilian Vassilev, "Time to Capitalize on Bulgaria's Role as the EU's Only Gateway for Russian Pipeline Gas", *Analyses & Alternatives*, 26 February 2025, see <https://altanalyses.org/en/2025/02/26/time-to-capitalize-on-bulgarias-role-as-the-eus-only-gateway-for-russian-pipeline-gas/>, accessed 16 July 2025.

Fuel Supply Diversification

Bulgaria remains reliant on Russian equipment and fuel for its Kozloduy nuclear power plant but is actively attempting to diversify nuclear fuel supply. In November 2022, Bulgaria's Parliament voted to reduce dependence on Russian sources,²³⁰⁷ despite an existing contract with Russia's TVEL for fuel provision until 2025 (included).²³⁰⁸ To align with the E.U.'s energy security strategy, Kozloduy's operator signed a ten-year contract with Westinghouse in December 2022 to supply fuel for Unit 5 starting in 2024.²³⁰⁹ The first Westinghouse fuel arrived in April 2024.²³¹⁰ The following month Unit 5 was partially refueled with 43 Westinghouse-manufactured assemblies,²³¹¹ and in May 2025 another 42 assemblies were loaded.²³¹² The phased transition to alternative fuel is to be completed by 2027. Additionally, in December 2024, Kozloduy signed a contract for a safety analysis to license the Westinghouse fuel assembly design for Unit 6.²³¹³

Besides the Westinghouse deal, the Kozloduy operator also signed a 10-year supply contract (2025–2034) with Framatome for Unit 6.²³¹⁴

Lifetime Extensions

The Kozloduy plant originally hosted six reactors, but the oldest four (VVER-440/v-230) were to be closed under a 1992 G7 agreement, as it was determined that they could not be economically upgraded to meet safety standards. Their closure was implemented in 2002 and 2006 as part of Bulgaria's E.U. accession process which concluded in 2007.²³¹⁵ The two operational VVER-1000

²³⁰⁷ - WNN, "Bulgarian Parliament Votes to Switch from Russian Nuclear Fuel", 10 November 2022, see <https://www.world-nuclear-news.org/Articles/Bulgarian-parliament-votes-to-switch-from-Russian>, accessed 26 July 2023.

²³⁰⁸ - TVEL, "TVEL and Kozloduy NPP Have Contracted Supplies of Russian Nuclear Fuel to Bulgaria through 2025", 19 December 2019, see https://www.tvel.ru/en/press-center/news/?ELEMENT_ID=8140, accessed 19 July 2023.

²³⁰⁹ - Westinghouse, "Westinghouse's VVER-1000 Nuclear Fuel Fabrication Agreement Helps Cement Bulgaria's Energy Security", Press Release, 22 December 2022, see <https://info.westinghousenuclear.com/uk/news-insights/westinghouse-vver-1000-nuclear-fuel-fabrication-agreement-helps-cement-bulgarias-energy>, accessed 4 November 2023.

²³¹⁰ - Westinghouse, "Westinghouse Delivers First VVER-1000 Fuel Reload to Bulgaria", Press Release, 29 May 2024, see <https://info.westinghousenuclear.com/news/westinghouse-delivers-first-vver-1000-fuel-reload-to-bulgaria>, accessed 26 June 2024.

²³¹¹ - Ministry of Energy, "Kozloduy Nuclear Power Plant Has Already Loaded the First 43 Cartridges of an Alternative Type of Fuel Produced by the U.S. Westinghouse", Government of Bulgaria, 29 May 2024, see <https://me.government.bg/en/news/kozloduy-nuclear-power-plant-has-already-loaded-the-first-43-cartridges-of-an-alternative-type-of-fuel-produced-by-the-u-s-westinghouse-3446.html>, accessed 31 July 2024.

²³¹² - Kozloduy Nuclear Power Plant, "Приключи Плановият Годишен Ремонт На Пети Блок На Аец 'Козлодуй'", 11 June 2025, see <https://www.kznpp.org/bg/novini/638>, accessed 27 June 2025; and Nuclear Regulatory Agency of Bulgaria, "Приключи второто горивно зареждане на реактора на блок 5 на АЕЦ „Козлодуй“ с касети RWFA", 17 June 2025, see <https://bnra.bg/bg/novini-bnra/prikladychi-vtoroto-gorivno-zarezhane-na-reaktora-na-blok-5-na-aets-kozloduy-s-kaseti-rwfa/>, accessed 20 July 2025.

²³¹³ - Westinghouse, "Westinghouse and Kozloduy NPP Sign New Contract for Safety Analysis to License Alternative Nuclear Fuel Design for Unit 6", Press Release, 20 December 2024, see <https://info.westinghousenuclear.com/news/westinghouse-and-kozloduy-npp-sign-new-contract-for-safety-analysis-to-license-alternative-nuclear-fuel-design-for-unit-6>, accessed 16 July 2025.

²³¹⁴ - Ministry of Energy, "Министър Христов: С подписаното споразумение с Фраматом завършва процесът по диверсификация на доставките за българската ядрена централа", Government of Bulgaria, 30 December 2022, see <https://www.me.government.bg/bg/news/ministar-hristov-s-podpisanoto-sporazumenie-s-framatom-zavarshva-procesat-po-diversifikaciya-na-dostavkite-za-balgarskata-yadrena-centrala-3128.html?p=eyJWYWdlJjozMHo=>, accessed 13 August 2025; and Council of Ministers, "Bulgaria and France Explore Opportunities for Cooperation in Power and Defense Sectors", Government of Bulgaria, 12 October 2023, see <https://www.gov.bg/special/en/Press-center/News/Bulgaria-and-France-explore-opportunities-for-cooperation-in-power-and-defense-sectors>, accessed 31 July 2024.

²³¹⁵ - European Commission, "Proposal for a Council Regulation on Community Financial Assistance with Respect to the Decommissioning of Units 1 to 4 of the Kozloduy Nuclear Power Plant in Bulgaria", Commission Staff Working Document COM(2009) 581 final, 27 October 2009, see <https://data.consilium.europa.eu/doc/document/ST-15112-2009-ADD-1/en/pdf>; and Michael Winfrey, "Bulgaria Fumes as EU Demands Nuke Reactor Shutdowns", *Reuters*, 21 January 2007, see <https://www.reuters.com/article/uk-eu-candidates-nuclear-idUSL0585015220061227>; both accessed 26 July 2023.

reactors (Units 5 and 6), commissioned in 1987 and 1991, are undergoing a refurbishment program to extend their lifetimes to 60 years, compared to the original 30-year licenses.²³¹⁶ Regulations originally limited renewed operational licenses to 10 years,²³¹⁷ so Unit 5 received a new license in 2017 to operate until 2027, and Unit 6 was relicensed in 2019 to operate until 2029.²³¹⁸

However, following amendments to the Act on the Safe Use of Nuclear Energy, licenses for both units were revised in mid-2024 and are now indefinite.²³¹⁹ Periodic safety reviews are still to be carried out at least every ten years, the results of which are to be approved by the regulator who specifies that “in the event that the results submitted do not show the necessary compliance with the safety requirements, the Chairman shall reasonably refuse to issue an order for approval, which shall constitute grounds for revoking the license concerned.”²³²⁰

Newbuild Projects

Efforts to expand nuclear capacity on an “accelerated schedule” continued in recent years despite the volatile political situation (see [past WNISR editions](#) for further details and earlier developments). In March 2023, state-owned Kozloduy NPP-Newbuild signed an MoU with vendor Westinghouse to plan one or two AP-1000 reactors at the site.²³²¹ The MoU was formalized in June 2023 through a Front-End Engineering and Design (FEED) contract,²³²² which was extended in October 2024.²³²³

An invitation for expressions of interest in the “engineering, construction, procurement and commissioning of new nuclear power plant on the approved site in Kozloduy with

²³¹⁶ - Roman Tsaturian, “Kozloduy’s Reactor Protection Upgrade”, RPC Radics LLC, *Nuclear Engineering International*, 10 April 2025, see <https://www.neimagazine.com/analysis/kozloduys-reactor-protection-upgrade/>, accessed 20 July 2025.

²³¹⁷ - Pavlin Groudev, Neli Zaharieva and Antoaneta Stefanova, “Status and Future Prospects of Nuclear Industry Development in Bulgaria”, Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, *Nuclear Engineering and Design*, Vol. 423, July 2024, see <https://linkinghub.elsevier.com/retrieve/pii/S0029549324002887>, accessed 7 August 2024.

²³¹⁸ - Nuclear Regulatory Agency of Bulgaria, “Пети блок на АЕЦ ‘Козлодуй’ получи нова 10 годишна лицензия за експлоатация”, 3 November 2017, see <https://bnra.bg/bg/novini-bnra/peti-blok-na-aets-kozloduy-poluchi-nova-10-godishna-litsenziya-za-eksplotatsiya/>, accessed 20 July 2025; and WNN, “Kozloduy Unit 6 Clear to Operate for Another 10 Years”, 2 October 2019, see <https://www.world-nuclear-news.org/Articles/Kozloduy-unit-6-clear-to-operate-for-another-10-ye>, accessed 4 April 2021.

²³¹⁹ - Government of Bulgaria, “Act on the Safe Use of Nuclear Energy”, as published by the Bulgarian Nuclear Regulatory Agency, as amended 20 August 2024, see https://bnra.bg/wp-content/uploads/1_act-on-the-safe-use-of-nuclear-energy-2024_eng-30.04.2025.pdf, accessed 22 July 2025; and Bulgarian Nuclear Regulatory Agency, “Изменени са три лицензии на АЕЦ „Козлодуй“”, 29 July 2024, see <https://bnra.bg/bg/novini-bnra/izmeneni-sa-tri-litsenzii-na-aets-kozloduy/>, accessed 15 October 2024.

²³²⁰ - Bulgarian Nuclear Regulatory Agency, “Annual Report 2024”, 2025, see https://bnra.bg/wp-content/uploads/Annual_Report_2024_EN_WEB.pdf, accessed 22 July 2025.

²³²¹ - Westinghouse, “Westinghouse Signs MOU with Bulgaria’s Kozloduy NPP-Newbuild for AP1000® Technology Deployment”, 2 March 2023, see <https://info.westinghousenuclear.com/news/westinghouse-signs-mou-with-bulgarias-kozloduy-npp-newbuild-for-ap1000-technology-deployment>, accessed 31 July 2024; and Kamen Kraev, “Westinghouse Signs Agreement to Begin Planning for New Nuclear at Kozloduy”, *NucNet*, 3 March 2023, see <https://www.nucnet.org/news/westinghouse-signs-deal-to-begin-planning-for-new-nuclear-at-kozloduy-3-5-2023>, accessed 30 May 2023.

²³²² - Westinghouse, “Westinghouse Signs Key Contract for AP1000® Reactor with Bulgaria’s Kozloduy NPP-Newbuild to Support Bulgaria’s Energy Future”, Press Release, 14 June 2023, see <https://info.westinghousenuclear.com/news/westinghouse-signs-kozloduy-contract-in-bulgaria>, accessed 31 July 2024.

²³²³ - Westinghouse, “Westinghouse Extends Key Contract to Build AP1000 Reactors in Bulgaria”, Press Release, 23 October 2024, see <https://info.westinghousenuclear.com/news/westinghouse-extends-key-contract-to-build-ap1000-reactors-in-bulgaria>, accessed 24 February 2025.

AP1000® technology” was issued in January 2024,²³²⁴ and by February, five companies—“Fluor BV, Bechtel Nuclear Power Company Limited, Hyundai Engineering & Construction Co., Ltd., a consortium led by China National Nuclear Corporation Overseas Ltd. and partner China Energy Engineering Group Tianjin Electric Power Construction Co., Ltd., as well as China Energy Engineering Corporation Limited”—had expressed interest.²³²⁵ Earlier press reports had also identified EDF (France) as a candidate.²³²⁶ Russian bidders had been barred from the process.

The same month, only Hyundai was preselected,²³²⁷ and the three parties—Westinghouse Electric Company, Hyundai Engineering & Construction, and Kozloduy NPP-Newbuild—finally signed an Engineering Services Contract in November 2024, making the project “irreversible” per then-caretaker Energy Minister Vladimir Malinov.²³²⁸ The contract runs for 12 months, and it covers site planning, licensing, permitting, project management, and operations & maintenance development for two AP-1000 reactors at Kozloduy.

As reported in WNISR2024, negotiations pertaining to the project’s financing also began in 2024. Since then, discussions with the U.S. Export-Import (EXIM) Bank have led to the issuance of a US\$8.6 billion Letter of Interest.²³²⁹ The U.S. EXIM Bank states in no ambiguous words:

EXIM is prepared to support American energy dominance, consistent with President Trump’s agenda by financing nuclear energy investments in Bulgaria which support American businesses, create jobs and prosperity for families and workers in America, and reduce the global influence of malign and adversarial states.²³³⁰

The Export-Import Bank of Korea is also expected to formulate an offer; it had vowed to submit such a document by September 2024, though it does not appear to have followed through as of mid-2025.²³³¹ Time is running out to meet the deadline set by the Bulgarian Parliament.

²³²⁴ - Kozloduy NPP New Builds’ PLC, “Invitation For Expression Of Interest—Selection of a Constructor for Engineering, Construction, Procurement and Commissioning of New Nuclear Power Plant on the Approved Site in Kozloduy with AP1000® Technology (EP+C Turnkey Contract, Called the Contract)”, January 2024, see <https://npp-nb.bg/wp-content/uploads/2024/01/Invitation-for-expression-of-interest-1.pdf>, accessed 1 August 2024.

²³²⁵ - Kozloduy NPP, “Information Notice”, 16 February 2024, see <https://www.kznpp.org/en/news/595>, accessed 1 August 2024.

²³²⁶ - Krassen Nikolov, “Bulgaria’s Two US Nuclear Reactors to Cost Under \$14 Billion”, *Euractiv*, 14 February 2024, see <https://www.euractiv.com/section/politics/news/bulgarias-two-us-nuclear-reactors-to-cost-under-14-billion/>, accessed 28 May 2024.

²³²⁷ - Kozloduy NPP, “Information Notice”, 16 February 2024, see <https://www.kznpp.org/en/news/595-INFORMATION-NOTICE>; and National Assembly of the Republic of Bulgaria, “РЕШЕНИЕ за провеждане на преговори с потенциален строител, включен в кратката листа на потенциални строители за инженеринг, строителство, доставка и въвеждане в експлоатация на ядрена централа на одобрената площадка в Козлодуй, с технология AP1000”, adopted 23 February 2024, see <https://www.parliament.bg/bg/desision/ID/165374>, both accessed 31 July 2024.

²³²⁸ - Westinghouse, “Westinghouse Signs Contract for Engineering of AP1000 Reactors in Bulgaria”, Press Release, 4 November 2024, see <https://info.westinghousenuclear.com/news/westinghouse-signs-contract-for-engineering-of-ap1000-reactors-in-bulgaria>, accessed 24 February 2025; and Ministry of Energy, “Minister Vladimir Malinov: The Construction of New Nuclear Capacities at Kozloduy Nuclear Power Plant Has Now Become Irreversible”, Government of Bulgaria, 4 November 2024, see <https://www.me.government.bg/en/news/minister-vladimir-malinov-the-construction-of-new-nuclear-capacities-at-kozloduy-nuclear-power-plant-has-now-become-irreversible-3530.html?p=eyJWYWdlJoiQ==>, accessed 20 July 2025.

²³²⁹ - EXIM, “Export-Import Bank of the U.S. Senior Team Meets with Bulgarian Minister of Energy to Discuss Nuclear Energy Financing”, Press Release, Export-Import Bank of the United States, 12 February 2025, see <https://www.exim.gov/news/export-import-bank-senior-team-meets-bulgarian-minister-energy-discuss-nuclear-energy-financing>, accessed 21 May 2025.

²³³⁰ - Ibidem.

²³³¹ - Ministry of Energy, “Minister alinov: We Expect by the End of October a Contract for the Engineering of the New Nuclear Capacities to Be Signed with Hyundai and Westinghouse”, Government of Bulgaria, 2 September 2024, see <https://www.me.government.bg/en/news/minister-alinov-we-expect-by-the-end-of-october-a-contract-for-the-engineering-of-the-new-nuclear-capacities-to-be-signed-with-hyundai-and-westinghouse-3502.html>, accessed 20 July 2025.

Indeed, based on a timeline decided by Parliament in December 2023, financing was to be secured by 30 July 2025, while the Final Investment Decision (FID) should occur by 31 August 2025 and be immediately followed by the EPC contract.²³³² In February 2025, the Bulgarian Minister of Energy confirmed that “a final investment decision is to be made by the end of the year and by then the financing will be secured and only then will the EPC contract be signed.”²³³³

As for the project’s costs, then-Bulgarian Energy Minister Ruman Radev had stated in February 2024 that they “should not exceed 14 billion” (he did not specify the currency at the time).²³³⁴ Reportedly, he further said that the cost of electricity generated by the new units would be capped at €65/MWh (US\$70/MWh), and that the indicative price was to be announced in a report by Westinghouse, due in March 2024.²³³⁵ As of mid-2025, WNISR has no knowledge of details from said report that would have been made available to the public and is not aware of any official estimate—be it provisional—having been released. In January 2025, Patrick Fragman, then-CEO of Westinghouse said in an interview “We should have much more narrow estimates about the project cost around the end of 2025,” or in other words “in 2026 we will have a cost estimate for the new units of Kozloduy NPP.”²³³⁶

The parliamentary timeline provides for the first unit to be commissioned by 31 December 2034.²³³⁷ Westinghouse has also indicated that commercial operation would begin ten years from now, in 2035.

The Belene Saga

Construction of a nuclear power plant at Belene in northern Bulgaria began in 1987 but was halted in 1990 and suspended in 1991. Construction resumed in 2008 but was abandoned again in 2012.

In October 2023, the Bulgarian government officially terminated the latest Belene nuclear project.²³³⁸ A few months prior, Parliament had authorized negotiations to potentially sell key equipment from Belene to Ukraine for the planned resumption of construction of Units 3

²³³² - National Assembly of the Republic of Bulgaria, “Решение за предприемане на действия по изграждането на 7-и и 8-и блок на площадка № 2 на АЕЦ „Козлодуй“ ЕАД с технология AP1000”, adopted 18 December 2023, promulgated 19 December 2023, see <https://dv.parliament.bg/DVWeb/showMaterialDV.jsp?sessionid=4DD3FC0824C6F823190C23654F2F2266?idMat=202021>, accessed 1 August 2024.

²³³³ - Ministry of Energy, “Minister Stankov: With the Construction of New Nuclear Capacities Bulgaria Will Guarantee Its Energy Independence”, Government of Bulgaria, 12 February 2025, see <https://www.me.government.bg/en/news/minister-stankov-with-the-construction-of-new-nuclear-capacities-bulgaria-will-guarantee-its-energy-independence-3597.html>, accessed 20 July 2025.

²³³⁴ - Yoana Vodenicharova, “Bulgarian, US Governments Sign Strategic Agreement on Nuclear Energy Development in Bulgaria”, *Bulgarian News Agency*, 12 February 2024, see <https://www.bta.bg/en/news/economy/617000-bulgarian-us-governments-sign-strategic-agreement-on-nuclear-energy-development>, accessed 31 July 2024.

²³³⁵ - *NEI Magazine*, “Bulgaria and USA Formalise Agreement on Kozloduy 7&8”, *Nuclear Engineering International*, 14 February 2024, see <https://www.neimagazine.com/news/bulgaria-and-usa-formalise-agreement-on-kozloduy-78-11512686/>, accessed 28 May 2024.

²³³⁶ - Ognyan Georgiev, “Patrick Fragman: In 2026 We Will Have a Cost Estimate for the New Units of Kozloduy NPP”, Interview with Patrick Fragman, CEO, Westinghouse, as published by *Kapital Insights*, 22 January 2025, see https://kinsights.capital.bg/energy/2025/01/22/4732775_patrick_fragman_in_2026_we_will_have_a_cost_estimate/, accessed 13 August 2025.

²³³⁷ - National Assembly of the Republic of Bulgaria, “Решение за предприемане на действия по изграждането на 7-и и 8-и блок на площадка № 2 на АЕЦ „Козлодуй“ ЕАД с технология AP1000”, adopted 18 December 2023, published 19 December 2023, see <https://dv.parliament.bg/DVWeb/showMaterialDV.jsp?sessionid=4DD3FC0824C6F823190C23654F2F2266?idMat=202021>, accessed 1 August 2024.

²³³⁸ - *NEI Magazine*, “Bulgaria Cancels Belene NPP Project”, 17 October 2023, see <https://www.neimagazine.com/news/newsbulgaria-cancels-belene-npp-project-11224401>, accessed 17 October 2023.

and 4 at the Khmelnytskyi nuclear plant in western Ukraine.²³³⁹ Political uncertainty over a joint E.U. stance on financial aid to Ukraine briefly disrupted proceedings in January 2024.²³⁴⁰ Nevertheless, in May 2024, a Ukrainian delegation, joined by U.S. nuclear experts, inspected the equipment at the Belene site.²³⁴¹

Although the Bulgarian Parliament decided in late 2023 to allocate funds from the equipment's sale to the Kozloduy construction project,²³⁴² completed the verification of the suitability and storage of the equipment in June 2024,²³⁴³ and Parliament extended the negotiation deadline by 180 days in September 2024,²³⁴⁴ the sale—approved by the Ukrainian parliament in 2025²³⁴⁵—was canceled by Bulgaria's minority government in April 2025.²³⁴⁶ However, Bulgarian Prime Minister Rossen Jeliakov commented that only the National Assembly could decide on the matter,²³⁴⁷ and in June 2025 then-Ukrainian Energy Minister German Galushchenko was quoted in *Interfax-Ukraine* as stating that “the issue is not closed, we have no official refusal from Bulgaria to continue negotiations.”²³⁴⁸

WNISR2024 had reported that “the idea [to complete Belene] was definitely abandoned in 2023,” but it seems new ideas have emerged. Voices in Bulgarian government and some influential politicians now suggest building AI data centers in partnership with the U.S., powered by nuclear energy from Belene, hinting at a potential revival of the Belene project.²³⁴⁹

²³³⁹ - Kamen Kraev, “Bulgaria / Minister to Begin Talks with Ukraine on Sale of Russia-Made Belene Nuclear Equipment”, *NucNet*, 6 July 2023, see <https://www.nucnet.org/news/minister-to-begin-talks-with-ukraine-on-sale-of-russia-made-belene-nuclear-equipment-7-4-2023>, accessed 28 May 2024.

²³⁴⁰ - *NEI Magazine*, “Bulgaria Holds Back on Sale of Belene Nuclear Equipment to Ukraine”, 16 January 2024, see <https://www.neimagazine.com/news/bulgaria-holds-back-on-sale-of-belene-nuclear-equipment-to-ukraine-11439134/>, accessed 28 May 2024.

²³⁴¹ - Valentin Evstatiev, “US, Bulgarian, Ukrainian Experts Conclude Joint Technical Assessment of Belene Nuclear Power Plant”, *Bulgarian News Agency*, 17 May 2024, see <https://www.bta.bg/en/news/economy/672420-us-bulgarian-ukrainian-experts-conclude-joint-technical-assessment-of-belene-n>, accessed 28 May 2024.

²³⁴² - National Assembly of the Republic of Bulgaria, “The National Assembly Adopted at Second Reading the Budgets of the National Health Insurance Fund and the State Social Insurance for 2024”, 18 December 2023, see <https://www.parliament.bg/en/news/ID/5897>, accessed 1 August 2024.

²³⁴³ - Ministry of Energy, “Minister Malinov: Bulgaria Will Support Ukraine's Energy Sector”, Government of Bulgaria, 12 June 2024, see <https://www.me.government.bg/en/news/minister-malinov-bulgaria-will-support-ukraine-s-energy-sector-3457.html>, accessed 1 August 2024.

²³⁴⁴ - National Assembly of Bulgaria, “The National Assembly Extended by 180 Days the Deadline for Negotiations with Ukraine for the Sale of Equipment Intended for the Belene NPP Project”, 11 September 2024, see <https://www.parliament.bg/en/news/ID/6104>, accessed 12 June 2025.

²³⁴⁵ - Martin Fornusek, “Parliament Approves Controversial Purchase of Russian Nuclear Reactors from Bulgaria”, *The Kyiv Independent*, 11 February 2025, see <https://kyivindependent.com/ukraines-parliament-approves-controversial-purchase-of-russian-nuclear-reactors-from-bulgaria/>, accessed 17 July 2025.

²³⁴⁶ - BTA, “Sale of Belene N-plant Equipment Will Be Suspended”, *Bulgarian News Agency*, 15 April 2025, see <https://www.bta.bg/en/news/economy/872657-sale-of-belene-n-plant-equipment-will-be-suspended>, accessed 21 July 2025.

²³⁴⁷ - Council of Ministers, “Prime Minister: Bourgas-West to Become New Container-Shipping Hub in the Black Sea”, Government of Bulgaria, 23 April 2025, see <https://www.gov.bg/special/en/Press-center/News/Prime-Minister-Bourgas-West-to-become-new-container-shipping-hub-in-the-Black-Sea>, accessed 21 July 2025.

²³⁴⁸ - *Interfax-Ukraine*, “Issue of Buying Equipment for Ukrainian Khmelnytsky NPP in Bulgaria Is Open, Project Not Cancelled – Minister”, 20 June 2025, see <https://en.interfax.com.ua/news/economic/1081420.html>, accessed 21 July 2025.

²³⁴⁹ - *Economic.bg*, “The Belene Nuclear Power Plant's Drama Is Getting a New Chapter”, 5 May 2025, see <https://www.economic.bg/en/a/view/the-belene-nuclear-power-plant-adventure-looks-set-to-continue>, accessed 21 July 2025.

However, the hypothetical project's future remains entirely speculative.²³⁵⁰ In the end the “decision” not to sell the equipment to Ukraine raises more questions than it answers.²³⁵¹

Energy Policy

Bulgaria's energy planning is guided by two key documents: the Energy Strategy for 2023 to 2053 and the updated Integrated National Energy and Climate Plan (INECP) released in January 2025. The Energy Strategy, announced in January 2023 by then-acting Energy Minister Rossen Hristov, outlines long-term goals, including the elimination of coal by 2038—incidentally corresponding to Germany's coal phaseout target date—with reductions starting in 2030, while maintaining Bulgaria's role as a regional electricity exporter.²³⁵² It envisions the installation of 7 GW of solar and 2 GW of wind power by 2030, increasing to 12 GW and 4 GW, respectively, by 2050, alongside investments in battery storage, electric vehicle charging stations, and additional hydropower.

Nuclear energy is a cornerstone of the Energy Strategy; it plans for 4 GW of additional nuclear capacity, including 2 GW of capacity at the Belene site—now cancelled—by 2035–2040 and an additional 2 GW at Kozloduy by 2045.²³⁵³ In comparison, the INECP specifies that total nuclear capacity is to reach 3.27 GW by 2035 and 4.53 GW in 2040 (when projections end).²³⁵⁴ Complementing this, the updated INECP mentions a 35 percent share of renewable energy in gross final energy consumption by 2030 and 49 percent in final electricity consumption (gross). It also emphasizes hydrogen infrastructure development, such as a 100 percent hydrogen pipeline and cross-border transport with Greece and Romania as well as energy efficiency measures like renovating buildings and constructing nearly zero-energy buildings.²³⁵⁵ Together, these plans aim to balance energy security, environmental sustainability, and economic growth while transitioning Bulgaria to a low-carbon economy.

In 2024, nuclear dominated by far the country's electricity mix accounting for 41.8 percent of power generation, followed by coal at 21.6 percent. The remainder was divided between solar PV (14.4 percent), hydro (7.8 percent), natural gas (5 percent), bioenergy (4.9 percent) and wind (4 percent).²³⁵⁶

²³⁵⁰ - Evgeni Ahmadzai, “Bulgaria to Sell Belene NPP Equipment to Ukraine”, *KAPITALInsights*, 6 July 2023, see https://kinsights.capital.bg/energy/2023/07/06/4504257_bulgaria_to_sell_belene_npp_equipment_to_ukraine/, 21 July 2025.

²³⁵¹ - Igor Todorović, “Bulgaria Canceling Sale of Equipment for its Belene Nuclear Plant to Ukraine”, *Balkan Green Energy News*, 22 April 2025, see <https://balkangreenenergynews.com/bulgaria-canceling-sale-of-equipment-for-its-belene-nuclear-plant-to-ukraine/>, accessed 23 April 2025.

²³⁵² - WNN, “Bulgaria Energy Strategy Includes Four New Nuclear Reactors”, 19 January 2023, see <https://www.world-nuclear-news.org/Articles/Bulgaria-sets-out-plans-for-four-new-nuclear-react>, accessed 22 January 2023; and Ministry of Energy, “Росен Христов: Енергетиката съдейства за конкурентоспособността на икономиката в криза”, Government of Bulgaria, 17 January 2023, see <https://www.me.government.bg/bg/news/rosen-hristov-energetikata-sadeistva-za-konkurentosposobnostta-na-ikonmikata-v-kriza-3137.html?p=eyJoeXBBIjoiaG9obmV3cyJ9>, accessed 25 August 2024.

²³⁵³ - *Balkan Green Energy News*, “Bulgaria's 2053 Energy Strategy: Coal Until 2030, New Nuclear Capacities”, 18 January 2023, see <https://balkangreenenergynews.com/bulgarias-2053-energy-strategy-coal-until-2030-new-nuclear-capacities/>, accessed 30 May 2023.

²³⁵⁴ - Ministry of Energy and Ministry of Environment and Water, “Integrated Plan Energy and Climate of the Republic of Bulgaria”, Government of Bulgaria, as released by European Commission, 15 January 2025, see https://commission.europa.eu/document/download/a3370b6f-98f5-4402-acee-df1fe505437_en?filename=bulgaria-final-updated-necp-2021-2030-submitted-2025_en.pdf, accessed 28 April 2025.

²³⁵⁵ - Ibidem.

²³⁵⁶ - EMBER, “Electricity Data Explorer—Share of Electricity Generation in Bulgaria”, 2025, see https://ember-energy.org/data/electricity-data-explorer/?entity=Bulgaria&metric=pct_share, accessed 21 July 2025.

Bulgaria is also considering the deployment of Small Modular Reactors.

Czech Republic



The Czech Republic has six Russian-designed reactors in operation at two sites. Dukovany houses four VVER-440/V-213 reactors and Temelín operates two VVER-1000/V-320 units. The units of Dukovany were connected to the grid in the years 1985 to 1987 and both units of Temelín in the year 2000. Each plant's operating license is unlimited but conditional on a positive period safety review every ten years. In 2024, nuclear power production stood at 28.2 TWh—a slight decrease from 28.9 TWh in 2023—and represented a 40.2 percent share in total electricity generation.

In late 2024, the Czech Republic issued an update of its National Energy and Climate Plan (NECP), which is also reflected in the ČEZ Group's annual report.²³⁵⁷ The ČEZ Group is a large energy utility company in the Czech Republic, which, among a range of power stations, operates the two nuclear power plants of the Czech Republic. According to the plan, by 2030, the nuclear share in electricity generation is to reach 44 percent, with a 2040 target to rise to a potential maximum of 68 percent, before decreasing again to 46 percent in 2050.²³⁵⁸

The NECP indicates three areas impacting nuclear capacity:

- ➔ The confirmation of the indefinite extension of the operating licenses of all existing units with an obligation to undergo an in-depth periodic safety review every ten years, see Czech Republic Focus in [WNISR2024](#). The current estimated operating lifetime is at least 60 years.
- ➔ The construction of two to four new large units at Dukovany and possibly Temelín with the first new unit planned to start up in 2036.
- ➔ The deployment of small and intermediate modular reactors at up to three locations with a total capacity of up to 3 GW by 2050 and a first unit operating by the mid-2030s.

Nuclear Fuel—Reducing Russia Dependencies

As reported in [previous issues of WNISR](#), the Czech Republic is looking to reduce its dependency on Russian natural uranium and fuel services including enrichment, conversion, and fuel-assembly fabrication. Further steps toward this goal were taken over the past year. Temelín and Dukovany are expanding their fresh fuel storage-capacities, which, once the

²³⁵⁷ - Government of the Czech Republic, “National Plan of the Czech Republic in the Area of Energy and Climate”, December 2024, see https://commission.europa.eu/document/download/3164cc75-45db-4898-bc63-d5f7d989c9c9_en?filename=CZ%20%E2%80%93%20FINAL%20UPDATED%20NECP%202021-2030%20%28English%29.pdf, accessed 28 April 2025; and Ministry of Industry and Trade, “The National Energy and Climate Plan of the Czech Republic”, Government of the Czech Republic, 20 December 2024, see <https://mpo.gov.cz/en/energy/strategic-and-conceptual-documents/the-national-energy-and-climate-plan-of-the-czech-republic--285295/>; also ČEZ Group, “2024 Annual Financial Report”, April 2025, see <https://www.cez.cz/webpublic/file/edee/ospol/fileexport/investori/vz-2024/cez-group-annual-financial-report-2024.pdf>; both accessed 20 May 2025.

²³⁵⁸ - Ibidem; and Ministry of Industry and Trade, “The Government Has Approved the Update of the National Energy Plan. It Lays Emphasis on the Development of Nuclear Energy and Renewables”, Press Release, Government of the Czech Republic, 18 December 2024, see <https://mpo.gov.cz/en/guidepost/for-the-media/press-releases/the-government-has-approved-the-update-of-the-national-energy-plan--it-lays-emphasis-on-the-development-of-nuclear-energy-and-renewables--285287/>, accessed 28 August 2025.

modification is implemented, would be able to hold more than ten fuel loads per site.²³⁵⁹ A fuel delivery contract for Russian fuel ended in 2024. Alternative fuel supply from Westinghouse—initially set to begin in 2024—was delivered at both sites in May and June 2025.²³⁶⁰ At the beginning, fuel of mixed origins would be loaded in the cores.

In October 2024, Framatome and ČEZ signed a Memorandum of Understanding regarding “Framatome’s own-design VVER-1000 fuel development program”.²³⁶¹ Earlier, in 2022, ČEZ had contracted Framatome for the supply of fuel assemblies for Temelín starting in 2024.²³⁶² This would in principle give access to another potential non-Russian fuel supplier besides Westinghouse, however, Framatome is planning to fabricate the fuel under a Russian license agreement in Lingen, Germany. The project still needs a permit from the relevant German authorities, which means that this option is taking more time than envisaged. A first delivery is now expected in 2026.²³⁶³ The two companies have been negotiating a further agreement for fuel supply of Dukovany for a few years (see *WNISR2024*) and were still discussing as of May 2025.²³⁶⁴ (See *Russia Nuclear Interdependencies*.)

In November 2024, the signature of a 10-year contract with Urenco on enrichment services for Dukovany and Temelín units “until the mid 2030s” was announced, without the mention of exact dates or volumes involved.²³⁶⁵

In April 2025, ČEZ signed a contract with Kazakhstan’s National Atomic Company Kazatomprom JSC for the supply of natural uranium concentrates, which is planned to cover approximately one-third of Temelín’s uranium needs for Westinghouse-manufactured fuel assemblies over the following seven years.²³⁶⁶

New Large Reactors at the Dukovany Site

As reported in previous *WNISR* editions, the Czech Republic started planning for new reactors over two decades ago. Originally, new units were planned to replace the capacity lost due to decommissioning of the existing units at the Dukovany site. During a long planning and tender

²³⁵⁹ - It is assumed that this information from knowledgeable sources refers to reloads; thus, there should eventually be a holding capacity for ten years of operation.

²³⁶⁰ - Westinghouse, “Westinghouse Completes First VVER Fuel Deliveries to Temelín and Dukovany Nuclear Power Plants”, Press Release, 16 June 2025, see <https://info.westinghousenuclear.com/news/westinghouse-completes-first-vver-fuel-deliveries-to-temelin-and-dukovany-nuclear-power-plants>, accessed 19 June 2025.

²³⁶¹ - Framatome, “Framatome Signs Memorandum of Understanding with ČEZ on Framatome Own Design VVER-1000 Fuel Program”, Press Release, 1 October 2024, see <https://www.framatome.com/medias/framatome-signs-memorandum-of-understanding-with-cez-on-framatome-own-design-vver-1000-fuel-program/>, accessed 24 April 2025.

²³⁶² - ČEZ, “We Are Strengthening the Energy Security of the Czech Republic: We Have Signed Contracts for the Supply of Fuel Assemblies with Westinghouse and Framatome”, Press Release, 28 June 2022, see <https://www.cez.cz/en/media/press-releases/we-are-strengthening-the-energy-security-of-the-czech-republic-we-have-signed-contracts-for-the-supply-of-fuel-assemblies-with-westinghouse-and-framatome-160156>, accessed 26 July 2023.

²³⁶³ - CitiGroup and Deutsche Bank, “Base Prospectus—ČEZ, a. s.—€8,000,000,000 Euro Medium Term Note Programme”, ČEZ, April 2025, see https://www.cez.cz/webpublic/file/edee/2025/04/cez-emtn-base-prospectus-_16-april-2025.pdf, accessed 13 July 2025.

²³⁶⁴ - Daniel Beneš, “Board of Directors’ Report on the Company’s Business Activities”, Chairman of the Board of Directors, and Chief Executive Officer, ČEZ, 14 May 2025, see https://www.cez.cz/webpublic/file/edee/ospol/fileexport-s/pro-investory/investor-relations/vh2025/aj/1a_en_zprava-pas-o-podnikatelske-cinnosti.pdf, accessed 12 July 2025.

²³⁶⁵ - *Platts Nuclear Fuel*, “CEZ Signs New Uranium Enrichment Services Contracts with Urenco”, Vol. 49, Issue 23, 8 November 2024; and Urenco, “Urenco Signs New Contracts with Czechia’s ČEZ”, 7 November 2024, see <https://www.urencocom/news/global/2024/urencocom-signs-new-contracts-with-czechias-cez>, accessed 12 July 2025.

²³⁶⁶ - CEZ Group, “Kazatomprom Signs a New Supply Agreement with ČEZ, a. s.”, Press Release, 15 April 2025, see <http://www.cez.cz/en/media/press-releases/kazatomprom-signs-a-new-supply-agreement-with-cez-a.-s.-218248>, accessed 20 May 2025.

process, led by ČEZ Group's Elektrárna Dukovany II (EDU II), finally three bids, provided by U.S.-Canadian Westinghouse, French Electricité de France (EDF), and Korea Hydro and Nuclear Power (KHNP), were received. See *Czech Republic Focus: Newbuild Projects in WNISR2024* for a more detailed account of the process.

In June 2024, ČEZ announced KHNP—offering its APR-1000 design, derived from the System 80 design by Westinghouse and a never-built, downsized version of KHNP's APR-1400 design—as its preferred bidder.²³⁶⁷ The following month, the government confirmed the selection of the Korean supplier for the construction of two units at Dukovany.²³⁶⁸

While the original tender was just for one unit, EDF and KHNP, had been asked to submit updated binding offers by April 2024 covering the construction of up to four reactors in the hope of reducing per unit costs.²³⁶⁹ KHNP's winning offer was announced to be “around CZK200 billion [US\$9.1 billion] per unit.”²³⁷⁰

Following the decision, Westinghouse as well as EDF filed appeals with the Czech Office for the Protection of Competition (ÚOHS), contesting the legality of several decisions along the procurement process.²³⁷¹ Further, building on an earlier dispute, Westinghouse asserted that KHNP was exporting technology protected by Westinghouse property rights,²³⁷² while EDF argued that the fixed price offered by KHNP—electricity generation reportedly for less than €90/MWh (US\$102/MWh)—would not be possible without Korean public subsidies which thus would constitute unfair competition.²³⁷³ In October 2024, EDF took the additional step to file a complaint with the European Commission against the Czech decision.²³⁷⁴

²³⁶⁷ - ČEZ, “ČEZ Evaluated Bids for the Construction of a New Nuclear Unit and Named Its Preferred Bidder, with Results Submitted to Ministry of Industry and Trade”, Press Release, ČEZ Group, 14 June 2024, see <http://www.cez.cz/en/media/press-releases/cez-evaluated-bids-for-the-construction-of-a-new-nuclear-unit-and-named-its-preferred-bidder-with-results-submitted-to-ministry-of-industry-and-trade-192269>, accessed 11 August 2024.

²³⁶⁸ - Government of the Czech Republic, “The Government Has Decided on a Preferred Supplier for the New Nuclear Power Source at Dukovany”, Press Release, 17 July 2024, see <https://vlada.gov.cz/en/media-centrum/aktualne/the-government-has-decided-on-a-preferred-supplier-for-the-new-nuclear-power-source--negotiations-on-the-construction-of-two-units-at-dukovany-will-be-214609/>, accessed 22 July 2024.

²³⁶⁹ - Ministry of Industry and Trade, “Nuclear Tender Enters the Next Stage. Government Is Going to Call on Interested Parties to Submit Binding Offers for the Construction of Several Block”, Press Release, Government of the Czech Republic, 31 January 2024, see <https://www.mpo.gov.cz/en/guidepost/for-the-media/press-releases/nuclear-tender-enters-the-next-stage--government-is-going-to-call-on-interested-parties-to-submit-binding-offers-for-the-construction-of-several-block--279624/>, accessed 5 June 2024.

²³⁷⁰ - Government of the Czech Republic, “The Government Has Decided on a Preferred Supplier for the New Nuclear Power Source at Dukovany”, Press Release, 17 July 2024, op. cit.

²³⁷¹ - Czech Office for the Protection of Competition, “Details on the Content of Westinghouse and EDF's Complaint Against Nuclear Tender”, Press Release, 3 September 2024, see <https://uohs.gov.cz/en/information-centre/press-releases/public-procurement/3967-details-on-the-content-of-westinghouse-and-edfs-complaint-against-nuclear-tender.html>, accessed 31 October 2024.

²³⁷² - *Nucleonics Week*, “Westinghouse Disputes KHNP Authority to Sell Reactor Technology in Czech Republic”, 24 July 2024, Vol. 65, Issue 30.

²³⁷³ - *Contexte*, “EDF et Westinghouse déposent des recours contre l'appel d'offres nucléaire tchèque remporté par le Coréen KHNP”, 28 August 2024, see <https://www.contexte.com/actualite/energie/edf-et-westinghouse-deposent-des-recours-contre-lappel-doffres-nucleaire-tcheque-remporte-par-le-coreen-khnp-199875.html>, accessed 4 November 2024.

²³⁷⁴ - François De Beaupuy, “EDF Complains to EU Over Czech Nuclear Deal With Korean Firm”, *BNN Bloomberg*, 8 October 2024, see <https://www.bnnbloomberg.ca/business/international/2024/10/08/edf-complains-to-eu-over-czech-nuclear-deal-with-korean-firm/>, accessed 9 October 2024; and Grace Symes and Jessica Sondgeroth, “Latest—EDF Complains to Brussels About KHNP's Czech Offering”, *Nuclear Intelligence Weekly*, 11 October 2024.

ÚOHS put a temporary hold on the conclusion of a contract with South Korea's KHNP then expected in March 2025.²³⁷⁵ In a first decision, the complaints were largely dismissed in October 2024;²³⁷⁶ later EDF's claims were rejected in a second and final decision.²³⁷⁷

In November 2024, the South Korean and the U.S. governments signed a Memorandum of Understanding (MoU) on Principles Concerning Nuclear Exports and Cooperation.²³⁷⁸ A second MoU was initialed in early January 2025, finalizing “the provisional understanding reached by the participants in November 2024.”²³⁷⁹ Finally, a few days later, Westinghouse, KHNP, and KHNP's parent company Korea Electric Power Corporation (KEPCO) sealed a direct final settlement agreement of the long-standing legal conflict between the two companies.²³⁸⁰ But while it published that an arrangement had been made, the terms of the deal were kept secret.

In May 2025, the European Commission sent a non-binding request to the Czech Republic, asking it to suspend the signing of the contract with KHNP until an investigation on whether KHNP received improper state subsidies related to the tender was concluded.²³⁸¹ A leaked version of the letter laid out that there were “significant indications” that KHNP may have received “foreign subsidies that are liable to distort the internal market”, in violation of E.U. regulations and signaled that the Commission was “in the process of preparing a decision initiating an in-depth investigation.”²³⁸² The dispute further escalated with the now majority government-owned EDU II company openly calling on EDF “to publish its offer immediately” to allow the public to judge the bids by themselves, suggesting that the French company was

²³⁷⁵ - Jason Hovet, “Czech Watchdog Prohibits Nuclear Power Contract Signing Amid Appeals”, *Reuters*, 30 October 2024, see <https://www.reuters.com/business/energy/czech-watchdog-prohibits-nuclear-power-contract-signing-amid-appeals-2024-10-30/>, accessed 30 October 2024; and Czech Office for the Protection of Competition, “The Office Decides on the Proposals of Westinghouse and EDF Against the Nuclear Tender Procedure In the First Instance”, Press Release, 31 October 2024, see <https://uohs.gov.cz/en/information-centre/press-releases/public-procurement/4013-the-office-decides-on-the-proposals-of-westinghouse-and-edf-against-the-nuclear-tender-procedure-in-the-first-instance.html>, accessed 31 October 2024.

²³⁷⁶ - Office for the Protection of Competition, “The Office Has Received Appeals Against Decisions on the Tender for the Construction of Nuclear Power Plant”, Press Release, 18 November 2024, see <https://uohs.gov.cz/en/information-centre/press-releases/public-procurement/4028-the-office-has-received-appeals-against-decisions-on-the-tender-for-the-construction-of-nuclear-power-plant.html>, accessed 22 May 2025.

²³⁷⁷ - Office for the Protection of Competition, “Rozklad EDF ve věci jaderného tendru byl zamítnut”, 24 April 2025, see <https://uohs.gov.cz/cs/informacni-centrum/tiskove-zpravy/verejne-zakazky/4192-rozklad-edf-ve-veci-jaderneho-tendru-byl-zamitnut.html>, accessed 24 April 2025.

²³⁷⁸ - *Nucleonics Week*, “South Korea Believes Czech Nuclear Plant Project Can Proceed Following US Agreement”, Vol. 65, Issue 45, 6 November 2024; and U.S. Department of Energy, “U.S.-Republic of Korea Reach Provisional Agreement on Nuclear Cooperation”, United States Government, 4 November 2024, see <https://www.energy.gov/articles/us-republic-korea-reach-provisional-agreement-nuclear-cooperation>, accessed 12 July 2025.

²³⁷⁹ - U.S. Department of Energy, “Joint Statement of the United States of America and the Republic of Korea on the Expansion of Peaceful Nuclear Energy”, United States Government, 10 January 2025, see <https://www.energy.gov/articles/joint-statement-united-states-america-and-republic-korea-expansion-peaceful-nuclear-energy>, accessed 12 July 2025.

²³⁸⁰ - Phil Chaffee, “Seoul Settles Nuclear IP Dispute With US”, *Nuclear Intelligence Weekly*, Vol. 19, No. 3, 17 January 2025; and Westinghouse Electric Company, “Westinghouse Announces Global Settlement Agreement with KEPCO and KHNP”, Press Release, 16 January 2025, see <https://info.westinghousenuclear.com/news/westinghouse-announces-global-settlement-agreement-with-kepc-and-khnp>, accessed 24 February 2025.

²³⁸¹ - *Agence France-Presse*, “Nucléaire en République tchèque : après la plainte d'EDF, la réplique de KHNP”, as published by *Connaissance des énergies*, 27 May 2025, see <https://www.connaissancedesenergies.org/afp/nucleaire-en-republique-tcheque-apres-la-plainte-dedf-la-replique-de-khnp-250527>, accessed 28 May 2025; and Stéphane Séjourné, “Request for Immediate Action to Suspend Contract Signature for the New Nuclear Reactors of Dukovany and Temelin, Czechia”, Executive Vice-President, Prosperity and Industrial Strategy, European Commission, addressed to Lukáš Vlček, Minister of Industry and Trade, Government of the Czech Republic, as released by *Euractiv*, 2 May 2025, see <https://www.euractiv.com/section/eet/news/commission-misled-press-over-french-pressure-on-czech-nuclear-deal/>, accessed 12 May 2025.

²³⁸² - *Contexte*, “La Commission européenne a elle aussi demandé à Prague de suspendre la signature du contrat pour la construction des réacteurs de Dukovany”, 13 May 2025, see https://www.contexte.com/fr/actualite/energie/la-commission-europeenne-a-elle-aussi-demande-a-prague-de-suspendre-la-signature-du-contrat-pour-la-construction-des-reacteurs-de-dukovany_227341, accessed 13 May 2025.

“not interested in winning the tender, but in ensuring that no nuclear power plant is built here in the Czech Republic at all.”²³⁸³

On 6 May 2025, the Czech Brno Regional Court prohibited the signature of the agreement with KHNP—reportedly set for the following day—until the legal case initiated by EDF against ÚOHS was fully processed in court.²³⁸⁴ On 4 June 2025, the Czech Supreme Administrative Court nullified the lower court’s injunction and paved the way for contracts to be finalized.²³⁸⁵ Prime Minister Fiala and representatives of ČEZ announced the signing of the engineering, procurement, and construction (EPC) contract for the EDU II project at a press conference the same day.²³⁸⁶ The agreement comprises the construction of two units of APR-1000 reactors at the Dukovany site (Units 5 and 6) for CZK 400 billion (~US\$18 billion). Target dates for completion are 2036 and 2037, respectively.²³⁸⁷

The implementation will be challenging. Besides many technical construction issues, the prescriptive Czech regulatory system is tailored toward Russian VVER reactors, the only nuclear technology operational in the country.

Meanwhile, in April 2025, the Czech government acquired 80 percent of the ČEZ project company Elektrárna Dukovany II (EDU II).²³⁸⁸ The government aims for 60 percent national content of the work commissioned in the framework of the project.²³⁸⁹

Small and Intermediate Modular Reactors

As mentioned above, ČEZ targets SMR deployment totaling to a capacity of up to 3 GW by 2050, with the first unit to be built at the Temelín site.²³⁹⁰ The very optimistically envisaged target period for the start of SMR deployment is 2030–2035. The SMR strategy took a step forward in October 2024, when Rolls-Royce, whose technology had previously been selected as preferred design, announced a strategic partnership with ČEZ, materializing in ČEZ gradually acquiring an equity investment of “approximately 20 percent” in Rolls Royce’s subsidiary Rolls-Royce

²³⁸³ - CEZ Group, “EDU II Company Calls on EDF to Publish a Bid for the Construction of a New Nuclear Power Plant in the Czech Republic”, Press Release, 12 May 2025, see <http://www.cez.cz/en/media/press-releases/edu-ii-company-calls-on-edf-to-publish-a-bid-for-the-construction-of-a-new-nuclear-power-plant-in-the-czech-republic-220331>, accessed 12 May 2025.

²³⁸⁴ - Jan Lopatka, “Czech Court Blocks Signing of \$18 Billion Nuclear Plant Deal with KHNP”, *Reuters*, 6 May 2025, see <https://www.reuters.com/sustainability/boards-policy-regulation/czech-court-halts-nuclear-plant-signing-with-khnp-after-last-minute-appeal-2025-05-06/>, accessed 6 July 2025; and Regional Court of Brno, “TISKOVÁ ZPRÁVA ve věci Elektrárna Dukovany II”, Czech Ministry of Justice, 6 May 2025, see <https://msp.gov.cz/documents/d/krajsky-soud-v-brne/tiskova-zprava-elektrarna-dukovany-ii-pdf>, accessed 9 May 2025.

²³⁸⁵ - Nejvyšší správní soud, “Nejvyšší správní soud zrušil předběžné opatření ve věci výstavby jaderných bloků v elektrárně Dukovany”, 4 June 2025, see <https://www.nssoud.cz/aktualne/tiskove-zpravy/detail/nejvyssi-spravni-soud-zrusil-predbezne-opatreni-ve-veci-vystavby-jadernych-bloku-v-elektrarne-dukovany>, accessed 6 July 2025.

²³⁸⁶ - Government of the Czech Republic, “Smlouva mezi Elektrárnou Dukovany II a KHNP na výstavbu dvou nových jaderných bloků v Dukovanech podepsána”, 4 June 2025, see <https://vlada.gov.cz/cz/media-centrum/aktualne/smlouva-mezi-elektrarnou-dukovany-ii-a-khnp-na-vystavbu-dvou-novych-jadernych-bloku-v-dukovanech-podepsana-220044/>, accessed 4 June 2025.

²³⁸⁷ - Ibidem; and Jo He-rim, “South Korea Inks \$18b Nuclear Export Deal with Czech Republic”, *The Korea Herald*, 6 June 2025, see <https://asianews.network/south-korea-inks-18b-nuclear-export-deal-with-czech-republic/>, accessed 22 August 2025.

²³⁸⁸ - ČEZ, “ČEZ Sells 80% Stake in Elektrárna Dukovany II to the State”, CEZ Group, 30 April 2025, see <http://www.cez.cz/en/investors/inside-information/cez-sells-80-stake-in-elektrarna-dukovany-ii-to-the-state-219757>, accessed 1 May 2025.

²³⁸⁹ - Chris Johnstone, “Czechs Seek KHNP Commitment on Local Share in Dukovany Nuclear Reactor Project”, *Power in Europe*, Issue 939, 28 February 2025.

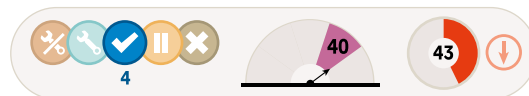
²³⁹⁰ - CEZ Group, “2024 Annual Financial Report”, April 2025, see <https://www.cez.cz/webpublic/file/edee/ospol/fileexport/investori/vz-2024/cez-group-annual-financial-report-2024.pdf>, accessed 20 May 2025.

SMR.²³⁹¹ The acquisition was sanctioned by the European Commission in February 2025²³⁹² and took effect in March 2025.²³⁹³ In addition, ČEZ contracted the company Amentum's Brno-based branch to prepare an environmental impact assessment for two sites, one being Temelín, the other Tušimice, where a coal-fired power station was due for decommissioning.²³⁹⁴ The Rolls-Royce SMR design features a 470-MWe pressurized water reactor.²³⁹⁵

Power System

In 2024, the Czech Republic produced a total of 74 TWh of electricity (gross). With 36 TWh, fossil fueled thermal power plants were leading, followed by nuclear power plants with 30 TWh, hydro and solar with 3.6 TWh each, and wind plants with 1 TWh. Close to 7 TWh of electricity was exported. Comparing the situation of 2024 with five years ago, the generation from hydro, wind, and nuclear power was practically unchanged. There was a significant 28-percent decrease in production from fossil fuels (36 TWh in 2024, down from 50.6 TWh in 2019) and a noteworthy 55-percent increase in production from solar power (3.6 TWh in 2024, up from 2.3 TWh in 2019), which however remains at a modest level contributing ten times less than fossil fuels—or 4.9 percent—to the total. Overall electricity production declined from 87 TWh gross in 2019 to 74 TWh in 2024, which was balanced by less exports and less domestic consumption.²³⁹⁶

Hungary



Hungary has one operating nuclear power plant at Paks, where four VVER-440/V-213 reactors provided 16 TWh (15.2 TWh net) or 42.8 percent of the country's electricity in 2024; whereas the production remained stable (around 0.1 TWh difference), the share in electricity generation dropped from 44.8 percent in 2023. It peaked at 53.2 percent in 2014.²³⁹⁷

Fuel for operating the Soviet-designed nuclear plant, so far, has been provided solely by Russian TVEL.²³⁹⁸ However, in late 2023, the Hungarian Parliament passed an amendment to

²³⁹¹ - Rolls Royce, "Rolls-Royce SMR and ČEZ Group Partner to Deploy SMRs in UK and Czechia", Press Release, 29 October 2024, see <https://www.rolls-royce.com/media/press-releases/2024/29-10-2024-rolls-royce-smr-and-cez-group-partner-to-deploy-smrs-in-uk-and-czechia.aspx>, accessed 6 July 2025.

²³⁹² - DG Competition, "Case M.11809 - Rolls-Royce / CEZ Holdings / Rolls-Royce SMR—Regulation (ec) No 139/2004 Merger Procedure—Article 6(1)(b) Non-Opposition", European Commission, 3 February 2025, see https://ec.europa.eu/competition/mergers/cases1/202506/M_11809_10481037_187_3.pdf, accessed 18 June 2025.

²³⁹³ - Rolls Royce, "ČEZ Group Investment into Rolls-Royce SMR", Press Release, 4 March 2025, see <https://www.rolls-royce-smr.com/press/on-29th-october-2024-rolls-royce-smr-announced-that-cez-group-cez-would-make-an-equity-investment-into-the-rolls-royce-smr-business>, accessed 6 July 2025.

²³⁹⁴ - Amentum, "Czechia's Largest Utility Selects Amentum for Small Modular Reactor Program", Press Release, 8 April 2025, see <https://www.amentum.com/news/czechias-largest-utility-selects-amentum-for-small-modular-reactor-program/>, accessed 19 April 2025.

²³⁹⁵ - Rolls-Royce SMR, "Our Technology", as of 12 July 2025, see <https://gda.rolls-royce-smr.com/our-technology>, accessed 12 July 2025.

²³⁹⁶ - Czech Statistical Office, "Energy", Updated 28 July 2025, see <https://csu.gov.cz/energy>, accessed 22 August 2025.

²³⁹⁷ - Energy Institute, "Statistical Review of World Energy 2025—Consolidated Dataset", 2025.

²³⁹⁸ - Patricia Lorenz, "Russian Grip on EU Nuclear Power", Wiener Umweltanwaltschaft, May 2022, Updated January 2024, see <https://wua-wien.at/images/stories/publikationen/russian-grip-on-eu-nuclear-power.pdf>, accessed 30 June 2024.

the official nuclear policy that would allow Hungary to seek alternative nuclear fuel sources.²³⁹⁹ In October 2024, the Hungarian government signed a contract with Framatome for the long-term fuel supply of the four VVER-440 reactors, starting in 2027.²⁴⁰⁰ For a detailed account and earlier developments of Hungarian dependence on Russian nuclear fuel, see [past WNISR editions](#) and [Russia Nuclear Interdependencies](#).

Paks I – Operating

Currently Paks I is licensed for 50 years of operation—following 20-year license extensions granted for each of the four reactors between 2012 and 2017—on the condition that a periodic safety review confirms required safety margins every decade for the duration of the license. In December 2023, the government officially communicated to the European Commission its intention to extend the operational lifetime of the four reactors by another 20 years, enabling operation to 70 years, i.e., until the 2050s. A detailed implementation plan shall be provided by 2028. Costs for “revamping the electric and control systems” were estimated at around €1.5 billion (US\$₂₀₂₃ 1.6 billion).²⁴⁰¹

While according to previous planning, Paks I would have been decommissioned once Paks II (see below) was connected to the grid, now parallel operation of Paks I and Paks II is envisaged. This raises, amongst various issues, questions about the environmental impact to the Danube River. A limit of 30°C water temperature is imposed to protect wildlife. Due to this limit, Paks I already had to reduce power output on several days in previous years, and despite that, temperatures reportedly still exceeded the limit on several occasions.²⁴⁰² In summer 2024, the government passed a decree under which, when water temperatures reach or exceed the limit, the Ministry of Energy can allow the units to continue operating at full power, if it considers reduced output or shutdown to threaten energy security,²⁴⁰³ and in 2025 an advisory body

²³⁹⁹ - Hungarian National Assembly, “H/6078—A kiégett üzemanyag és a radioaktív hulladék kezelésének nemzeti politikájáról szóló 21/2015. (V. 4.) OGY határozat módosításáról”, promulgated 14 December 2023, see https://www.parlament.hu/web/guest/efutar?p_p_id=hu_parlament_cms_pair_portlet_PairProxy_INSTANCE_q8HC5agunho98&p_p_lifecycle=1&p_p_state=maximized&p_p_mode=view&p_auth=Emnspn6I&_hu_parlament_cms_pair_portlet_PairProxy_INSTANCE_q8HC5agunho98_pairAction=%2Finternet%2Fcplsql%2Fogy_irom.irom_adat%3Fp_ckl%3D42%26p_izon%3D6078; and *Magyar Közlöny*, “Az Országgyűlés 30/2023. (XII. 14.) OGY határozata a kiégett üzemanyag és a radioaktív hulladék kezelésének nemzeti politikájáról szóló 21/2015. (V. 4.) OGY határozat módosításáról*”, 14 December 2024, see <https://magyarkozlony.hu/dokumentumok/e7f59a2fd69403f98627395c1ffdo48976c5d75/megtekintes>; both accessed 30 July 2025.

²⁴⁰⁰ - Framatome, “Framatome to Supply Fuel To Hungarian VVER Reactors”, Press Release, 25 October 2024, see <https://www.framatome.com/medias/framatome-to-supply-fuel-to-hungarian-vver-reactors/>, accessed 24 April 2025.

²⁴⁰¹ - WNN, “Hungary Aims To Extend Life Of Paks Nuclear Plant By 20 Years”, *World Nuclear News*, 7 December 2023, see <https://www.world-nuclear-news.org/Articles/Hungary-aims-to-extend-life-of-Paks-nuclear-plant>, accessed 29 May 2024; and MVM Paks Atomerőmű Zrt, “Sajtóközlemény: Bejelentették az Európai Unió számára az üzemidő további meghosszabbítását”, Press Release, 5 December 2023, see https://atomeromu.mvm.hu/Rolunk/Hirek/20231205_sajtokejaras; also Origo, “20 évvel hosszabbodhat meg a Paks Atomerőmű üzemideje”, 5 December 2023, see <https://www.origo.hu/gazdasag/2023/12/paks-atomeromu-uzemido-beruhazas-mvm-csoport>; both accessed 30 July 2025.

²⁴⁰² - Orsolya Fülöp, “According to Hidden Data, the Paks NPP Has Repeatedly Heated the Danube Above Environmental Limits”, *Atlatszo*, 17 December 2024, see <https://english.atlatszo.hu/2024/12/17/according-to-hidden-data-the-paks-npp-has-repeatedly-heated-the-danube-above-environmental-limits/>, accessed 30 July 2025.

²⁴⁰³ - *Reuters*, “Hungary to Allow Nuclear Plant to Exceed Danube Water Temperature Limit”, 27 July 2024, see <https://www.reuters.com/business/energy/hungary-allow-nuclear-plant-exceed-danube-water-temperature-limit-2024-07-27/>, accessed 30 July 2025; and Nemzeti Jogszabálytár, “15/2001. (VI. 6.) KöM rendelet az atomenergia alkalmazása során a levegőbe és vízbe történő radioaktív kibocsátásokról és azok ellenőrzéséről”, Ministry of Justice, Government of Hungary, 16 August 2024, see <https://njt.hu/jogszabaly/2001-15-20-66.8>, accessed 1 August 2025.

recommended to increase the temperature limit by 2°C.²⁴⁰⁴ While such an increase might reduce the low power days for Paks I with a combined capacity of roughly 2 GW, it is unclear how Paks I and Paks II with a combined capacity of roughly 4.4 GW would operate within those limits. Constructing cooling towers or adding air cooling that could ease the water availability constraints are not considered and would be extremely pricey.

Paks II – Planned

For a decade and a half, plans have been discussed and developed to build additional nuclear power plants. In March 2009, Parliament approved a government decision-in-principle to build additional reactors²⁴⁰⁵ and a tender was prepared according to E.U. rules. In 2014, the Paks II project, consisting of two 1200-MW VVER-1200s (Paks-5 and -6), was suddenly awarded to Rosatom without reference to any public tender, with Russia financing 80 percent of the project through loans.²⁴⁰⁶ The original 2014 Russian-Hungarian bilateral financing agreement consisted of a €10 billion (US\$₂₀₁₄ 13 billion) loan to the Hungarian state. Hungary would have to invest 20 percent or up to €2.5 billion (US\$₂₀₁₄ 3.3 billion) into the project. In April 2021, the loan terms were revised to allow Hungary to start repaying the loan in 2031, five years later than originally agreed.²⁴⁰⁷

Legal Challenges to State Aid for Paks II

In November 2016, the European Commission cleared the award of the contract to Rosatom of any infringement of its procurement rules,²⁴⁰⁸ and in March 2017, it also approved the financial package for Paks II.²⁴⁰⁹ However, in February 2018 the Austrian government filed a legal action challenging the validity of the decision.²⁴¹⁰ In November 2022, the European General Court sided with the Commission, notably arguing that because Hungary's state aid for the Paks II project "concerns solely the costs of investment in two new reactors intended to replace the four old reactors [...] and with no operating aid being foreseen, the effect on the energy

²⁴⁰⁴ - About Hungary, "Advisory Body Recommends Temperature Threshold for Paks Discharge along Danube Stretch", Cabinet Office of the Prime Minister, Government of Hungary, 20 May 2025, see <https://abouthungary.hu/news-in-brief/advisory-body-recommends-temperature-threshold-for-paks-discharge-along-danube-stretch>, accessed 30 July 2025.

²⁴⁰⁵ - PAKS II, "Background of the Project", Undated, see <https://www.paks2.hu/web/paks-2-en/background-of-the-project>; and WNN, "Hungarian Parliament Approves Paks Expansion", 31 March 2009, see <https://www.world-nuclear-news.org/Articles/Hungarian-parliament-approves-Paks-expansion>; both accessed 28 July 2023.

²⁴⁰⁶ - Csaba Tóth, "Hungary, Russia Sign Paks II Implementation Agreements", *The Budapest Beacon*, 9 December 2014, see <https://budapestbeacon.com/hungary-russia-sign-3-implementation-agreements-paks-ii/>, accessed 27 July 2023.

²⁴⁰⁷ - Marton Dunai, "CORRECTED-Hungary Gets 5-Year Payment Delay on Russian-Led Nuclear Plant Project", *Reuters*, 29 April 2021, see <https://www.reuters.com/article/hungary-nuclearpower-russia-financing-idINL8N2MM8SW>, accessed 27 July 2023.

²⁴⁰⁸ - Philip Blenkinsop, "EU Drops Part of Reservation to Hungary's Paks Nuclear Project", *Reuters*, 18 November 2016, see <https://www.reuters.com/article/us-hungary-nuclearpower-eu-idUSKBN13DoQN>, accessed 27 July 2023.

²⁴⁰⁹ - European Commission, "Commission Decision (EU) 2017/2112 of 6 March 2017 on the Measure/Aid Scheme/State Aid SA.38454—2015/C (ex 2015/N) which Hungary Is Planning to Implement for Supporting the Development of Two New Nuclear Reactors at Paks II Nuclear Power Station", L 317/45, Official Journal of the European Union, 6 March 2017, see <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017D2112>, accessed 27 July 2023.

²⁴¹⁰ - *Official Journal of the European Union*, "Case T-101/18—Action Brought on 21 February 2018 — Austria v Commission", published 30 April 2018, C152/40, see <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A62018TNo101&qid=1717880757515>, accessed 8 June 2024.

market will only be limited.”²⁴¹¹ The Austrian government subsequently filed an appeal. In February 2025, the European Court of Justices’ Advocate General proposed as legal solution that the court uphold the Austrian government’s appeal and set aside the earlier judgment from the General Court.²⁴¹² The court is yet to render its judgment.

The financial intergovernmental agreement and the Engineering, Procurement and Construction (EPC) contract were subject to draft amendments in 2023. According to the government, the new amendments were approved by the European Commission in May 2023,²⁴¹³ allowing for the amended contracts to be signed and enforced in August 2023.²⁴¹⁴ In fact this marked the sixth amendment of the EPC contract, as it had been revised in the past notably to extend completion dates.²⁴¹⁵

Paks II Licensing and Construction Process

Despite the economy-wide sanctions against Russian companies, Paks II is proceeding, as Hungary obtained an exclusion of the project from potential future E.U. sanctions in June 2024, by making it the main condition for its government to approve the E.U.’s 14th sanctions package against Russia.²⁴¹⁶

Although construction licenses for the two new VVER-1200 reactors were already granted in August 2022,²⁴¹⁷ only site preparation works and construction of certain components was possible as the license was tied to several conditions, most notably the approval of the preliminary safety analysis report, which was not granted in 2022.

In August 2024, the core catcher for the Paks II first unit (Paks-5) was delivered to the site following a 42-day shipment by a water route organized by an Austrian company.²⁴¹⁸

²⁴¹¹ - General Court, “Report of Cases—Judgment of the General Court (Third Chamber)—Judgment of 30.11.2022 Case T-101/18 [Extracts]—Austria v Commission”, ECLI:EU:T:2022:728, Court of Justice of the European Union, 30 November 2022, see <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:62018TJ0101&qid=1717881256039>, accessed 8 June 2024.

²⁴¹² - Court of Justice of the European Union, “Advocate General Medina Proposes to Set Aside the Judgment of the General Court That Upheld the Commission’s Decision to Approve Aid from Hungary for Two New Nuclear Reactors at Paks”, Press Release No 24/25, 27 February 2025, see <https://curia.europa.eu/jcms/upload/docs/application/pdf/2025-02/cp250024en.pdf>, accessed 27 February 2025; and Court of Justice of the European Union, “Opinion of Advocate General Medina delivered on 27 February 2025—Case C-59/23 P - Republic of Austria vs European Commission”, InfoCuria, 27 February 2025, see <https://curia.europa.eu/juris/document/document.jsf?docid=295863&dclang=EN>, accessed 20 May 2025.

²⁴¹³ - David Dalton, “European Commission Has Approved Changes to Paks 2 Nuclear Contracts with Russia, Says Foreign Minister”, *NucNet*, 26 May 2023, see <https://www.nucnet.org/news/european-commission-has-approved-changes-to-paks-2-nuclear-contracts-with-russia-says-foreign-minister-5-5-2023>; and WNN, “EC Outlines Approval Grounds for Paks II Contract Amendments”, 30 May 2024, see <https://world-nuclear-news.org/Articles/EC-outlines-approval-grounds-for-Paks-II-contract>; both accessed 9 June 2024.

²⁴¹⁴ - Paks II Ltd, “The Amendment of the EPC Contract Has Been Signed”, 18 August 2023, see <https://www.paks2.hu/web/paks-2-en/w/the-amendment-of-the-epc-contract-has-been-signed>, accessed 28 August 2023.

²⁴¹⁵ - Paks II Nuclear Power Plant Company Ltd. and Atomstroyexport, “Amendment No. 5 to Engineering, Procurement, and Construction (EPC) Contract relating to the Construction of Paks II Nuclear Power Plant Units 5 and 6, Hungary—dated December 9, 2014”, entered 18 August 2023, see <https://www.paks2.hu/documents/44400/98136/Amendment%20No.%205.%20to%20EPC%20Contract.pdf/f6a21b69-4157-0003-011b-e0a2fa54a772>, accessed 31 July 2025.

²⁴¹⁶ - Anita Zimmermann, Camille Gijs, Victor Jack and Koen Verhelst, “EU Approves First-Ever Sanctions on Russian Gas”, *Politico*, 20 June 2024, see <https://www.politico.eu/article/eu-approves-first-ever-sanctions-russian-gas-Ing-vladimir-putin-ukraine-invasion/>, accessed 30 June 2024.

²⁴¹⁷ - HAEA, “The HAEA Issued the Construction License to Paks II. Ltd.”, Press Release, Hungarian Atomic Energy Authority, 26 August 2022, see <https://www.haea.hu/web/v3/HAEAportal.nsf/web?OpenAgent&article=news&uid=273E525123362584C12588AA002F9FE1>, accessed 9 June 2024.

²⁴¹⁸ - Paks II Ltd, “The Core-Catcher Has Arrived in Paks”, 1 August 2024, see <https://www.paks2.hu/web/paks-2-en/w/the-core-catcher-has-arrived-in-paks>, accessed 24 October 2024.

Furthermore, manufacturing of the reactor pressure vessels for Units 5 and 6 has commenced in Russia, as well as production of the Arabelle turbine for Unit 5 in Belfort, France.²⁴¹⁹

In November 2024, the Hungarian Atomic Energy Authority (HAEA) finally approved the preliminary safety analysis report, a key condition in the construction license for starting work on the nuclear island.²⁴²⁰ However, the partial collapse of a berm at the pit of Unit 5 in January 2025 halted work in the area pending reinforcement measures to preserve the integrity of the structure.

In June 2025, upon reviewing the implemented requirements, the regulator authorized resumption of work in the zone, but noted that “other activities, such as the pouring of the first concrete, may only commence once the conditions and hold points set out in other HAEA permits have been met and accepted.”²⁴²¹

Export of Siemens I&C for Paks II?

As reported in previous WNISR editions, export grants for the Instrumentation and Control (I&C) System, which was to be provided by Siemens Energy with Framatome, were being withheld by the German government in early 2023.²⁴²² As retaliation, the Hungarian government threatened Siemens with the cancellation of other orders, e.g. for locomotives, and was seeking to focus on Framatome as a major European supplier for nuclear plant components.²⁴²³ See also [Russia Nuclear Interdependencies](#) on Siemens implications.

In March 2023, Péter Szijjártó, Minister of Foreign Affairs and Trade, had suggested bringing Russian suppliers into the mix if Framatome failed to “take over leadership of the [Franco-German] consortium.”²⁴²⁴ Reportedly, the Hungarian government had been working on

²⁴¹⁹ - Paks II Ltd, “Production of Important Large-Scale Equipment Has Begun”, 8 April 2025, see www.paks2.hu/en/web/paks-2-en/w/production-of-important-large-scale-equipment-has-begun, accessed 31 July 2025.

²⁴²⁰ - HAEA, “Hatósági döntés az új atomerőművi blokkokra vonatkozó létesítési engedélyben meghatározott visszatartási pont feloldásáról”, 29 November 2024, see <https://www.haea.gov.hu/web/v3/OAHPortal.nsf/web?OpenAgent&article=news&uid=2BF22B4C22DF1874C1258BE4004E29AB>, accessed 31 July 2025; and PAKS II, “Péter Szijjártó: We Have Received the Most Important Approval for the First Concrete Pouring of Paks II”, 29 November 2024.

²⁴²¹ - HAEA, “Paks II Project—Cracks in the Wall of the Working Pit of the Nuclear Island of Unit 5 and the Detachment of the Corners of the Southern Lower Part”, *Nuclear Safety Bulletin*, June 2025, see [https://www.haea.gov.hu/web/v3/HAEAportal.nsf/626175C2CD6EE667C1258CC0003662AD/\\$File/bulletin%20eng_2025_1.pdf](https://www.haea.gov.hu/web/v3/HAEAportal.nsf/626175C2CD6EE667C1258CC0003662AD/$File/bulletin%20eng_2025_1.pdf); and HAEA, “The HAEA Has Authorised the Continuation of Certain Construction Activities in the Entire Area of the Unit 5 Working Pit of The Paks Nuclear Power Plant”, 19 June 2025, see <https://www.haea.gov.hu/web/v3/HAEAportal.nsf/web?OpenAgent&article=news&uid=00CD0A04B2AE310CC1258CC000211B28>; both accessed 31 July 2025.

In early July 2025, the head of Rosatom reportedly announced “pouring of first concrete” for October/November 2025, “if everything goes as we plan”; see TASS, “First Concrete Pouring at Paks-2 NPP in Hungary Planned in October-November 2025”, 3 July 2025, see <https://tass.com/economy/1984855>, accessed 25 July 2025.

²⁴²² - *Portfolio*, “Harmadszorra is beleszállt a német kormányba Szijjártó Péter és belengette a még szorosabb orosz együttműködést”, 22 February 2023, see <https://www.portfolio.hu/gazdasag/20230222/harmadszorra-is-beleszallt-a-nemet-kormanyba-szijjarto-peter-es-belengette-a-meg-szorosabb-orosz-egyuttmukodest-598634>, accessed 1 March 2023; and Krisztina Than, “UPDATE 1-Germany ‘Blocking’ Equipment for Paks Reactors, Hungarian Minister Says”, *Reuters*, 14 February 2023, see <https://www.reuters.com/article/hungary-nuclear-siemens-idINL1N34U1M2>, accessed 28 July 2023.

²⁴²³ - *Hungary Today*, “Government to Restrict Business Relations with Siemens”, 15 May 2023, see <https://hungarytoday.hu/government-to-restrict-business-relations-with-siemens/>, accessed 5 June 2023; and Paks II, “Szijjártó: We Will Further Increase the French Involvement in the Paks NPP Expansion Project”, Press Release, 13 March 2023, see <https://www.paks2.hu/web/paks-2-en/w/szijjarto-we-will-further-increase-the-french-involvement-in-the-paks-npp-expansion-project>, accessed 10 June 2024.

²⁴²⁴ - *NEI Magazine*, “France or Russia to Provide Equipment to Paks-II if Germany Refuses”, 3 March 2023, see <https://www.neimagazine.com/news/france-or-russia-to-provide-equipment-to-paks-ii-if-germany-refuses-10648100>, accessed 28 July 2023.

sidelining Siemens to cooperate solely with Framatome.²⁴²⁵ However, at the opening of Siemens Energy's new gas-turbine component manufacturing facility in Budapest in May 2024, Szijjártó said, in a surprise announcement, that the company would indeed be delivering I&C equipment to the Paks II plant through its Hungarian subsidiary.²⁴²⁶ Apparently, Siemens neither confirmed nor denied the information.

After the announcement of the project's exemption from future E.U. sanctions, Paks II CEO Gergely Jákli was quoted as saying in June 2024 that he was "certain that Siemens Energy will [...] fulfill its contractual obligations," albeit noting that Germany's Federal Office for Economic Affairs and Export Control might still block the export.²⁴²⁷ Meanwhile, the Minister of Foreign Affairs and Trade apparently took the exemption to mean that European companies would no longer require their domestic authorities' permission to participate in the project.²⁴²⁸ Later in June 2025, it was announced that Siemens Energy was relocating its dedicated division to Budapest, in an apparent attempt to evade the need for German authorities' consent.²⁴²⁹ There are, however, still doubts if this measure really could substitute application for and granting of an export license from the competent German authorities.²⁴³⁰

Energy Policy Developments—Solar Provides One Quarter of Power

Renewable energies have been increasing significantly over the past decade, driven by the expansion of solar PV that went from just 89 MW in 2014 to 7.7 GW in 2024, representing over 88 percent of the country's renewable power capacity.²⁴³¹ Consequentially, electricity production from solar has accelerated by a factor of 2.5 in just three years from 3.8 TWh (10.5 percent) in 2021 to 9.4 TWh (24.6 percent) in 2024.²⁴³² According to EMBER, in 2024 Hungary had the highest share (25 percent) of solar in its electricity mix worldwide.²⁴³³

*In 2024, Hungary had the highest share (25 percent)
of solar in its electricity mix worldwide*

²⁴²⁵ - Dániel Deme, "Government to Side-Step Siemens in Another Blow for German Industry", *Hungary Today*, 8 June 2023, see <https://hungarytoday.hu/government-to-side-step-siemens-in-another-blow-for-german-industry/>, accessed 28 July 2023.

²⁴²⁶ - Rainer Ackermann, "Dual und in Paks dabei", *The Budapest Times*, 25 May 2024, see <https://www.budapester.hu/?p=70917>, accessed 30 May 2024.

²⁴²⁷ - Sarkadi-Illyés Csaba, "Arccal nyugat felé: Paks II. túléli az orosz-ukrán háborút", *Economx.hu*, 26 June 2024, see <https://www.economx.hu/belfold/paks-ii-jakli-gergely-oroszorszag-szankcio-atomenergia.792002.html>, accessed 30 June 2024.

²⁴²⁸ - Paks II Ltd, "Paks II. Project Receives Exemption from EU Sanctions", 24 June 2024, see <https://www.paks2.hu/web/paks-2-en/w/paks-ii-project-receives-exemption-from-eu-sanctions>, accessed 1 August 2025.

²⁴²⁹ - Paks II Ltd, "Siemens Energy, the Supplier of Control Engineering Has Received the Green Light", 3 June 2025, see <https://www.paks2.hu/web/paks-2-en/w/siemens-energy-the-supplier-of-control-engineering-has-received-the-green-light>; accessed 30 July 2025.

²⁴³⁰ - Informed Sources, Personal Communication, 25 June 2025.

²⁴³¹ - IRENA, "Renewable Capacity Statistics 2024", International Renewable Energy Agency, March 2024, see https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2024/Mar/IRENA_RE_Capacity_Statistics_2024.pdf?rev=a587503ac9a2435c8d13e40081d2ec34, accessed 17 April 2024; and IRENA, "Renewable Energy Statistics 2025", July 2025, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jul/IRENA_DAT_RE_Statistics_2025.pdf, accessed 31 July 2025.

²⁴³² - EMBER, "Electricity Data Explorer—Share of Electricity Generation in Hungary", Updated 2025, see https://ember-energy.org/data/electricity-data-explorer/?metric=pct_share&entity=Hungary, accessed 30 July 2025.

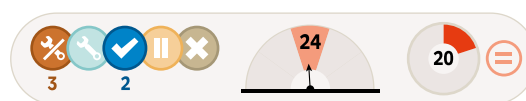
²⁴³³ - EMBER, "Global Electricity Review 2025", 8 April 2025, see <https://ember-energy.org/latest-insights/global-electricity-review-2025>, accessed 30 July 2025.

Hungary's updated National Energy and Climate Plan from October 2024²⁴³⁴ defines a 12-GW solar PV target for 2030, while wind power capacity shall triple to a modest 1 GW. However, those numbers should be read with care. Deployment of renewables in Hungary is mainly limited by the power grid. The planned capacity expansions for wind and solar reflect planned extensions of the Hungarian grid. Grid planning took place at a time when the Hungarian legislation was unfavorable for wind power, but it has been amended since.²⁴³⁵ The ratio between wind and solar capacities might change; according to sources, it likely will change. Whatever the contribution of individual sources, the total renewable electricity generation share is to reach 32 percent by 2030.

The plan assumes continued operation of all four reactors at Paks I, plus the commissioning of the planned Paks II reactors, amounting to a total 4.4 GW of nuclear capacity. Accordingly, it is expected that nuclear power will account for about 20 percent of power capacity by 2040 and 18 percent of the projected 2050 mix.²⁴³⁶ However, Hungary is also looking into deploying Small Modular Reactors (SMRs), whose inclusion to official energy policies would affect the projected power mix.²⁴³⁷

According to EMBER, natural gas contributed 18.7 percent to the Hungarian electricity production in 2024. The remainder consisted of a mix of coal (6.3 percent), bioenergy (4.6 percent), hydro (0.6 percent), and “other” fossil fuels (1.2 percent).²⁴³⁸

Romania



Romania has one nuclear power plant at Cernavodă, where two Canadian-designed CANDU heavy-water reactors are in operation, with a total capacity of 1.3 GW. In 2024, they provided 10.4 TWh net (10.9 TWh or 20.1 percent of gross generation), slightly down from 10.6 TWh net in the previous year and just shy of the historic maximum of 20.5 percent in 2020.²⁴³⁹

The Romanian electricity mix is dominated by hydro that supplied 26.6 percent of the country's power in 2024, followed by nuclear (20.4 percent²⁴⁴⁰), gas (18.6 percent), and coal (13 percent). Non-hydro renewable generation is dominated by wind that supplied 12.2 percent of the electricity in 2024. Solar PV supplied only 7.9 percent. This, however, is more than

²⁴³⁴ - Government of Hungary, “National Energy and Climate Plan—2024 Update”, filed with European Commission, 16 October 2024, see https://commission.europa.eu/publications/hungary-final-updated-necp-2021-2030-submitted-2024_en, accessed 30 July 2025.

²⁴³⁵ - Lilla Majoros, “Green Light for Wind Power Projects in Hungary”, Attorney, KCG Partners, *CEE Legal Matters*, 24 January 2024, see <https://ceelegalmatters.com/briefings/25471-green-light-for-wind-power-projects-in-hungary>, accessed 30 July 2025.

²⁴³⁶ - Government of Hungary, “National Energy and Climate Plan—2024 Update”, filed with European Commission, 16 October 2024, op. cit.

²⁴³⁷ - Rolls-Royce SMR, “Hungary Looks to Rolls-Royce SMR to Answer Its Future Energy Needs”, Press Release, 20 June 2025, see <https://www.rolls-royce-smr.com/press/hungary-looks-to-rolls-royce-smr-to-answer-its-future-energy-needs>; and U.S. Embassy in Hungary, “Polish and Hungarian Firms Sign Landmark Commercial Arrangement for U.S. Small Modular Reactor Deployments in Hungary”, 30 July 2025, see <https://hu.usembassy.gov/news-small-modular-reactor-deployments-in-hungary/>, accessed 18 August 2025.

²⁴³⁸ - EMBER, “Electricity Data Explorer—Share of Electricity Generation in Hungary”, Updated 2025, op. cit.

²⁴³⁹ - Energy Institute, “Statistical Review of World Energy—Consolidated Dataset”, 2025, op. cit.

²⁴⁴⁰ - Percentages reported by Energy Institute and EMBER slightly differ.

double of the 2023 share, which was only 3.9 percent.²⁴⁴¹ The higher share in 2024 came from an addition of 1.7 GW of solar capacity. For 2025, more than 2 GW of additional solar capacity is expected.²⁴⁴² This is complemented by a substantial rollout of battery storage, with the country aiming for 5 GW by the end of 2026.²⁴⁴³

Romania's final National Energy and Climate Plan envisions a total of 8.2 GW of solar PV, 7.3 GW of wind, and 6.9 GW of hydro capacities by 2030, bringing the share of renewables in the electricity mix to 75 percent. The country is also planning a coal phaseout by 2032. Moreover, the plan envisions the expansion of nuclear capacities, including 1.4 GW from the slightly uprated existing reactors, 462 MW from Small Modular Reactors (SMRs) scheduled to be commissioned in 2030, and another 1.4 GW from two new 700-MW units to start up at Cernavodă in 2031 and 2032, respectively. Total operating nuclear capacity would thus rise to 3.2 GW by 2035.²⁴⁴⁴

Plans for Romania to become the first European country to deploy SMRs have been ongoing since March 2019, when U.S. company NuScale and Romanian power utility Nuclearelectrica signed a first MoU to explore the potential of SMR deployment.²⁴⁴⁵ The company RoPower—co-owned by Nuclearelectrica and Nova Power & Gas—was created specifically to develop 462 MW of SMR capacity (six 77-MW NuScale units) at the site of a former coal power plant at the Doicești in 2022, and Front-End Engineering and Design (FEED) studies have been ongoing since.²⁴⁴⁶ Formal approval for transitioning to FEED Phase 2 was received in late 2023,²⁴⁴⁷ and Fluor was contracted in July 2024 to carry out related activities, which are due to last 15 months²⁴⁴⁸. Refer to [past editions of the WNISR](#) for more details.

Over the course of 2024, preparatory design and licensing work continued. Building on early U.S. support to the project, U.S. EXIM (Export-Import Bank of the United States) committed a US\$98 million loan in late 2024 for Phase 2 of the FEED studies; formal approval for negotiations with RoPower ensued,²⁴⁴⁹ but there is no indication as of mid-2025 that the loan agreement was finalized. While the project's completion was initially planned for 2027 or

²⁴⁴¹ - EMBER, “Yearly Electricity Data”, Updated 2025, see <https://ember-energy.org/data/yearly-electricity-data>, accessed 8 August 2025.

²⁴⁴² - Patrick Jowett, “Romania's 2024 Solar Additions Hit 1.7 GW”, *PV Magazine*, 31 January 2025, see <https://www.pv-magazine.com/2025/01/31/romanas-2024-solar-additions-hit-1-7-gw/>, accessed 20 June 2025.

²⁴⁴³ - Marija Maisch, “Romania Aims to Roll Out 5 GW of Energy Storage by End 2026”, *PV Magazine*, 22 July 2024, see <https://www.pv-magazine.com/2024/07/22/romania-aims-to-roll-out-5-gw-of-energy-storage-by-end-2026/>, accessed 20 June 2025.

²⁴⁴⁴ - Government of Romania, “Integrated National Energy and Climate Plan of Romania—2025-2030 Update”, October 2024, see https://commission.europa.eu/publications/romania-final-updated-necp-2021-2030-submitted-2024_en, accessed 28 April 2025.

²⁴⁴⁵ - Nuclearelectrica, “NuScale and Romanian Energy Company Sign Agreement to Explore SMRs for Romania”, Press Release, 19 March 2019, see <https://www.nuclearelectrica.ro/2019/03/19/nuscale-and-romanian-energy-company-sign-agreement-to-explore-smrs-for-romania/?lang=en>, accessed 4 August 2023.

²⁴⁴⁶ - Nuclearelectrica, “S.N. Nuclearelectrica S.A.—Annual Report 2024”, March 2025, see https://nuclearelectrica.ro/ir/wp-content/uploads/sites/3/2025/03/SNN_EN_Raport_CA_Anual_2024_all.pdf, accessed 20 June 2025.

²⁴⁴⁷ - Ibidem.

²⁴⁴⁸ - Nuclearelectrica, “Doicești SMR Project Continues: RoPower Nuclear and Fluor Corporation Sign FEED 2 Contract for Project Development”, Press Release, 24 July 2024, see <https://nuclearelectrica.ro/snn/en/2024/07/24/doicesti-smr-project-continues-ropower-nuclear-and-fluor-corporation-sign-feed-2-contract-for-project-development/>, accessed 6 August 2025.

²⁴⁴⁹ - Nuclearelectrica, “S.N. Nuclearelectrica S.A.—Annual Report 2024”, March 2025, op. cit.

2028,²⁴⁵⁰ and U.S. institutions had issued letters of interest for US\$4 billion in financial support early on,²⁴⁵¹ RoPower is yet to take a final investment decision.

In a presentation of their quarterly report in May 2025, NuScale’s president and CEO stated “discussions are underway to extend the project into the detailed design phase, a critical step that would enable the submission of a final investment decision application to the Romanian Government by late Q1 or early Q2 2026,”²⁴⁵² and Nuclearelectrica in its annual report still expects the first unit to be connected to the grid “by the end of this decade”, though it notes “the timeline will be fine-tuned after completion of the FEED studies...”²⁴⁵³

In a June 2025 announcement ahead of its subsequent general meeting, Nuclearelectrica presented its intent to bring all six modules to the grid by 2031.²⁴⁵⁴ While the planned site has been fully leased to RoPower,²⁴⁵⁵ the operation of the first SMR by 2030 seems highly unlikely given that

- ➔ the chosen 77-MW module was only recently licensed in the U.S. (May 2025)²⁴⁵⁶ and is yet to be in Romania (a “pre-license” was granted by regulatory agency CNCAN in October 2023, but a full license of the design or project permit has not been granted yet),²⁴⁵⁷
- ➔ NuScale has never built a single reactor anywhere (see [chapter on SMRs](#)), and
- ➔ the FEED study might be delayed.²⁴⁵⁸

The two operational Romanian PHWRs are the only CANDU reactors operating in Europe. Construction started between 1982 and 1987 on five units. Following years-long construction interruptions, Unit 1 was completed in 1996 and Unit 2 started up in 2007, respectively 14 and

²⁴⁵⁰ - Phil Chaffee, “Newbuild: Romania Talks of Building ‘Europe’s First SMR’”, *Nuclear Intelligence Weekly*, 5 November 2021; and Nuclearelectrica, “NuScale and Nuclearelectrica Reach Agreement at COP26 to Initiate the Deployment of the First Small Modular Reactor in Europe”, 4 November 2021, see <https://www.nuclearelectrica.ro/2021/11/04/nuscale-and-nuclearelectrica-reach-agreement-at-cop26-to-initiate-the-deployment-of-the-first-small-modular-reactor-in-europe/?lang=en>, accessed 4 August 2023.

²⁴⁵¹ - Nuclearelectrica S. A., “U.S. and Multinational Public-Private Partners Look to Finance up to \$275 Million for the Small Modular Reactor (SMR) Project in Romania US EXIM and FDC Issue Letters of Interest for \$4 Billion Financing”, Press Release, 20 May 2023, see <https://nuclearelectrica.ro/snn/en/2023/05/20/u-s-and-multinational-public-private-partners-look-to-finance-up-to-275-million-for-the-small-modular-reactor-smr-project-in-romania-us-exim-and-fdc-issue-letters-of-interest-for-4-billion-financ/>, accessed 6 August 2025.

²⁴⁵² - NuScale Power Corporation, “FQ1 2025 Earnings Call—Monday, May 12, 2025”, transcript by S&P Global Market Intelligence, 12 May 2025, see <https://40210592.fs1.hubspotusercontent-na1.net/hubfs/40210592/Website/Investors/2025/SMR-1Q25-Transcript.pdf>, accessed 6 August 2025.

²⁴⁵³ - Nuclearelectrica, “S.N. Nuclearelectrica S.A.—Annual Report 2024”, March 2025, op. cit.

²⁴⁵⁴ - Nuclearelectrica, “Note Regarding the Approval of the Ordinary General Meeting of Shareholders of the ‘Investment Strategy of Nuclearelectrica S.A. for the Period 2025 - 2030, with an Outlook to 2035’”, 26 June 2025, see https://nuclearelectrica.ro/ir/wp-content/uploads/sites/3/2025/07/ogms-2-Nota-AGA-Strategiei-de-Investitii-a-Societatii-Nationale-Nuclearelectrica-S.A_EN_rt.pdf; and Nuclearelectrica, “Capital Investment Strategy 2025-2030 with 2035 Outlook—Development, Innovation and Sustainability”, June 2025, see <https://nuclearelectrica.ro/ir/wp-content/uploads/sites/3/2025/07/Livrabil-3-Capital-investment-strategy-ENG-v2.pdf>; both accessed 6 August 2025.

²⁴⁵⁵ - Radu Dumitrescu, “Industrial Park in Southern Romania Fully Leased for NuScale Small Modular Reactor”, *Romania Insider*, 28 April 2025, see <https://www.romania-insider.com/industrial-park-southern-romania-nuscale-smr-april-2025>, accessed 20 June 2025.

²⁴⁵⁶ - U.S. NRC, “NRC Approves Standard Design for NuScale US460 Small Modular Reactor”, Press Release 25-033, United States Nuclear Regulatory Commission, 29 May 2025, see <https://www.nrc.gov/cdn/doc-collection-news/2025/25-033.pdf>, accessed 1 June 2025.

²⁴⁵⁷ - Nuclearelectrica, “Nuclearelectrica and NuScale Power Salute the Approval by CNCAN of the Licensing Basis Document (LBD) for the NuScale Small Modular Reactor Powerplant with a Gross Installed Power of 462 MWe”, Press Release, 29 September 2023, see <https://www.nuclearelectrica.ro/2023/09/29/nuclearelectrica-and-nuscale-power-salute-the-approval-by-cncan-of-the-licensing-basis-document-lbd-for-the-nuscale-small-modular-reactor-powerplant-with-a-gross-installed-power-of-462-mwe/?lang=en>, accessed 4 November 2023.

²⁴⁵⁸ - Nuclearelectrica, “S.N. Nuclearelectrica S.A.—Annual Report 2024”, March 2025, op. cit.

24 years after construction originally started. Both were partly funded by the Canadian Export Development Corporation, and Unit 2 was also partly funded by the Euratom Loan Facility. Construction of the remaining three units was interrupted and, so far, has not resumed.

As with other ageing CANDU reactors, major refurbishment will be needed to ensure continued operation past the initially envisaged 30-year lifetime. In 2017, the plan to upgrade Unit 1 to allow for a 30-year lifetime extension was initiated.²⁴⁵⁹ In December 2024, an Engineering, Procurement and Construction (EPC) contract was signed between Nuclearelectrica and an international consortium consisting of the Canadian company AtkinsRéalis, Italian Ansaldo Nucleare, the Canadian Commercial Corporation, and Korea Hydro & Nuclear Power (KHNP).²⁴⁶⁰ The contract, valued at €1.9 billion (US\$₂₀₂₄ 2 billion),²⁴⁶¹ was approved by the shareholders of Nuclearelectrica in January 2025,²⁴⁶² and by the Canadian government in March 2025.²⁴⁶³

Total investment required for the refurbishment program is estimated at €3.5 billion (US\$4 billion).²⁴⁶⁴ The timeline for the project envisions a temporary shutdown of the reactor from 2027 to 2029 to allow for refueling and refurbishment work to be carried out, after which it is to resume operations for 30 years. As of mid-2025, it appears the unit might now be expected to resume operation in 2030,²⁴⁶⁵ and according to the Annual Report 2024 of Nuclearelectrica, the “kick-off [remains scheduled for] Q4 2027.”²⁴⁶⁶

Additionally, various foreign companies have been involved in attempts to revive the construction of Units 3, 4, and 5 of the Cernavodă plant. For example, in November 2013, Nuclearelectrica and China General Nuclear (CGN) signed a letter of intent for the construction of Units 3 and 4.²⁴⁶⁷ Though it was followed by further preliminary arrangements, this project did not materialize. Refer to [earlier editions of the WNISR](#) for details.

²⁴⁵⁹ - Nuclearelectrica, “Resolution number 9 /28.09.2017 of the Extraordinary General Meeting of Shareholders of Societatea Nationala Nuclearelectrica S.A.”, 28 September 2017, see <https://www.nuclearelectrica.ro/wp-content/uploads/2017/08/Hotarare-AGEA-28.09.2017-ORA-12-ENG.pdf>, accessed 2 August 2023; and *NEI Magazine*, “Romania to Upgrade Cernavoda 1”, 5 October 2017, see <https://www.neimagazine.com/news/romania-to-upgrade-cernavoda-1-5940262/>, accessed 19 June 2024.

²⁴⁶⁰ - Nuclearelectrica, “S.N. Nuclearelectrica and the International Consortium AtkinsRéalis, Ansaldo Nucleare, Canadian Commercial Corporation and Korea Hydro & Nuclear Power Co Significantly Advance the Refurbishment of Cernavoda NPP Unit 1 Through the Engineering, Procurement and Construction (EPC) Contract”, Press Release, 19 December 2024, see <https://nuclearelectrica.ro/snn/en/2024/12/19/s-n-nuclearelectrica-and-the-international-consortium-atkinsrealis-ansaldo-nucleare-Acanadian-commercial-corporation-and-korea-hydro-nuclear-power-co-significantly-advance-the-refurbishment-of-cer/>, accessed 6 August 2025.

²⁴⁶¹ - Ibidem.

²⁴⁶² - Nuclearelectrica, “Note—No. E-DCF-NOTA AGA-APROB-03481-21-07-25”, July 2025, see <https://nuclearelectrica.ro/ir/wp-content/uploads/sites/3/2025/07/egms-2-EGMS-Approval-for-a-Loan-Facility-of-540-mil.-EUR-for-the-Refurbishment-of-Unit-1.pdf>, accessed 6 August 2025.

²⁴⁶³ - CCC, “CCC Achieves Key Milestone in \$2.85 Billion Contract to Extend Life of CANDU® Reactor in Romania”, Canadian Commercial Corporation, 4 March 2025, see <https://www.ccc.ca/en/announcements/ccc-achieves-key-milestone-in-2-85-billion-contract-to-extend-life-of-candu-reactor-in-romania/>, accessed 20 June 2025.

²⁴⁶⁴ - Nuclearelectrica, “Note—No. E-DCF-NOTA AGA-APROB-03481-21-07-25”, July 2025, op. cit.; and Nuclearelectrica, “Capital Investment Strategy 2025-2030 with 2035 Outlook—Development, Innovation and Sustainability”, June 2025, op. cit.

²⁴⁶⁵ - Nuclearelectrica, “Capital Investment Strategy 2025-2030 with 2035 Outlook—Development, Innovation and Sustainability”, June 2025, op. cit., p. 21.

²⁴⁶⁶ - Nuclearelectrica, “S.N. Nuclearelectrica S.A.—Annual Report 2024”, March 2025, op. cit.

²⁴⁶⁷ - CGN, “CGN Was Selected as the Final Investor in Cernavoda 3&4”, China General Nuclear Power Group, 15 October 2014, see http://en.cgnp.com.cn/encgnp/c100866/2014-10/15/content_2457db7298314476ac518ab8bc15626c.shtml, accessed 6 August 2025.

Most recently, there has been some development regarding the resumption of construction work at Units 3 and 4, whose respective constructions are supposedly 52 and 30 percent complete.²⁴⁶⁸ In October 2024, the Romanian Energy Minister Sebastian Burduja said that the government was “putting this strategic project onto a path of no return, and in 2031-2032 [Romania] will have two new nuclear reactors at Cernavodă.”²⁴⁶⁹ The Limited Notice to Proceed (LNTP), the first phase of an EPC Management (EPCM) contract valued at €3.2 billion (US\$₂₀₂₄ 3.4 billion), was signed in November by Nuclearelectrica’s subsidiary EnergoNuclear with a joint venture consisting of Fluor, AtkinsRéalis, Ansaldo Nucleare, and Sargent & Lundy. This first part of the EPCM contract covers preliminary work for the next 24–30 months. However, the second phase of construction implementation (80–84 months), i.e. the Final Notice to Proceed (FNTP), remains “subject to commercial terms being further refined and agreed and the Final Investment Decision being taken in line with the Support Agreement between the Romanian State and SNN.”²⁴⁷⁰ Adding up the allocated time for the two phases of the contract, and assuming the fastest possible completion of the whole project, including construction, in 104 months (8.7 years), the target of operating both units by 2032 is mathematically slightly out of scope.

The project is to be financed by a complete loan guarantee by the Romanian state and has received support totaling €6.1 billion (US\$7.01 billion) from the U.S. EXIM Bank, Canada, and Italy. According to Nuclearelectrica, in July 2024 the European Commission’s Directorate General for Energy provided a “positive opinion” after assessing “the technical and nuclear safety aspects of the project”.²⁴⁷¹ There is no official estimate of the total cost of the project, but over the years, various statements drew an estimated range of “at least €6.5 billion [US\$₂₀₂₃ 7 billion]”²⁴⁷² to US\$8 billion.²⁴⁷³

²⁴⁶⁸ - EnergoNuclear, “Cernavoda 3 & 4 – Prietenos cu natura”, 2024, see <https://www.energonuclear.ro/tehnologii/cernavoda-3-4-prietenos-cu-natura>; and Nuclearelectrica, “Cernavoda NPP Units 3 and 4 Project”, 2014, see https://www.nuclearelectrica.ro/wp-content/uploads/2014/09/a_Units-3-and-4-Project-presentation.pdf, both accessed 6 August 2025.

²⁴⁶⁹ - Ministry of Energy, “Ministrul Energiei, Sebastian Burduja: ‘Este cu siguranță cea mai mare realizare a mandatului meu ca ministru al energiei: visul unităților 3 și 4 de la Cernavodă devine realitate. După decenii de așteptare, punem acest proiect strategic pe un drum fără întoarcere, iar în 2031-2032 vom avea două noi reactoare nucleare la Cernavodă’”, Press Release, Government of Romania, 28 October 2024, see <https://energie.gov.ro/pas-istoric-pentru-unitatile-3-si-4-de-la-cernavoda/>, accessed 6 August 2024; and Igor Todorović, “Nuclearelectrica to Sign Deal on New Cernavodă Reactors, Start Preliminary Works”, *Balkan Green Energy News*, 29 October 2024, see <https://balkangreenenergynews.com/nuclearelectrica-to-sign-deal-on-new-cernavoda-reactors-start-preliminary-works/>, accessed 20 June 2025.

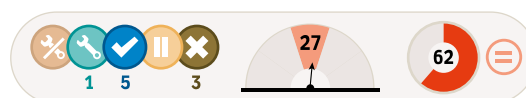
²⁴⁷⁰ - Nuclearelectrica, “EnergoNuclear, a Nuclearelectrica Fully Owned Subsidiary, and FCSA Joint Venture Comprised of Fluor B.V., Fluor Energy Transition Inc. Wilmington Bucharest Branch, AtkinsRéalis, Ansaldo Nucleare S.p.A., S&L Engineers, Ltd. and Sargent & Lundy Energie S.R.L sign the Engineering, Procurement and Construction Management (EPCM) LNTP Phase Contract for the Advancement of Cernavoda NPP Units 3 and 4 at COP 29 in Baku”, Press Release, 15 November 2024, see <https://nuclearelectrica.ro/snn/en/2024/11/15/energonuclear-a-nuclearelectrica-fully-owned-subsidiary-and-fcsa-joint-venture-comprised-of-fluor-b-v-fluor-energy-transition-inc-wilmington-bucharest-branch-atkinsrealis-ansaldo-nucleare-s-p-a/>, accessed 6 August 2025.

²⁴⁷¹ - Nuclearelectrica, “The Adoption of the Positive Opinion of the European Commission on the Project of Units 3 and 4 at CNE Cernavoda”, Press Release, 2 July 2024, see <https://nuclearelectrica.ro/snn/en/2024/07/02/the-adoption-of-the-positive-opinion-of-the-european-commission-on-the-project-of-units-3-and-4-at-cne-cernavoda/>, accessed 6 August 2025.

²⁴⁷² - Luiza Ilie, “Romanian Planned Two Nuclear Reactors Estimated to Cost Around \$7 Bln”, *Reuters*, 19 July 2023, see <https://www.reuters.com/article/business/energy/romanian-planned-two-nuclear-reactors-estimated-to-cost-around-7-bln-idUSL8N3953FN/>, accessed 26 August 2024.

²⁴⁷³ - U.S. Embassy in Romania, “Ambassador Adrian Zuckerman at the DOE Intergovernmental Agreement Signing Event”, Press Release, 9 October 2020, see <https://ro.usembassy.gov/ambassador-adrian-zuckerman-at-the-doe-intergovernmental-agreement-signing-event/>, accessed 3 August 2023.

Slovakia



Slovakia, like neighboring countries such as the Czech Republic and Hungary, is heavily reliant on nuclear energy for electricity production. Over the past 20 years, nuclear energy has continuously contributed over 50 percent of Slovakia's electricity. This share rose to a historical maximum of 61.3 percent in 2023 (61.5 percent in 2024) following the commissioning of the Mochovce-3 reactor, and nuclear generation remained stable in 2024.²⁴⁷⁴

Slovenské Elektrárne (SE), which until May 2025 was jointly owned by the Czech energy group Energetický a Průmyslový Holding (EPH), the Italian utility ENEL (Ente Nazionale per l'Energia Elettrica), and the Slovakian government, is now co-owned by EPH (66 percent) and the Slovak state (34 percent).²⁴⁷⁵ The company operates two nuclear power plants: Jaslovské Bohunice and Mochovce. Jaslovské Bohunice houses two operational VVER-440/V-213 reactors, while the Mochovce plant, as of mid-2025, has three similar reactors connected to the grid. Together, these facilities provide a total capacity of 2.3 GW.²⁴⁷⁶ A fourth unit at Mochovce has been completed in recent years and is currently undergoing pre-commissioning testing.

The commissioning of Mochovce-3 led to a 15 percent increase in Slovakia's nuclear electricity production as it rose from 15.9 TWh (15 TWh net) in 2022 to 18.3 TWh (17.4 TWh net) in 2023. In 2024, nuclear provided a stable 18.2 TWh (17.3 TWh net) representing 61.5 percent of the country's total electricity generation.²⁴⁷⁷

The country has three closed reactors at the Bohunice site. The first is the A-1 reactor, a small 93-MW unit that began operation in 1972 but was closed in 1977 following a series of accidents. The other two are VVER-440/V-230 reactors, which were closed in 2006 and 2008, respectively, as part of Slovakia's agreement to join the European Union in 2004²⁴⁷⁸ (for more information see [Slovakia in Decommissioning Status Report](#)).

The operating Units 3 and 4 of the Bohunice plant (commonly known as Bohunice V2), which have been in commercial operation since 1985, underwent an extensive modernization program between 2000 and 2010. This program included capacity uprates, increasing their output from 440 MWe to 505 MWe (gross). Similarly, the capacities of Units 1 and 2 at the Mochovce

²⁴⁷⁴ - Energy Institute, "Statistical Review of World Energy 2025—Consolidated Dataset", June 2025, see https://www.energyinst.org/_data/assets/excel_doc/0008/1656215/EI-Stats-Review-ALL-data.xlsx, accessed 27 June 2025 and Energy Institute, "Statistical Review of World Energy 2025", 74th Edition, June 2025.

²⁴⁷⁵ - EPH, "EPH Completes the Acquisition of Enel's Stake in Slovenské Elektrárne", Energetický a Průmyslový Holding, A.s., 23 May 2025, see <https://www.ephholding.cz/en/press-releases/eph-completes-the-acquisition-of-enels-stake-in-slovenske-elektrarne/>; and Enel, "Closing of the Sale to EPH of the Residual Interest in the Stake Held by Enel Produzione in Slovenské Elektrárne in Execution of the Early Call Option Foreseen by the 2020 Contract. Over 1.1 Billion Euros of Loans Granted by Enel Group Companies Have Already Been Collected with a Positive Effect on Debt According to the Rating Agencies' Frameworks", 23 May 2025, see <https://corporate.enel.it/en/media/explore-press-releases/press/2025/05/closing-of-the-sale-to-eph-of-the-residual-interest-in-the-stake-held-by-enel-produzione-in-slovenske-elektrarne-in-execution-of-the-early-call-option-foreseen-by-the-2020-contract-over-11-billion-euros-of-loans-granted-by-enel-group-companies-have-already-been-collected-with-a-positive-effect-on-debt-according-to-the-rating-agencies-frameworks>; both accessed 18 July 2025.

²⁴⁷⁶ - IAEA-PRIS, "Country Statistics—Slovak Republic", 17 July 2025, see <https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=SK>, accessed 18 July 2025.

²⁴⁷⁷ - Energy Institute, "Statistical Review of World Energy 2025", June 2025, op. cit.

²⁴⁷⁸ - *Official Journal of the European Union*, "Protocol No 9 on Unit 1 and Unit 2 of the Bohunice V1 Nuclear Power Plant in Slovakia" of the "Act Concerning the Conditions of Accession of the Czech Republic, the Republic of Estonia, the Republic of Cyprus, the Republic of Latvia, the Republic of Lithuania, the Republic of Hungary, the Republic of Malta, the Republic of Poland, the Republic of Slovenia and the Slovak Republic and the Adjustments to the Treaties on which the European Union is founded", L 236/33, 23 September 2003, see https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AJOL_2003_236_R_0033_01&qid=1719411537059, accessed 26 June 2024.

plant, which began operation in 1998 and 2000, respectively, were updated from 440 MWe to 470 MWe and eventually 500 MWe (gross).²⁴⁷⁹ SE plans to operate Bohunice Units 3 and 4 until 2044 and 2045, respectively, and Mochovce Units 1 and 2 until “at least” 2058 and 2060, respectively.²⁴⁸⁰

The Mochovce Saga

In April 2006, the Italian utility ENEL acquired a 66-percent stake in SE and committed to investing €2 billion (US\$₂₀₀₆ 2.5 billion) between 2006 and 2013.²⁴⁸¹ This included funding the completion of Mochovce-3 and -4, two Soviet-era VVER-440/V-213 reactors, whose construction began in January 1985 but was halted in 1993.²⁴⁸²

After a long process muddled by financial issues causing disputes between the Slovak government and ENEL, Mochovce-3 finally achieved first criticality on 22 October 2022, was connected to the grid on 31 January 2023, and reached full capacity on 22 September 2023 (see [section on Slovakia](#) in [WNISR2023](#) for a detailed account of the construction and financing history).²⁴⁸³ Following a 114-hour test run in October, SE announced on 17 October 2023 that the reactor’s commissioning was complete.²⁴⁸⁴

Unit 3’s grid connection, planned for 2012 when construction resumed, was delayed by another 11 years, while Unit 4, then set for 2013, faces at least a 12-year delay since construction resumed, with uncertainty around the latest 2025 target. Estimated project costs rose from €₂₀₀₇ 2.8 billion (US\$₂₀₀₇ 3.8 billion) at the 2007 relaunch to €₂₀₂₀ 6.2 billion (~US\$₂₀₂₀ 7 billion) by December 2020.²⁴⁸⁵ In February 2025, SE closed a €3.6 billion (US\$4.1 billion) Term and Revolving Facilities Agreement with a bank consortium, which SE termed “the largest corporate debt refinancing in Slovakia to date” that would “primarily be used to refinance existing senior and subordinated indebtedness and fund general corporate purposes, including working capital.” SE also stated that “completing the nuclear power plant Mochovce 4 is the Company’s primary short-term objective.”²⁴⁸⁶

²⁴⁷⁹ - Ludovit Kupca, “Long Term Operation of Bohunice NPP”, presented at the 4th International Conference on Nuclear Power Plant Life Management, 23 October 2017, see <https://www.iaea.org/publications/13640/nuclear-power-plant-life-management?supplementary=91871>, accessed 12 September 2023, and IAEA-PRIS, “Nuclear Power Reactors in the World”, various editions.

²⁴⁸⁰ - GRS, “Nuclear energy in Slovakia”, Gesellschaft für Anlagen- und Reaktorsicherheit, 2 March 2023, see <https://www.grs.de/en/nuclear-energy-slovakia-02032023>, accessed 12 September 2023, and IAEA, “Executive Summary”, see https://www.iaea.org/sites/default/files/documents/review-missions/56_mochovce_salto_em_executive_summary.pdf, accessed 29 July 2025.

²⁴⁸¹ - Enel, “Enel: Acquisition of 66% of Slovenske Elektrarne Completed”, Press Release, 28 April 2006, see <https://www.enel.com/media/explore/search-press-releases/press/2006/04/enel-acquisition-of-66-of-slovenske-elektrarne-completed>, accessed 5 August 2023.

²⁴⁸² - IAEA-PRIS, “Reactor Details–Mochovce-3”, as of 15 April 2019. This date was later changed, and as of mid-2025 construction suspension is indicated as 27 January 1990; see IAEA-PRIS, “Reactor Details–Mochovce-3”, Updated 28 July 2025, see <https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=544>, accessed 29 July 2025.

²⁴⁸³ - Kamen Kraev, “Mochovce-3 Generates First Power After Successful Grid Connection”, *NucNet*, 1 February 2023, see <https://www.nucnet.org/news/mochovce-3-generates-first-power-after-successful-grid-connection-2-3-2023>, accessed 18 August 2023.

²⁴⁸⁴ - SE, “Energetické spúšťanie 3. bloku Mochoviec je dokončené”, Press Release, Slovenské Elektrárne, 17 October 2023, see <https://www.seas.sk/tlacove-spravy/mochovce-3-spustanie-preukazny-chod/>, accessed 31 May 2024.

²⁴⁸⁵ - WNN, “Mochovce New-Build Project Receives Loan Boost”, 24 December 2020, see <https://www.world-nuclear-news.org/Articles/Mochovce-new-build-project-receives-loan-boost>, accessed 10 April 2021.

²⁴⁸⁶ - SE, “Slovenské elektrárne Secures €3.6 bn Financing, Highlighting Confidence in Nuclear Industry”, Press Release, 5 February 2025, see <https://www.seas.sk/en/press-releases/refinancing/>, accessed 29 July 2025.

In October 2024, SE confirmed the successful testing of active and passive emergency systems at Mochovce-4.²⁴⁸⁷ Cold hydrostatic testing began in December 2024,²⁴⁸⁸ followed by hot hydrostatic testing in March 2025²⁴⁸⁹. These tests verify the safety, pressure resistance, and leak tightness of the primary circuit and related components. Active testing with nuclear fuel is planned next, pending approval from the Slovak nuclear regulatory authority.

SE is planning a district heating system using waste heat from the Mochovce plant to supply the town of Tlmače.²⁴⁹⁰ The status of the licensing procedure for the project is unclear.

A significant issue in Slovakia, just as on the global level, is the lack of qualified staff (welders, engineers, operators etc.) in the sector, going as far as creating the need to rehire senior workers who have already retired.²⁴⁹¹ This issue becomes particularly acute, as observed in Slovakia, when combined with challenges in educating and training new personnel in a timely way as well as difficulties in transferring knowledge amongst an imbalanced mix of young and experienced operators. According to knowledgeable sources, the resulting shortage of experienced professionals, coupled with the only option to hire inexperienced staff, has contributed to a rise in the number of reportable events in recent years.

New Reactor for Bohunice

The Jaslovské Bohunice site has long been considered for new nuclear projects. In 2009, the Nuclear Energy Company of Slovakia (Jadrová energetická spoločnosť Slovenska or JESS), a joint venture by Jadrová a vyrad'ovacia spoločnosť (JAVYS, 51 percent) and ČEZ, was established for the so-called NJZ project, which envisioned the construction of a Generation III PWR with a capacity of up to 1700 MW (net).²⁴⁹² In February 2023, JESS requested a siting permit for a new reactor²⁴⁹³ and received a permit in May 2024 for a new generation PWR with an electrical output of up to 1200 MW (gross).²⁴⁹⁴

²⁴⁸⁷ - SE, "Mochovce 4: bezpečnostné systémy prešli funkčnými skúškami", Press Release, 22 October 2024, see <https://www.seas.sk/novinky/mochovce-4-hydroakumulator/>, accessed 23 October 2024.

²⁴⁸⁸ - SE, "Mochovce: Cold Hydro Test Started on Unit 4", Press Release, 20 December 2024, see <https://www.seas.sk/en/press-releases/mochovce-cold-hydro-test-started-on-unit-4/>, accessed 29 July 2025.

²⁴⁸⁹ - SE, "Slovenské Elektrárne Started Hot Hydro Test at Mochovce 4", Slovenské Elektrárne, 21 March 2025, see <https://www.seas.sk/en/press-releases/mochovce-4-hot-hydro-test/>, accessed 29 July 2025.

²⁴⁹⁰ - SE, "Slovenské elektrárne plánujú z Mochoviec vykurovať Tlmače", 16 January 2025, see <https://www.seas.sk/novinky/slovenske-elektrarne-planuju-z-mochoviec-vykurovat-tlmace/>, accessed 29 July 2025.

²⁴⁹¹ - Lucia Filčíková, "Jadrový priemysel volá dôchodcov naspäť do práce. Potrebuje ich do nových projektov", *Trend*, 20 May 2024, see <https://www.trend.sk/spravy/jadrov-y-priemysel-vola-dochodcov-naspat-prace-potrebuje-ich-novych-projektov>, accessed 22 July 2025; and Viktor Sedlak, "Európa sa vracia k jadru, no chýbajú jej experti. Slovensko nie je výnimkou", *Trend*, 30 May 2025, see <https://www.trend.sk/ekonomika/europa-vracia-jadru-chybaju-jej-experti-slovensko-nie-je-vynimkou>, accessed 23 July 2025.

²⁴⁹² - Ministry of the Environment, "Nový jadrový zdroj v lokalite jasločské Bohunice—Záverčné Stanovisko", 1404/2016 – 3.4/hp, Government of the Slovak Republic, 15 April 2016, see https://www.jess.sk/media/1471-2023_zs-njz-jaslovske-bohunice-zverejnene-15-04-2016-pdf.pdf; and JESS, "The Ministry of Environment of the Slovak Republic Issued a Positive Final Opinion on the Project of a New Nuclear Source", Press Release, Jadrová energetická spoločnosť Slovenska, 15 April 2016, see <https://www.jess.sk/en/the-ministry-of-environment-of-the-slovak-republic-issued-a-positive-final-opinion-on-the-project-of-a-new-nuclear-source>; both accessed 22 August 2023.

²⁴⁹³ - JESS, "Project New Nuclear Source", 2024, see <https://www.jess.sk/en/project-new-nuclear-source>, accessed 26 June 2024.

²⁴⁹⁴ - JESS, "JESS získala 30.5.2024 právoplatné povolenie na umiestnenie jadrového zariadenia v lokalite Jaslovské Bohunice", 12 June 2024, see <https://www.jess.sk/jess-ziskala-30-5-2024-pravoplatne-povolenie-na-umiestnenie-jadroveho-zariadenia-v-lokalite-jaslovske-bohunice>, accessed 21 July 2025.

In July 2023, JAVYS signed an MoU with Westinghouse to explore deploying both its AP-1000 and AP-300 SMR in Slovakia.²⁴⁹⁵ In May 2024, Prime Minister Fico, who took office for a fourth (non-consecutive) term in October 2023, announced plans for a 1200-MW state-owned nuclear power plant at the Bohunice site.²⁴⁹⁶

The Minister of Economy D. Saková stated during a press conference in November 2024 that “initial construction work should take place in April 2032, the first fuel loading in early 2038, and commissioning in 2038 as well.”²⁴⁹⁷ A statement put out by the ministry at the time mapped the same milestones and indicated that a tender was expected to be launched in 2027.²⁴⁹⁸ Reportedly, the project was then expected to cost €10 billion (US\$₂₀₂₄ 10.9 billion);²⁴⁹⁹ as of June 2025, a significantly inflated figure of €13–15 billion (US\$14.8–17 billion) was circulating in media reports.²⁵⁰⁰ In its annual report released in March 2025, JAVYS expects commissioning by 2040.

In May 2025, Prime Minister Fico negotiated with representatives of Westinghouse in Bratislava to expand cooperation in the nuclear field including through the potential construction of an AP-1000,²⁵⁰¹ and in June 2025, following a meeting with Economy Minister D. Saková, he stated that an intergovernmental agreement with the U.S. on the construction of a new nuclear power plant was being prepared but that “we are waiting for the final position of the USA.”²⁵⁰²

The situation regarding potential suppliers and the tender procedure for the planned 1200-MW nuclear power plant at Bohunice remains unclear. On the one hand, only Rosatom and EDF offer reactor designs with the announced 1200 MW electrical output, on the other hand Westinghouse officially stated that it would be interested in deploying an AP-1000 reactor in Slovakia.²⁵⁰³ In fact, in spite of the model name, the reference unit power of the six so far completed AP-1000s in the U.S. and China varies between 1117 MW and 1170 MW.

²⁴⁹⁵ - Westinghouse, “Interest in Westinghouse AP300™ Small Modular Reactor, AP1000® Technology Surging in Europe as Slovakia Begins Deployment Discussions”, Press Release, 17 July 2023, see <https://info.westinghousenuclear.com/news/westinghouse-ap300-smr-ap1000-interest-in-europe-slovakia-deployment-discussions>, accessed 22 August 2023.

²⁴⁹⁶ - Ministry of Economy, “A Working Meeting Held Between R. Fico and D. Saková: We Plan to Build a New Nuclear Reactor Under the State Ownership”, Government of Slovakia, 13 May 2024, see <https://www.economy.gov.sk/en/press/a-working-meeting-held-between-r-fico-and-d-sakova-we-plan-to-build-a-new-nuclear-reactor-under-the-state-ownership?csrt=6462939600134771250>, accessed 29 July 2025.

²⁴⁹⁷ - TASR, “Saková: Verejné obstarávanie na nový jadrový blok by malo byť v 2025”, *TERAZ.sk*, 20 November 2024, see <https://www.teraz.sk/ekonomika/sakova-verejne-obstaravanie-na-novy/837700-clanok.html>, accessed 25 July 2025.

²⁴⁹⁸ - Ministry of Economy, “Vláda SR schválila kroky potrebné na výstavbu nového veľkého jadrového zdroja na Slovensku”, Press Release, Government of Slovakia, 19 November 2024, see <https://www.economy.gov.sk/top/vlada-sr-schvalila-kroky-potrebne-na-vystavbu-noveho-velkeho-jadroveho-zdroja-na-slovensku>, accessed 29 July 2025.

²⁴⁹⁹ - Albin Sybera, “Slovak Government Wants to Launch New Nuclear Tender in 2027”, *bne IntelliNews*, 21 November 2024, see <https://www.intellinews.com/slovak-government-wants-to-launch-new-nuclear-tender-in-2027-354395/>, accessed 22 July 2025.

²⁵⁰⁰ - *The Slovak Spectator*, “Americans May Build Slovakia's Next Nuclear Power Plant”, 18 June 2025, see <https://spectator.sme.sk/business/c/the-next-nuclear-power-plant-in-slovakia-may-be-built-by-americans>, accessed 19 June 2025.

²⁵⁰¹ - Westinghouse, “Westinghouse Strengthens Partnership in Slovakia”, 9 April 2025, see <https://info.westinghousenuclear.com/blog/westinghouse-strengthens-partnership-in-slovakia>; and Westinghouse, “Spoločnosť Westinghouse rokovala s predstaviteľmi slovenskej vlády o rozšírení spolupráce v jadrovej oblasti”, Press Release, 14 May 2025, see <https://info.westinghousenuclear.com/slovakia/news-insights/spolocnost-westinghouse-rokovala-s-predstavitelmi-slovenskej-vlady>, both accessed 21 July 2025.

²⁵⁰² - *The Slovak Spectator*, “The Next Nuclear Power Plant in Slovakia May Be Built by Americans”, 18 June 2025, see <https://spectator.sme.sk/business/c/the-next-nuclear-power-plant-in-slovakia-may-be-built-by-americans>, accessed 18 June 2025.

²⁵⁰³ - Westinghouse, “Spoločnosť Westinghouse rokovala s predstaviteľmi slovenskej vlády o rozšírení spolupráce v jadrovej oblasti” 14 May 2025, op. cit.

The ambiguity of the process extends to the tender, with conflicting reports about its timeline and format. The opposition parties SaS (Sloboda a Solidarita) and Progressive Slovakia (PS) have criticized the government's decision to move forward with the planned 1200-MW nuclear power plant at Bohunice without a public tender. SaS expressed concerns over the lack of transparency, alleging that Westinghouse was selected as the supplier without proper scrutiny or competition. Karol Galek of SaS suggested that the process was being conducted behind closed doors, raising fears of backroom deals. PS also criticized the government for prioritizing nuclear energy over the development of renewable energy sources.²⁵⁰⁴

SMR Dreams

In September 2023, SE received a US\$2 million grant from the U.S. Government's "Project Phoenix"—a subprogram of the Foundational Infrastructure for the Responsible Use of Small Modular Reactor Technology (FIRST) program—alongside Poland and the Czech Republic, to explore converting coal-fired power plants to zero-carbon Small Modular Reactor (SMR) nuclear energy.²⁵⁰⁵ A feasibility study launched in 2024 and expected to conclude in 2025, is to evaluate five potential sites, including Nováky, Vojany, Bohunice, and Mochovce, based on technical and infrastructural criteria. Ultimately, the process excluded Nováky from consideration. As of early 2024, SE planned to complete SMR design and licensing by 2029. The timeline is ambiguous as it states for 2035 "implementation project, construction, commissioning" without clarifying what is to start and what is to be completed by then.²⁵⁰⁶

Agreements signed in summer 2023 between JAVYS, Westinghouse, and EDF also include collaboration on SMR designs like the AP-300 and Nuward.²⁵⁰⁷

In October 2024, Slovakia received a further US\$5 million grant under the U.S.-led "Nuclear Expediting the Energy Transition (NEXT)" project—also under the FIRST program—which supports the implementation of SMR programs. SE CEO Branislav Strýček highlighted that SMRs are intended to complement, not replace, existing nuclear sources. The grant will fund activities such as consulting on technical and regulatory requirements, collaboration with universities and nuclear facilities, and "preparation of strategies for the introduction of SMRs."²⁵⁰⁸

²⁵⁰⁴ - *The Slovak Spectator*, "Americans May Build Slovakia's Next Nuclear Power Plant", 18 June 2025, op. cit.

²⁵⁰⁵ - First Program, "Project Phoenix – Out of the Ashes – Conversion of Coal to Clean SMR Energy Supply - Foundational Infrastructure for Responsible use of SMR Technology (FIRST) Program", Foundational Infrastructure for Responsible Use of SMR Technology, Undated, see <https://www.smr-first-program.net/project-phoenix/>, accessed 30 June 2024; and Ministry of Economy, "Slovensko so svojimi susedmi dostane z projektu Phoenix 2 milióny USD na štúdiu uskutočniteľnosti malých modulárnych reaktorov", Government of Slovakia, 10 November 2023, see <https://www.economy.gov.sk/top/slovensko-so-svojimi-susedmi-dostane-z-projektu-phoenix-2-miliony-usd-na-studiu-uskutocnitelnosti-malych-modularnych-reaktoroch>; accessed 31 May 2024.

²⁵⁰⁶ - Ibidem; and SE, "It's Already Getting Underway: Project Phoenix for SMRs in Slovakia", Press Release, Slovenské Elektrárne, 14 February 2024, see <https://www.seas.sk/en/news/project-phoenix-start-smr-slovakia/>, accessed 24 June 2024; and SE, "Annual Report 2024", 2024, see <https://www.seas.sk/wp-content/uploads/a5/b5/Annual-report-2024.pdf>, accessed 28 July 2025.

²⁵⁰⁷ - Westinghouse, "Interest in Westinghouse AP300™ Small Modular Reactor, AP1000® Technology Surging in Europe as Slovakia Begins Deployment Discussions", Press Release, 17 July 2023, op. cit.; and JAVYS, "JAVYS and EDF Signed a Framework Cooperation Agreement", Press Release, 25 August 2023, see <https://www.javys.sk/mobile/en/information-service/news-press-release/press-releases/2073-javys-and-edf-signed-a-framework-cooperation-agreement>, accessed 26 June 2024.

²⁵⁰⁸ - Ministry of Economy, "Slovensko získalo ďalší grant na podporu a zavádzanie jadrových programov a inovácií, vrátane malých modulárnych reaktorov", Press Release, Government of Slovakia, 9 October 2024, see <https://www.economy.gov.sk/top/slovensko-ziskalo-dalsi-grant-na-podporu-a-zavadzanie-jadrovych-programov-a-inovacii-vratane-malych-modularnych-reaktorov?csrt=1298749905469457560>, accessed 21 July 2025.

In August 2024, Slovak nuclear engineering firm VUJE partnered with U.K.-based Newcleo to advance modular reactor technologies and next-generation fuel system solutions in Slovakia. The collaboration focuses on Newcleo's lead-cooled fast reactor (LFR) design and mixed-oxide (MOX) fuel.²⁵⁰⁹ In December 2023, an MoU between Newcleo, JAVYS, and the Slovak Ministry of Economy had already been signed, setting up the first stages of a collaboration on the deployment of so-called Advanced Modular Reactors in Slovakia.²⁵¹⁰ By January 2025, the partnership evolved into a joint venture between Newcleo and JAVYS to develop and construct up to four LFR-AS-200 reactors at the Bohunice V1 site, with the possible assistance of VUJE during the initial feasibility study and "subsequent activities" as provided under a framework agreement signed the same day.²⁵¹¹ In June 2025, at a conference in Bohunice, JAVYS (51 percent) and Newcleo (49 percent) signed the Founder's Agreement to establish the Centre for the Development of Spent Nuclear Fuel Utilisation (CVP) and VUJE and Newcleo signed a Memorandum of Understanding "regarding cooperation in the design and development of scalable data centres in connection with...AMR projects."²⁵¹² No implementation timeline was communicated.

Russian Ties and Other Contradictions

Slovakia, like many other countries in the region, remains heavily dependent on Russian energy resources, including gas, oil, and nuclear fuel. As of April 2023, 60 percent of natural gas, 95 percent of oil, and all nuclear fuel for its VVER-440 reactors were sourced from Russia.²⁵¹³ While raw oil imports declined to about 75 percent in 2024,²⁵¹⁴ indicating gradual diversification, Slovakia continues to import Russian gas via the TurkStream pipeline and re-exports a significant portion to Austria. Efforts to reduce dependency include a deal with Azerbaijan to transport gas via Ukrainian pipelines.²⁵¹⁵ However, long-term contracts, such as the one with Gazprom valid until 2034, and favorable Russian oil prices have reinforced this reliance, which significantly alleviates the burden on Slovakia's budget.²⁵¹⁶ This dependency

²⁵⁰⁹ - Newcleo, "newcleo and VUJE Sign Agreement on Advanced Nuclear Technology Development", Press Release, 7 August 2024, see <https://www.newcleo.com/news-insights/newcleo-and-vuje-sign-agreement-on-advanced-nuclear>, accessed 29 July 2025.

²⁵¹⁰ - Newcleo, JAVYS and Ministry of Economy of Slovakia, "Memorandum of Understand ("MoU")", December 2023, see <https://www.mhsr.sk/uploads/files/gdwP7hIY.pdf>, accessed 30 July 2025.

²⁵¹¹ - Newcleo, "Newcleo Signs Landmark Agreements with Slovakian Companies for up to Four GEN IV Reactors in Bohunice", Press Release, 15 January 2025, see <https://www.newcleo.com/news-insights/newcleo-signs-landmark-agreements-with-slovakian-companies-for-up-to-four>, accessed 5 January 2025.

²⁵¹² - JAVYS, "Slovakia Strengthens Its Ambitions in Nuclear Energy: A Joint Venture for the Development of Advanced Reactors and Spent Fuel Reprocessing Is Established", Press Release, 23 June 2025, see <https://www.javys.sk/en/information-service/news-press-release/press-releases/2098-slovakia-strengthens-its-ambitions-in-nuclear-energy-a-joint-venture-for-the-development-of-advanced-reactors-and-spent-fuel-reprocessing-is-established>; and JAVYS, "Slovakia Enters a New Era of Nuclear Energy: JAVYS and Newcleo Sign Major Shareholder Agreement", Press Release, 4 June 2025, see <https://www.javys.sk/en/information-service/news-press-release/press-releases/2097-slovakia-enters-a-new-era-of-nuclear-energy-javys-and-newcleo-sign-major-shareholder-agreement>; both accessed 21 July 2025.

²⁵¹³ - Victor Jack, "You Don't Scare Us: Slovakia Shrugs Off Kremlin Energy Retaliation for Arming Ukraine", *Politico*, 3 April 2023, see <https://www.politico.eu/article/slovakia-russia-energy-fossil-fuel-retaliation-war-ukraine-jets/>, accessed 5 June 2023.

²⁵¹⁴ - Łukasz Ogrodnik and Tymon Pastucha, "Slovakia Remains Dependent on Russian Energy", Polish Institute of International Affairs, 14 March 2025, see <https://www.pism.pl/publications/slovakia-remains-dependent-on-russian-energy>, accessed 12 May 2025.

²⁵¹⁵ - Jason Hovet and Jan Lopatka, "Slovakia Lays Plans to Receive Gas from Azerbaijan", Reuters, as published on *Gas Processing & LNG*, 13 May 2024, see <http://gasprocessingnews.com/news/2024/05/slovakia-lays-plans-to-receive-gas-from-azerbaijan/>, accessed 1 June 2024.

²⁵¹⁶ - Łukasz Ogrodnik and Tymon Pastucha, "Slovakia Remains Dependent on Russian Energy", Polish Institute of International Affairs, 14 March 2025, op. cit.

has financial and political consequences, including strained relations with Ukraine over energy disputes and reduced profits for state-owned energy companies.

In the nuclear sector, Slovakia's reliance on Russian technology and fuel remains significant, with record imports of 230 tons of nuclear fuel in 2023²⁵¹⁷ and 178 tons in 2024 (see [Figure 55](#)). While agreements with French and U.S. companies, such as Framatome and Westinghouse, aim to diversify nuclear fuel sources starting in 2027, the current delivery contract with Rosatom-owned TVEL was extended to 2030 (see [Russia Nuclear Interdependencies](#)).

In May 2023, SE signed an MoU with France's Framatome to cooperate on providing "100% European" fuel for VVER reactors.²⁵¹⁸ By July 2024, a contract was signed for Framatome to supply fuel to Bohunice and Mochovce starting in 2027. In August 2023, SE also reached an agreement with Westinghouse Electric Sweden AB, with deliveries expected one year after licensing and approval.²⁵¹⁹ In February 2024, SE Chairman Branislav Strýček stated at Westinghouse's 5th Annual VVER Forum that he "[expected] to finish the licensing process by 2026-2027."²⁵²⁰

However, the government noted in early 2025 that:

Only some spare parts from alternative suppliers are available on the market, such as several firms in Slovakia, the Czech Republic. Most spare parts are from the Russian Federation. SE, a.s. currently only uses spare parts and maintenance services from suppliers from the Russian Federation, which are critical for the safe operation of their nuclear facilities.²⁵²¹

The slow pace of diversification is compounded by the pro-Russian stance of Prime Minister Robert Fico's administration, which has prioritized economic gains over energy supply independence. This approach undermines E.U. sanctions on Russia and complicates the E.U.'s goal of reducing reliance on Russian energy, including ending all Russian gas and oil imports by the end of 2027.²⁵²² Additionally, the Fico government has shifted Slovakia's foreign policy, halting military aid to Ukraine and aligning with Hungary in blocking E.U. initiatives, further highlighting the political implications of its energy supply dependency.²⁵²³ The construction of a new VVER would cement that dependency for decades.

²⁵¹⁷ - Bellona, "Europe Doubled its Import of Russian Nuclear Fuel for 2023, Data Say", 15 March 2024, see <https://bellona.org/news/nuclear-issues/2024-03-europe-russian-nuclear-fuel>, accessed 1 June 2024.

²⁵¹⁸ - Framatome, "Framatome signs Memorandum of Understanding with Slovenské elektrárne to extend long-term partnership" Press Release, 31 May 2023, see <https://www.framatome.com/medias/framatome-signs-memorandum-of-understanding-with-slovenske-elektrarne-to-extend-long-term-partnership/>, accessed 23 July 2023.

²⁵¹⁹ - SE, "Strengthening Slovakia's Energy Security: Slovenské Elektrárne Concluded a Fuel Supply Agreement with Westinghouse", Press Release, 25 August 2023, see <https://www.seas.sk/en/press-releases/slovenske-elektrarne-nuclear-fuel-westinghouse/>, accessed 27 June 2024.

²⁵²⁰ - Westinghouse, "Westinghouse Organizes VVER Fuel Forum with Customers", Press Release, 22 February 2024, see <https://info.westinghousenuclear.com/news/westinghouse-organizes-vver-fuel-forum-with-customers>, accessed 1 June 2024.

²⁵²¹ - Government of Slovakia, "Update of the Integrated National Energy and Climate Plan 2021-2030", March 2025, released 16 April 2025, see https://commission.europa.eu/document/download/7508acc9-b266-4100-ac2f-6fa4ecd77f17_en?filename=Slovakian%20final%20NECP-English%20version.pdf, accessed 28 April 2025.

²⁵²² - European Commission, "Commission Proposes a Plan to Phase Out Russian Gas and Oil Imports", 17 June 2025, see https://commission.europa.eu/news-and-media/news/commission-proposes-plan-phase-out-russian-gas-and-oil-imports-2025-06-17_en, accessed 30 July 2025.

²⁵²³ - Andrew Higgins, "Slovakia Says It's Halting Arms Deliveries to Ukraine", *The New York Times*, 26 October 2023, see <https://www.nytimes.com/2023/10/26/world/europe/slovakia-weapons-ukraine-war.html>, accessed 1 June 2024; and Rory Sullivan, "Slovakia's PM Slams EU Over Plan to End Russian Gas Imports by 2027", *euronews*, 7 May 2025, see <https://www.euronews.com/2025/05/07/slovakias-prime-minister-rejects-eu-plan-to-halt-russian-gas-imports-by-end-of-2027>, accessed 22 July 2025; also Łukasz Ogrodnik and Tymon Pastucha, "Slovakia Remains Dependent on Russian Energy", 14 March 2025, op. cit.

Energy Policy Outlook

As previously indicated, Slovakia heavily depends on nuclear energy for electricity generation with the second largest nuclear share in the electricity production mix in the world in 2024 (behind France). Hydropower accounted for around 16.4 percent, natural gas 9.2 percent, bioenergy 5.1 percent, and coal 1.8 percent of total electricity production. Solar photovoltaics made up just 2.3 percent of the electricity mix.²⁵²⁴ Wind energy so far hardly exists in the mix.

In April 2025, the final version of the Integrated National Energy and Climate Plan 2021–2030 was submitted to the European Commission.²⁵²⁵ Based on the report, over the past decade, Slovak solar PV capacity has steadily increased, reaching approximately 850 MW by 2023. By 2024, the installed capacity exceeded 1 GW, with an annual installation rate of 100 MW expected to continue. Projections indicate that by the end of 2025, the installed capacity will reach 1.2 GW, with an estimated electricity production of approximately 1.3 TWh.²⁵²⁶ Expansion is also planned for the wind sector with a capacity target of 750 MW by 2030, producing an estimated 1.5 TWh of electricity annually.²⁵²⁷

Ján Karaba, the executive director of SAPI (Slovak Sustainable Energy Association), highlighted the challenges facing renewable energy in Slovakia, stating that “despite promises from the Ministry of Economy and the Ministry of Investment and Development to increase funding for this program from EU funds, it is still unclear when this will happen. Experience shows that it could take months, or even a year.”²⁵²⁸

Meanwhile, the head of the Slovak energy regulator, Jozef Holjenčík, has been a long-time critic of renewables, describing them as “unreliable” and their development as “chaotic”, while also warning against “speculators” and “political promoters of green ideology”. Such attitudes and delays make it more difficult for Slovakia to achieve the E.U. climate target of a national 23 percent share of renewable energy by 2030, a goal that is already significantly lower than the E.U.’s overall target of 42.5 percent.²⁵²⁹

Slovenia



Slovenia’s electricity production is roughly divided among three main sources as of 2024: nuclear energy at 34 percent (8 percent below the historic maximum of 42 percent in 2022), hydropower at 31 percent, and coal at 20.3 percent. Fossil fuels made up 23.8 percent of the national power mix. Solar came in at 8.9 percent.²⁵³⁰

²⁵²⁴ - EMBER, “Electricity Data Explorer— Share of Electricity Generation in Slovakia”, Updated 2025.

²⁵²⁵ - Government of Slovakia, “Update of the Integrated National Energy and Climate Plan 2021–2030”, March 2025, op. cit.

²⁵²⁶ - Ibidem.

²⁵²⁷ - Ibidem.

²⁵²⁸ - SAPI, “Solárna energia je dôležitá súčasť energetiky v Európe, nové technologické riešenia prinášajú ďalší potenciál”, Press Release, Slovak Sustainable Energy Association, 20 June 2025, see <https://www.sapi.sk/clanok/solarna-energia-je-dolezitita-sucast-energetiky-v-europe-nove-technologicke-riesenia-prinasaju-dalsi-potencial>, accessed 23 July 2025.

²⁵²⁹ - Lucia Lauková, “Slovakia to End Renewable Subsidies by 2026”, *Euractiv*, 19 March 2025, see <https://www.euractiv.com/section/eet/news/slovakia-to-end-renewable-subsidies-by-2026/>, accessed 23 April 2025.

²⁵³⁰ - EMBER, “Electricity Data Explorer— Share of electricity generation in Slovenia”, Updated 2025, see https://ember-energy.org/data/electricity-data-explorer/?entity=Slovenia&metric=pct_share, accessed 31 July 2025.

JEK

Slovenia operates a single nuclear power plant, Krško, which it jointly owns with Croatia. The 688-MW Westinghouse Pressurized Water Reactor (PWR) is referred to as JEK (Jedrska elektrarna Krško) in Slovenia and NEK (Nuklearna elektrarna Krško) in Croatia. In 2024, the plant produced 5.8 TWh of electricity (gross) or 34 percent of total generation. This marked a slight decrease from 35.3 percent in 2023, despite a marginal increase of about 0.2 TWh (gross) in absolute nuclear generation compared to the previous year.²⁵³¹

The Krško reactor, operational since 1983 with an initial 40-year license, underwent a refurbishment program in 2012,²⁵³² and its license was extended to 60 years in 2015. Despite Austrian opposition²⁵³³ (see [previous WNISR editions](#)), Slovenian authorities approved an additional 20 years of operation in 2023, allowing the plant to run until 2043.²⁵³⁴ The IAEA had previously carried out a pre-SALTO mission (Safety Aspects of Long Term Operation) in 2021²⁵³⁵ and conducted a SALTO mission in 2025.²⁵³⁶ After the latest mission, the team recommended that the operator further develop a systematic approach for overseeing the long-term operation program; adequately document the methodology and results for identifying relevant systems, structures, and components (SSCs) for ageing management; and complete and fully document the ageing management of electrical and instrumentation and control systems, structures, and components (I&C SSCs).²⁵³⁷

²⁵³¹ - Statistical Office of Slovenia, “Electricity (GWh), Slovenia, annually”, Provisional Data, July 2025, see <https://pxweb.stat.si/SiStatData/pxweb/en/Data/-/1817602S.px/table/tableViewLayout2/>, accessed 31 July 2025.

²⁵³² - SNSA, “Slovenian Technical Review Report on the Krško NPP Ageing Management Program—Final Report”, Slovenian Nuclear Safety Administration, Ministry of the Environment and Spatial Planning, Government of the Republic of Slovenia, December 2017, see <https://www.ensreg.eu/sites/default/files/attachments/slovenia.pdf>, accessed 2 September 2023.

²⁵³³ - Umweltbundesamt, BIEGE Nuklearexpertise, Ebner ZT and pulswerk, “Umweltverträglichkeitsprüfung—KKW Krško/Slowenien—Laufzeitverlängerung”, Federal Environment Agency, commissioned/published by the Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation, and Technology, Government of Austria, 2022, see <https://www.umweltbundesamt.at/uvp-kkw-krsko-lte>, accessed 30 July 2022.

²⁵³⁴ - Ministry of the Environment and Spatial Planning, “Life span of the Krško Nuclear Power Plant (NEK) extended until 2043”, Press Release, Government of Slovenia, 16 January 2023, see <https://www.gov.si/en/news/2023-01-16-life-span-of-the-krsko-nuclear-power-plant-nek-extended-until-2043/>, accessed 3 March 2023.

²⁵³⁵ - IAEA, “IAEA Concludes Long Term Operational Safety Review of Slovenia’s Krško Nuclear Power Plant”, Press Release 63/2021, 15 October 2021, see <https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operational-safety-review-of-slovenias-krsko-nuclear-power-plant>; and IAEA, “Peer Review and Advisory Services Calendar—Safety Aspects of Long Term Operation (SALTO), Undated, see <https://www.iaea.org/services/review-missions/calendar?type=3169&year%5Bvalue%5D%5Byear%5D=&location=All&status=All>; both accessed 2 September 2023.

²⁵³⁶ - IAEA, “IAEA Concludes Long Term Operation Safety Review of Slovenia’s Krško Nuclear Power Plant”, Press Release 38/2025, 23 May 2025, see <https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operation-safety-review-of-slovenias-krsko-nuclear-power-plant>, accessed 31 July 2025.

²⁵³⁷ - Ibidem.

JEK2

In 2006, the Slovenian government proposed adding a new plant at the Krško site,²⁵³⁸ with GEN Energija beginning feasibility studies for two 1100-MW reactors,²⁵³⁹ initially estimated at €2 billion (US\$₂₀₀₆ 2.5 billion).²⁵⁴⁰

By 2010, plans shifted to a single 1100–1600-MW reactor with a target grid connection by 2025.²⁵⁴¹ However, by 2015, limited progress had delayed the scheduled connection date to 2030.²⁵⁴²

Slovenia's Long-Term Climate Strategy Until 2050, adopted in 2021, set a 43 percent renewables target by 2030—increased to 55 percent in the 2025 NECP update—and called for a decision on new nuclear development by 2027, including Small Modular Reactors (SMRs) as an option.²⁵⁴³ This led the Ministry of Infrastructure to issue an “energy permit” for JEK2 shortly after in 2021.²⁵⁴⁴

In 2022, Prime Minister Golob pledged a referendum on the newbuild project once a technology is selected, aiming for broad national consensus.²⁵⁴⁵ By July 2023, GEN Energija still planned a final decision by late 2027 having updated its JEK2 application in June 2023 to accommodate a larger capacity of up to 2400 MW, hoping to “expand the range of potential suppliers.”²⁵⁴⁶

In May 2024 a parliamentary resolution on the “long-term peaceful use of nuclear energy in Slovenia” was adopted. The resolution emphasizes the supposed necessity of the JEK2 project and the deployment of SMRs for the decarbonization of the Slovenian power system.²⁵⁴⁷

The same month, alongside adopting a resolution on the “peaceful use of nuclear energy,” the Slovenian Parliament voted to hold the referendum with rare bipartisan support (71 votes for,

²⁵³⁸ - Government Office for Growth, “Resolution on National Development Projects for the Period 2007-2023”, Government of Slovenia, December 2006, see http://www.slovenijajutri.gov.si/fileadmin/urednik/publikacije/resolution_en.pdf, accessed 1 July 2024.

²⁵³⁹ - GEN Group, “Letno poročilo 2006”, March 2007, see https://www.gen-energija.si/files/materials/10/pdf/Letno_porocilo2006_1b.pdf, accessed 3 June 2024.

²⁵⁴⁰ - Jan Bratanic, “Slovenia Pushes on With Pricey Nuclear Project to Phase Out Coal”, *Bloomberg*, 18 October 2023, see <https://www.bloomberg.com/news/articles/2023-10-18/slovenia-pushes-on-with-pricey-nuclear-project-to-phase-out-coal>, accessed 3 June 2024; and Government Office for Growth, “Resolution on National Development Projects for the Period 2007-2023”, Government of Slovenia, December 2006, op. cit.

²⁵⁴¹ - GEN Group, “Annual Report 2010”, June 2011, see https://www.gen-energija.si/files/materials/6/pdf/GEN_LP_2010_ENG_web_2c.pdf https://www.gen-energija.si/files/materials/6/pdf/GEN_LP_2010_ENG_web_2c.pdf, accessed 3 June 2024.

²⁵⁴² - GEN Group, “Annual Report 2015 of the Company GEN and the GEN Group”, May 2016, see https://www.gen-energija.si/files/materials/34/pdf/GEN_2015_ENG_LP_interactive_2.pdf, accessed 3 June 2024.

²⁵⁴³ - Government of the Republic of Slovenia, “Resolution on Slovenia's Long-Term Climate Strategy Until 2050 (ReDPS50)”, 24 August 2021, p. 30–34, see https://unfccc.int/sites/default/files/resource/LTS1_SLOVENIA_EN.pdf, accessed 2 September 2023.

²⁵⁴⁴ - Ministry of Infrastructure, “Ministry of Infrastructure Issues an Energy Permit for the Second Nuclear Reactor Unit in Krško”, Press Release, Government of Slovenia, 20 July 2021, see <https://www.gov.si/en/news/2021-07-20-ministry-of-infrastructure-issues-an-energy-permit-for-the-second-nuclear-reactor-unit-in-krsko/>, accessed 2 September 2023.

²⁵⁴⁵ - Prime Minister's Office, “Predsednik vlade dr. Robert Golob obiskal Nuklearno elektrarno Krško (NEK)”, Government of Slovenia, 28 October 2022, see <https://www.gov.si/novice/2022-10-28-predsednik-vlade-dr-robert-golob-obiskal-nuklearno-elektrarno-krsko-nek/>, accessed 1 July 2024.

²⁵⁴⁶ - JEK2, “Prime Minister Dr. Golob Announced a Preliminary Decision on the JEK2 Project During His Visit to Krško”, 16 June 2023, see <https://jek2.si/en/news/prime-minister-dr-golob-announced-a-preliminary-decision-on-the-jek2-project-during-his-visit-to-krsko/>; and JEK2, “Questions and Answers—In Which Stage is the JEK2 Project?”, Undated, see <https://jek2.si/en/questions-and-answers/>; both accessed 1 July 2024.

²⁵⁴⁷ - National Assembly of Slovenia, “1419. Resolucija o dolgoročni miroljubni rabi jedrske energije v Sloveniji »Jedrska energija za prihodnost Slovenije« (ReDMRJE)”, stran 3952., *Uradni List*, 24 May 2024, see <https://www.uradni-list.si/glasilo-uradni-list-rs/vsebina?urlid=2024443&stevilka=1419>, accessed 1 August 2025.

6 against). Critics, including the Levica (“Left”) party, argued the referendum amounted to a “blank cheque” for a potentially unviable project.²⁵⁴⁸

However, the majority of parliamentary parties, including the governing Freedom Movement and the opposition party, Slovenian Democratic Party (which initially tabled the proposal), decided to revoke the consultative referendum initiative.²⁵⁴⁹ They attributed this decision to a loss of public trust due to controversies, legal challenges, and criticism raised by environmental groups and experts over the legality of the process and the formulation of the question put to referendum, and they identified the need for more comprehensive public information, as emphasized by President Nataša Pirc Musar.²⁵⁵⁰

Though planning for the referendum was cancelled, it is expected to be implemented in 2028 at the latest, before the final investment decision, according to Prime Minister Golob.²⁵⁵¹ The government remains committed to the project and the majority party is working on framework legislation pertaining to it. Following the referendum’s cancellation, GEN Energija announced it was continuing work on the JEK2 project while exploring the potential use of SMR technology in Slovenia.²⁵⁵²

In May 2024, GEN Energija presented a study suggesting that a 1300-MW reactor would be the optimal size. Estimated overnight construction costs ranged from €9.3 billion (US\$₂₀₂₄ 10.1 billion) for a 1000-MW reactor to €15.4 billion (US\$₂₀₂₄ 16.7 billion) for a 1650-MW reactor. GEN Energija is aiming for a final investment decision for JEK2 by 2028, construction to begin in 2032, and grid connection by 2039.²⁵⁵³

Meanwhile the JEK2 project is moving forward with two remaining potential technology vendors, EDF and Westinghouse, following KHNP’s withdrawal from the bidding competition in January 2025.²⁵⁵⁴ Both vendors have signed contracts to prepare feasibility studies, with each provider conducting its own study. The total estimated value of the two studies is €8.3 million (US\$9.4 million), and they are expected to be completed by the third quarter of 2025.²⁵⁵⁵

2548 - Agenzia ANSA, “Slovenian MPs Support Referendum on New Krsko Nuclear Plant”, 23 May 2024, see https://www.ansa.it/nuova_europa/en/news/sections/news/2024/05/23/slovenian-mps-support-referendum-on-new-krsko-nuclear-plant_2410c099-3a62-4661-8d70-e795b3c4fed8.html, accessed 3 June 2024.

2549 - Delo, “Gibanje Svoboda za umik referenduma o Jeku 2”, 21 October 2024, see <https://www.delo.si/novice/slovenija/sds-predlaga-preklic-referenduma-o-izvedbi-projekta-jek-2>, accessed 31 July 2025.

2550 - The Slovenia Times, “Nuclear Energy Expansion Referendum Abandoned”, 22 October 2024, see <https://sloveniatimes.com/41185/nuclear-energy-expansion-referendum-abandoned>; and Daria Sito-Sucic, “Slovenia Cancels Referendum on New Nuclear Plant”, Reuters, 24 October 2024, see <https://www.reuters.com/world/europe/slovenia-cancels-referendum-new-nuclear-plant-2024-10-24/>; both accessed 1 August 2025; and WNN, “Slovenia’s Referendum on New Nuclear Cancelled”, 25 October 2024, see <https://world-nuclear-news.org/articles/slovenias-referendum-on-new-nuclear-cancelled>, accessed 8 May 2025.

2551 - Gibanje Svoboda, “Zavajanje javnosti onemogočilo avtonomno referendumsko odločanje”, Freedom Movement, 24 October 2024, see <https://gibanjesvoboda.si/svoboda/zavajanje-javnosti-onemogocilo-avtonomno-referendumsko-odlocanje/>, accessed 1 August 2025.

2552 - GEN energija, “Čas je za razmislek o celoviti dolgoročni energetske strategiji Slovenije”, Press Release, 22 November 2024, see <https://www.gen-energija.si/medijsko-sredisce/novice/351/as-je-za-razmislek-o-celoviti-dolgoroni-energetski-strategiji-slovenije>; and GEN energija, “GEN energija nadaljuje projekt JEK2 in proučuje področje malih modularnih reaktorjev”, Press Release, 30 January 2025, see <https://www.gen-energija.si/medijsko-sredisce/novice/359/gen-energija-nadaljuje-projekt-jek2-in-prouuje-podroje-malih-modularnih-reaktorjev>; both accessed 1 August 2025.

2553 - GEN energija “GEN energija predstavila oceno ekonomike projekta JEK2”, 21 May 2024, see <https://www.gen-energija.si/medijsko-sredisce/novice/326/gen-energija-predstavila-oceno-ekonomike-projekta-jek2>, accessed 1 July 2024.

2554 - GEN energija, “GEN energija nadaljuje projekt JEK2 in proučuje področje malih modularnih reaktorjev”, 30 January 2025, op. cit.

2555 - Ibidem; and JEK2, “Potencialni ponudniki za postavitev JEK2”, see <https://jek2.si/dobavitelji/>, accessed 30 July 2025.

On 1 July 2025, the announcement of the “initiative for the drafting of a National Spatial Plan (NSP) for the construction of a new nuclear power plant in Krško” was published by the Ministry of Natural Resources and Spatial Planning.²⁵⁵⁶ A public consultation was scheduled to last from 1 July to 30 September 2025.²⁵⁵⁷

Slovenia’s Dependency on Coal

Slovenia is targeting to phase out coal entirely by 2033, with significant reductions in coal use by 2030, particularly through scaling down operations at the Šoštanj thermal power plant.²⁵⁵⁸ This transition scenario is based on the expansion of renewable energy sources, optimistic growth in nuclear energy output, and the establishment of 500 MW of gas-based capacity that can later transition to renewable fuels like hydrogen. While a 100-percent renewable energy scenario has been modeled for 2050, its characteristics remain somewhat obscure in the National Energy and Climate Plan (NECP) outline.²⁵⁵⁹

Slovenia’s updated NECP, submitted in 2025, aims at climate neutrality by 2050, with a 55 percent reduction in GHG emissions by 2033, aligning with the E.U.’s Fit for 55 package. It sets specific renewable energy goals, including a 33 percent share in end-use energy, 55 percent in electricity production, 45 percent in heating and cooling, and 26 percent in transport by 2030.²⁵⁶⁰

FORMER SOVIET UNION

Armenia



Armenia has practically no fossil fuel resources, especially when compared to its neighbors Azerbaijan and Iran.²⁵⁶¹ Yet, in 2022, natural gas—all imported—represented over 60 percent of its primary energy supply.²⁵⁶² Besides natural gas, Armenia relies heavily on nuclear energy,

²⁵⁵⁶ - Ministry of Natural Resources and Spatial Planning, “Javna objava pobude v postopku državnega prostorskega načrtovanja za Jedrsko elektrarno Krško 2”, Government of Slovenia, 1 July 2025, see <https://www.gov.si/novice/2025-07-01-javna-objava-pobude-v-postopku-drzavnega-prostorskega-nacrtovanja-za-jedrsko-elektrarno-krsko-2/>; and JEK2, “Publication of an Initiative in the National Spatial Planning Procedure for JEK2”, 1 July 2025, see <https://jek2.si/en/news/publication-of-an-initiative-in-the-national-spatial-planning-procedure-for-jek2/>; both accessed 1 August 2025.

²⁵⁵⁷ - JEK2, “Z javno objavo pobude za pripravo DPN začetek trimesečnega obdobja za informiranje javnosti in podajanje pripomb glede prostorske ureditve JEK2”, 24 June 2025, see <https://jek2.si/novice/z-javno-objavo-pobude-za-pripravo-dpn-zacetek-trimesecnega-obdobja-za-informiranje-javnosti-in-podajanje-pripomb-glede-prostorske-ureditve-jek2/>; and JEK2, “Minister za naravne vire in prostor obiskal Informacijsko pisarno JEK2 v Krškem”, 3 July 2025, see <https://jek2.si/novice/minister-za-naravne-vire-in-prostor-obiskal-informacijsko-pisarno-jek2-v-krskem/>; both accessed 1 August 2025.

²⁵⁵⁸ - Government of Slovenia, “Up-to-Date Comprehensive National Energy and Climate Plan of the Republic of Slovenia”, submitted to the European Commission, drafted 18 December 2024, filed January 2025, see https://commission.europa.eu/publications/slovenia-final-updated-necp-2021-2030-submitted-2025_en, accessed 1 August 2025.

²⁵⁵⁹ - Ibidem.

²⁵⁶⁰ - Ibidem.

²⁵⁶¹ - Government of Armenia, “Approval of the Nationally Determined Contribution 2021-2030 of the Republic of Armenia to Paris Agreement”, April 2021, see <https://unfccc.int/sites/default/files/NDC/2022-06/NDC%20of%20Republic%20of%20Armenia%20%202021-2030.pdf>, accessed 13 August 2024.

²⁵⁶² - IEA, “Armenia - Energy Consumption 2022”, International Energy Agency, 2022, see <https://www.iea.org/countries/armenia/natural-gas> accessed 10 July 2025.

and together the two accounted for about 70 percent of its electricity production in 2024.²⁵⁶³ Most of the natural gas is imported from Russia²⁵⁶⁴ via the North Caucasus–Transcaucasia Pipeline. Armenia’s efforts to trade electricity for Iranian gas have been limited by its inability to compete with Russian gas prices.

Armenia still operates a single reactor, in operation since 1980, at the Metsamor nuclear power plant (also known as the Armenian Nuclear Power Plant, or ANPP), located approximately 30 km from the capital, Yerevan. In 2024, the reactor generated 2.6 TWh of electricity, accounting for 30.8 percent of the country’s total electricity production and meeting slightly less than one-third of its electricity demand. This output has remained relatively stable since 2022. In 2024, about 30 percent of Armenia’s electricity was produced from renewable sources, primarily hydropower that produced around 20 percent, although solar energy has steadily grown to almost 10 percent. The remaining 40 percent was generated from natural gas.²⁵⁶⁵

Nuclear energy in Armenia faces significant geological and geopolitical challenges. Located in a seismically active region, the country is vulnerable to earthquakes.²⁵⁶⁶ The collapse of the Soviet Union triggered the Nagorno-Karabakh conflict with Azerbaijan, leading to two wars. Geopolitically, Armenia has been historically dependent on Russia but is now “pursuing deeper ties with the European Union, strengthening cooperation with the United States, and seeking normalization with Turkey.”²⁵⁶⁷ In March 2025, a bill to launch the process of accession to the E.U. was officially signed into law.²⁵⁶⁸

The Metsamor reactor, a first-generation Soviet-designed VVER-440/V-270, is considered to have the least adequate safety systems among operating VVER designs. Similar reactors from that era in other countries have since been closed. Following a major earthquake in December 1988, Armenia closed its two reactors in March 1989. However, severe power shortages during the early 1990s, caused by a post-Soviet energy blockade amid the First Nagorno-Karabakh War, led to the decision to reopen Unit 2 in 1993. The unit resumed operation in 1995.²⁵⁶⁹

The closure of Metsamor has been repeatedly delayed due to stalled plans for a replacement (see past *WNISR* editions). In 2011, the Armenian Nuclear Regulatory Authority extended the

²⁵⁶³ - EMBER, “Electricity Data Explorer—Share of Electricity Generation in Armenia”, 2025, see https://ember-energy.org/data/electricity-data-explorer/?entity=Armenia&metric=pct_share&data=generation&fuel=total&tab=main&chart=trend, accessed 14 May 2025.

²⁵⁶⁴ - World Bank Group, “Country Climate and Development Report”, November 2024, see <https://documents1.worldbank.org/curated/en/099110524115029619/pdf/P18076418d641b0e91954b113281d9a1165.pdf>, accessed 31 August 2025.

²⁵⁶⁵ - EMBER, “Electricity Data Explorer—Share of Electricity Generation in Armenia”, 2025, op. cit.

²⁵⁶⁶ - Artsvik Davtyan, Aren Nazaryan, and Anya Sarkisova “Armenia’s Seismology Specialists: Predicting Earthquakes in a Tunnel”, *Hetq*, 5 April 2025, see <https://hetq.am/en/article/173621>, accessed 10 July 2025.

²⁵⁶⁷ - Jason Corcoran, “Armenia Is Breaking Up With Russia – And Putin Can’t Stop It”, *The Moscow Times*, 9 June 2025, see <https://www.themoscowtimes.com/2025/06/09/armenia-is-breaking-up-with-russia-and-putin-cant-stop-it-a89393>, accessed 11 July 2025.

²⁵⁶⁸ - Felix Light, “Armenia Adopts Law to Launch EU Accession Process”, *Reuters*, 4 April 2025, see <https://www.reuters.com/world/asia-pacific/armenia-adopts-law-launch-eu-accession-process-2025-04-04/>, accessed 22 May 2025; and National Assembly of Armenia, “Parliament Debates Civil Initiative on Launching Process of RA Accession to EU in Second Reading”, 26 March 2025, see http://www.parliament.am/news.php?cat_id=2&NewsID=21934&year=2025&month=03&day=26&lang=eng, accessed 18 July 2025.

²⁵⁶⁹ - WNA, “Nuclear Power in Armenia”, World Nuclear Association, Updated 10 May 2024, see <https://world-nuclear.org/information-library/country-profiles/countries-a-f/armenia>, accessed 13 August 2024; and ANPP, “Annual Financial Statements and Independent Auditor’s Report—For the Year Ended 31 December 2024”, Armenian Nuclear Power Plant, April 2025, see https://armeniannpp.am/page_files/documents/hashvetvutyun/FS%20ANPP%202024%20eng.pdf, accessed 18 July 2025.

reactor's license to 2021, and required annual safety checks starting in 2016.²⁵⁷⁰ In 2012, the government announced plans to operate it until 2026.²⁵⁷¹ Upgrades completed in 2021 extended its lifespan and increased its capacity from 407.5 MW to 448 MW (gross).²⁵⁷²

After the lifetime extension project was approved and related contracts were sealed in late 2023, Rosatom began work in 2024 to further extend the unit's lifetime to 2036 by testing the reactor pressure vessel material, assessing the effects of ageing on its strength and brittleness. Annealing of the pressure vessel was undertaken during the process to extend the reactor's life until 2026, but further tests are to be carried out.²⁵⁷³

The construction of a new reactor is also fraught with geopolitical tensions. Russia is keen to maintain and expand its nuclear relationship with Armenia.²⁵⁷⁴ At the same time, the U.S. is pushing for a shift away from Russian influence. In January 2025, the U.S., still led by the Biden administration, and the Armenian government extended their ties by signing a Charter on Strategic Partnership.²⁵⁷⁵ This partnership does not include military security guarantees but focuses on energy security. Negotiations were initiated towards a so-called "123 Agreement", which enables a cooperation in the field of civil nuclear energy.²⁵⁷⁶ In April 2025 the U.S. Ambassador to Armenia discussed the possibilities of Armenia's nuclear sector based on the new strategic partnership with representatives from Westinghouse.²⁵⁷⁷ In response to Armenia's growing ties with the U.S., the Russian Ambassador to Armenia, in a May 2025 visit to ANPP, stated, "Rosatom is ready to offer Armenian colleagues nuclear power plants of Russian design with reactors of various capacities, distinguished by enhanced safety and economic efficiency."²⁵⁷⁸

2570 - IAEA, "IAEA Concludes Long-Term Operational Safety Review at Armenia's Nuclear Power Plant", Press Release 61/2018, 10 December 2018, see <https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operational-safety-review-at-armenias-nuclear-power-plant>, accessed 13 August 2024.

2571 - Tigran Avetisyan, "Armenian Nuclear Plant To Operate Until 2026", *Radio Free Europe/Radio Liberty*, 18 October 2012, see <https://www.azatutjun.am/a/24744093.html>, accessed 13 August 2025.

2572 - *NEI Magazine*, "Life Extension Work Completed at Armenian NPP", *Nuclear Engineering International*, 18 November 2021, see <https://www.neimagazine.com/news/life-extension-work-completed-at-armenian-npp-9260626/>, accessed 13 August 2024; and IAEA-PRIS, "Country Details—Armenia", Updated 17 July 2025, see <https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=2>, accessed 18 July 2025.

2573 - *NEI Magazine*, "Rosatom Supports Armenian NPP Life Extension", 2 August 2024, see <https://www.neimagazine.com/news/rosatom-begins-work-to-support-life-extension-of-armenian-npp/>, accessed 13 August 2024; and Rosatom, "Newsletter #284—Year in Review: Preserve and Increase", December 2024, see <https://rosatomnewsletter.com/2024/12/19/year-in-review-preserve-and-increase/>, accessed 21 May 2025.

2574 - Rosatom, "Head of ROSATOM Alexei Likhachev and Prime Minister of the Republic of Armenia Nikol Pashinyan Discussed Cooperation in the Field of Atomic Energy Use", 3 May 2023, see <https://www.rosatom.ru/en/press-centre/news/head-of-rosatom-alexei-likhachev-and-prime-minister-of-the-republic-of-armenia-nikol-pashinyan-discu/>, accessed 18 July 2025; and Lia Avagyan, "Russia Ready to Offer Various Nuclear Reactor Designs to Armenia, Says Ambassador", *CivilNet*, 15 May 2025, see <https://www.civilnet.am/en/news/950634/russia-ready-to-offer-various-nuclear-reactor-designs-to-armenia-says-ambassador/>, accessed 19 May 2025.

2575 - Ministry of Foreign Affairs, "The Signing of the Strategic Partnership Charter between the Republic of Armenia and the United States of America Took Place in Washington", Press Release, Government of Armenia, 14 January 2025, see <https://www.mfa.am/en/press-releases/2025/01/14/the/13032>, accessed 21 May 2025.

2576 - Alexander Pracht, "How Armenia's New Partnership with the U.S. Is Likely to Affect Its Energy Sector", *Civilnet*, 20 January 2025, see <https://www.civilnet.am/en/news/813062/how-armenias-new-partnership-with-the-u-s-is-likely-to-affect-its-energy-sector/>, accessed 11 July 2025; and Ministry of Foreign Affairs, "Statement by Foreign Minister of Armenia Ararat Mirzoyan at the Signing Ceremony of Armenia - U.S. Strategic Partnership Charter", Government of Armenia, 14 January 2025, see https://www.mfa.am/en/speeches/2025/01/14/Mirzoyan_Blinken/13031, accessed 21 May 2025.

2577 - *Armenpress*, "US Ambassador Discusses Armenia's Nuclear Energy Sector with Westinghouse Representatives", 22 April 2025, see <https://armenpress.am/en/article/1217865>, accessed 21 May 2025.

2578 - Lia Avagyan, "Russia Ready to Offer Various Nuclear Reactor Designs to Armenia, Says Ambassador", *CivilNet*, 15 May 2025, op. cit.

In June 2023, the Armenian government established a working group to explore various options for nuclear newbuild, including Small Modular Reactors (SMRs).²⁵⁷⁹ In January 2024, Prime Minister Nikol Pashinyan, described the option of modular reactors as “politically interesting” and stated that “the accident of the latter does not require emergency response zones. In other words, if there is an accident, we will not apply measures to protect the population within a radius of a hundred kilometer.”²⁵⁸⁰ However, the credibility of such prospects has drawn some skepticism, such as from Armenia’s former Deputy Minister Hakob Vardanyan who reportedly stated in February 2025 that “the likelihood of constructing a modular nuclear power plant in Armenia is extremely low, as such plants have not yet been built anywhere in the world.”²⁵⁸¹

As of mid-2025, the vendor and technology for the project remain undecided,²⁵⁸² and the Armenian government has reportedly declined to provide any updates on the matter.²⁵⁸³

However, in March 2025, the establishment of a new state-owned company for the construction of the nuclear power plant was accelerated. Armenian Minister of Territorial Administration and Infrastructure, David Khudatyan stated:

The government has established a closed joint-stock company to develop a proposal for a new nuclear power plant model. It will later oversee the technical requirements and supervision before handing it over to operators. The staffing structure will soon be approved, and we are simultaneously working on extending the lifespan of the existing plant.²⁵⁸⁴

Nuclear energy is not the only option under consideration, as there is a growing emphasis on renewable energy. Solar energy is on the rise, and solar power generation has increased sixfold since 2020.²⁵⁸⁵ Armenia’s updated Nationally Determined Contribution (NDC), submitted to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat in 2021, states a 2030-target of at least 15 percent renewable energy, with plans to deploy 1 GW of solar capacity.²⁵⁸⁶ The government’s 2021 energy sector development plan underscores the importance of renewables, stating:

The fact that the solar and wind technologies are considered as part of the least cost solution for new generation under all scenarios stresses the importance to Armenia of ensuring a policy and institutional environment that supports development of these technologies to the maximum extent possible, not only to ensure the lowest cost generation but also to minimize

²⁵⁷⁹ - *ArmenPress*, “PM Pashinyan Activates Task Force in Charge of Construction of New Nuclear Power Reactor”, 6 June 2023, see <https://armenpress.am/en/article/1112610>, accessed 28 August 2024.

²⁵⁸⁰ - Prime Minister of Armenia, “Activity Report 2023 of the Nuclear Safety Committee Presented to PM Pashinyan”, Press Release, 16 January 2024, see <https://www.primeminister.am/en/press-release/item/2024/01/16/Nikol-Pashinyan-Nuclear-Safety-Committee-Report/>, accessed 28 August 2024.

²⁵⁸¹ - Arshaluys Mghdesyan, “Armenia unlikely to build modular nuclear power plant, says former official”, *Civilnet*, 13 February 2025, see <https://www.civilnet.am/en/news/817184/armenia-unlikely-to-build-modular-nuclear-power-plant-says-former-official/>, accessed 22 May 2025.

²⁵⁸² - Grace Symes, “Armenia: Yerevan in Talks With All Potential Nuclear Suppliers”, *Nuclear Intelligence Weekly*, 6 September 2024; and *NEI Magazine*, “Armenian PM Confirms Country’s Interest in New NPP and SMRs”, 19 January 2024, see <https://www.neimagazine.com/news/armenian-prime-minister-confirms-countrys-interest-in-new-npp-and-smrs-11447511/>, accessed 11 July 2025.

²⁵⁸³ - *NEI Magazine*, “Armenia Establishes New Company for NPP Construction”, 4 March 2025, see <https://www.neimagazine.com/news/armenia-establishes-new-company-for-npp-construction/>, accessed 21 April 2025.

²⁵⁸⁴ - *Ibidem*.

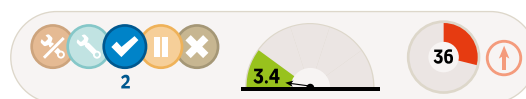
²⁵⁸⁵ - EMBER, “Electricity Data Explorer—Share of Electricity Generation in Armenia”, 2025, op. cit.

²⁵⁸⁶ - Government of Armenia, “Approval of the Nationally Determined Contribution 2021-2030 of the Republic of Armenia to Paris Agreement”, April 2021, op. cit.

reliance on other imported energy sources and to strengthen Armenia's energy security and competitiveness.²⁵⁸⁷

In June 2024, the World Bank approved a US\$40 million loan to help advance the country's energy transition by upgrading its power grid.²⁵⁸⁸ However, it remains uncertain whether the recent nationalization of the electric network marks the first step toward modernizing the system. Economists have raised concerns that nationalizing the power grid could harm the investment climate. As Haykaz Fanyan, head of the Armenian Centre for Socio-Economic Studies, a Yerevan-based think tank, explained: "Initiating a process of forced re-nationalization, especially without compensation, will inevitably damage Armenia's investment attractiveness."²⁵⁸⁹

Belarus



Belarus, along with the United Arab Emirates, is one of only two newcomer countries to connect its first nuclear power plant to the grid in the past 14 years since Iran started up its first commercial reactor in 2011.

The contract to build the Belarusian nuclear power plant—also known as Ostrovets, after the name of the nearby town—with two VVER-1200 units, was signed with Russia's Atomstroyexport in 2011.²⁵⁹⁰ Two years later, in November 2013, first concrete was poured for Unit 1. Construction of Unit 2 began six months later, in April 2014. The original plan envisioned commissioning the units in 2019 and 2021, but they were delayed by two and almost three years, respectively. The two units were connected to the grid in November 2020 and May 2023 and entered commercial operation in June 2021 and November 2023.²⁵⁹¹

Before the launch of the first unit of the Belarusian plant, more than 97 percent of Belarus's electricity was generated by gas-fired power plants over the decade between 2010 and 2019. In 2019, total electricity generation stood at around 40.5 TWh. The commissioning of the first reactor primed a continuous growth of nuclear in the electricity mix. By the end of 2024, the nuclear plant was generating 36.5 percent of the country's electricity, while total national generation increased to 45.3 TWh. Electricity generation from gas-fired power plants declined

²⁵⁸⁷ - Government of Armenia, "Republic of Armenia Energy Sector Development Strategic Program to 2040", 2021, see <https://policy.asiapacificenergy.org/sites/default/files/Energy%20Sector%20Development%20Strategic%20Program%20to%202040%20.pdf>, accessed 13 August 2024.

²⁵⁸⁸ - World Bank Group, "Armenia's Transition to Clean Energy and Power Transmission Grid Upgrades to Benefit from World Bank Support", Press Release, 3 June 2024, see <https://www.worldbank.org/en/news/press-release/2024/06/03/armenia-s-transition-to-clean-energy-and-power-transmission-grid-upgrades-to-benefit-from-world-bank-support>, accessed 13 August 2024.

²⁵⁸⁹ - Elen Muradyan, "Economists Warn Armenia's Planned Power Grid Nationalization Threatens Investment Climate", *CivilNet*, 18 June 2025, see <https://www.civilnet.am/en/news/957622/economists-warn-armenias-planned-power-grid-nationalization-threatens-investment-climate/>; and Alexander Pracht, "Pashinyan Calls to Nationalize Electricity Network After Arrest of Billionaire Critic", *CivilNet*, 18 June 2025, see <https://www.civilnet.am/en/news/957571/pashinyan-calls-to-nationalize-electricity-network-after-arrest-of-billionaire-critic/>; both accessed 11 July 2025.

²⁵⁹⁰ - Atomstroyexport, "Belarusian NPP, Republic of Belarus", Rosatom, 2021, see <http://ase-ec.ru/en/projects/belarus-npp/>, accessed 30 May 2025.

²⁵⁹¹ - IAEA - PRIS, "Country Statistics—Belarusian-1", Updated 29 May 2025, see <https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=1056>, accessed 30 May 2025; and IAEA - PRIS, "Country Statistics—Belarusian-2", Updated 6 June 2025, see <https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=1061>, accessed 7 June 2025.

in absolute terms by 12.2 TWh—from 39.2 TWh in 2019 to 27 TWh in 2024. Renewable energy sources (including hydro) account for about 2 percent of the national electricity mix.²⁵⁹²

Even before the second unit of the nuclear power plant was completed, senior Belarusian officials began discussing the possibility of building a third unit at the existing site²⁵⁹³ or constructing a second plant at a different location. Belarusian leader Alexander Lukashenko reconfirmed the existence of such plans in March 2025,²⁵⁹⁴ when he reportedly said, “this [the expected growth in power demand] is why we’ve asked Russians to build the second nuclear power plant if possible. We will build it on our own. Except for the reactor...We have specialists.” However, such plans have been under discussion since the very beginning of Ostrovets’ construction—as early as 2012²⁵⁹⁵—but no concrete details have emerged so far.

In 2011, Russia agreed to lend Belarus up to US\$10 billion for 25 years to cover 90 percent of its first plant’s expected costs. The remaining 10 percent was to be financed by Belarus. According to the agreement, the funds from the Russian loan were to be used exclusively to pay for goods, works, and services of Russian origin used in the construction of the nuclear power plant.²⁵⁹⁶ In 2021, citing delays in the construction of the plant, Lukashenko negotiated easier loan terms; the start of debt repayments was postponed by two years from 2021 to 2023,²⁵⁹⁷ and the loan interest rate was reportedly reduced from 4.11 percent to 3.3 percent.²⁵⁹⁸ In 2023, Belarus secured another loan revision, extending disbursements through 2023 and delaying repayments to April 2024. Initially, repayments under the loan could be made in either US dollars or Russian rubles. However, following the signing of the supplementary agreement in 2023, all settlements were switched to Russian rubles only.²⁵⁹⁹

It is difficult to assess the total investment, especially given the fluctuations in exchange rates and commercial confidentiality regarding actual payments. In 2019, Lukashenko said that the actual price of the nuclear plant would be below US\$7 billion. However, he declined to name the exact figure, citing commercial confidentiality.²⁶⁰⁰ Speaking about the possibility of building a second nuclear power plant in the country, Lukashenko also repeatedly said that it could be partially financed using saved credit funds.²⁶⁰¹

2592 - EMBER, “Electricity Data Explorer”, 2025, see <https://ember-energy.org/data/electricity-data-explorer>, accessed 3 August 2025.

2593 - BelTA, “В Минэнерго рассказали о перспективах строительства третьего энергоблока”, *Belarusian Telegraph Agency*, 3 February 2023, see <https://belta.by/economics/view/v-minenergo-rasskazali-o-perspektivah-stroitelstva-tretjego-energobloka-548139-2023/>, accessed 10 July 2025.

2594 - BelTA, “Lukashenko Reaffirms Plans to Build Second Nuclear Power Plant in Belarus”, 14 March 2025, see <https://eng.belta.by/president/view/lukashenko-reaffirms-plans-to-build-second-nuclear-power-plant-in-belarus-166262-2025/>, accessed 10 July 2025.

2595 - Атомная энергия 2.0, “Лукашенко: ‘Я бы хотел и вторую АЭС построить в Белоруссии’”, 25 December 2012, see <https://www.atomic-energy.ru/news/2012/12/25/37964>, accessed 10 July 2025.

2596 - NEI Magazine, “Russia Amends Terms for Belarus NPP Loan Agreement”, 29 March 2021, see <https://www.neimagazine.com/news/russia-amends-terms-for-belarus-npp-loan-agreement-8633297/>, accessed 14 August 2024.

2597 - Ibidem.

2598 - Polina Smertina, “Спорный атом”, *Kommersant*, 31 October 2023, see <https://www.kommersant.ru/doc/6311718>, accessed 30 May 2025.

2599 - Interfax, “Russian Duma Ratifies New Terms of Loan For Belarusian NPP”, 21 September 2023, see <https://interfax.com/newsroom/top-stories/94765/>, accessed 30 May 2025.

2600 - BelTA, “Belarusian Nuclear Power Plant to Cost Less Than \$10bn”, 19 April 2019, see <https://eng.belta.by/president/view/belarusian-nuclear-power-plant-to-cost-less-than-10bn-120494-2019/>, accessed 14 August 2024.

2601 - Interfax, “Lukashenko Again Raises Issue of Second Nuclear Power Plant in Belarus”, 2 July 2024, see <https://interfax.com/newsroom/top-stories/103922/>, accessed 10 July 2025.

In 2023, the Russian Ministry of Finance stated in an explanatory note to the new loan agreement that the total amount of credit used would be around US\$5.36 billion²⁶⁰² and total budget revenues from the loan would be US\$6.65 billion, likely accounting for interest.²⁶⁰³ In August 2024, Lukashenko was also quoted as saying that only US\$5.36 billion from the loan had actually been used.²⁶⁰⁴ In 2020, the head of Rosatom stated in an interview that the company was working on the Belarusian nuclear project with minimal profit, and that despite the contract being denominated in US dollars, settlements were made in Russian rubles.²⁶⁰⁵

Russia and Belarus have signed several agreements on managing radioactive waste and spent nuclear fuel. In 2019, Belarus adopted a national strategy that identified reprocessing in Russia with the return of waste as the preferred spent fuel management option. The total cost of this approach was estimated at US\$2.5–3.5 billion over the plant's lifetime (up to 100 years).²⁶⁰⁶ A 2022 bilateral agreement formalized this scenario,²⁶⁰⁷ and in 2023, Rosatom subsidiary TVEL agreed²⁶⁰⁸ to help Belarus develop infrastructure for final waste disposal.

The Belarusian plant became Rosatom's first export project featuring VVER-1200 reactors, following the construction of four such units in Russia. The reference design was Leningrad II, with two VVER-1200/V-491 units, connected to the grid between 2018 and 2020.²⁶⁰⁹

Nevertheless, several incidents and irregular situations occurred during the construction and commissioning phases in Belarus. In 2016, the reactor pressure vessel at Unit 1 was dropped during installation and had to be replaced. Eventually, a vessel, originally meant for Russia's never completed Baltic plant, was shipped to Belarus.²⁶¹⁰ Following the rushed commissioning, Unit 1 experienced numerous failures of transformers²⁶¹¹ and the turbogenerator. The commissioning of Unit 2 was also delayed by more than a year due to contamination of the primary circuit with ion-exchange resins in 2022.²⁶¹²

²⁶⁰² - Polina Smertina, "Спорный атом", *Kommersant*, 31 October 2023, op. cit.

²⁶⁰³ - *Interfax*, "Russian Duma Ratifies New Terms of Loan for Belarusian NPP", 21 September 2023, op. cit.

²⁶⁰⁴ - *Nucleonics Week*, "Belarus Looking at Additional Reactors as Power Consumption Grows", 28 August 2024, Vol. 65, Issue 35.

²⁶⁰⁵ - Alexey Venediktov, "Алексей Лихачев: 'Мы работаем на минимальном запасе рентабельности в Белоруссии'", interview with Alexey Likhachev, Director General, Rosatom, *Echo of Moscow*, as published on Атомная энергия 2.0, 16 September 2020, see <https://www.atomic-energy.ru/interviews/2020/09/16/106923>, accessed 30 May 2025.

²⁶⁰⁶ - Островецкого РУП ЖКХ, "Совмин утвердил Стратегию обращения с отработанным ядерным топливом БелАЭС", 28 August 2019, see <https://www.ostr-jkh.lpy.by/e/359-sovmin-utverdil-strategiyu-obrascheniya-s-otrabotannym-yadernym-toplivom-belaes>, accessed 30 May 2025.

²⁶⁰⁷ - *Interfax*, "Russia, Belarus Sign Agreement on Management of Spent Nuclear Fuel", 21 November 2022, see <https://interfax.com/newsroom/top-stories/85185/>, accessed 30 May 2025.

²⁶⁰⁸ - Rosatom, "Seeds of Cooperation", Newsletter #271, November 2023, see <https://rosatomnewsletter.com/2023/11/29/seeds-of-cooperation/>, accessed 7 June 2025.

²⁶⁰⁹ - Government of Belarus, "National Report of the Republic of Belarus on the Implementation of the Convention on Nuclear Safety", as released by the IAEA, 2022, see https://www.iaea.org/sites/default/files/24/02/cns_belarus_national_report_2022_9th_rm.pdf, accessed 30 May 2025.

²⁶¹⁰ - WNN, "Russia to Use Baltic NPP Reactor Vessel for Ostrovets 2", 25 April 2017, see <https://www.world-nuclear-news.org/Articles/Russia-to-use-Baltic-NPP-reactor-vessel-for-Ostrov>, accessed 7 June 2025.

²⁶¹¹ - Andrei Ozharovsky, "Imported Transformers Behind November Outage at Belarusian Nuclear Plant", translated by Charles Digges, Bellona, 18 March 2021, see <https://bellona.org/news/nuclear-issues/2021-03-imported-transformers-behind-november-outage-at-belarusian-nuclear-plant>, accessed 30 May 2025.

²⁶¹² - Bellona, "Bloomberg Article With Comments by Bellona Draws Sharp Reaction from Kremlin", 21 December 2023, see <https://bellona.org/news/nuclear-issues/2023-12-bloomberg-article-with-comments-by-bellona-draws-sharp-reaction-from-kremlin>, accessed 30 May 2025.

During the plant's construction, Lithuania raised concerns under the Espoo Convention, whose parties in 2019 concluded that Belarus provided adequate technical data but failed to justify the site choice.²⁶¹³ Lithuania has consistently demanded improvements to the plant's quality and safety in recent years, sending letters to both Belarus and the IAEA, as well as the E.U., calling for the suspension of the plant's operation until all issues are resolved.²⁶¹⁴

Moreover, the Belarusian regime does not foster trust through access to information in complex and high-risk matters such as nuclear projects. The E.U. has “imposed a series of sanctions against Belarus in response to the country's fraudulent elections of 2020, its human rights abuses, and its complicity with Russia's military aggression against Ukraine.” These sanctions are directed against individuals and specific sectors, primarily related to financial transactions and the import-export of certain products, including coal and crude oil.²⁶¹⁵

However, moving towards isolating Belarus is not a strategy universally adopted in the E.U. In April 2023, Hungary and Belarus signed a Memorandum of Cooperation in the Field of Nuclear Energy.²⁶¹⁶ This was followed in 2024 with the signature of a Roadmap for Cooperation between the Belarusian Nuclear Power Plant and its Hungarian counterparts. Another roadmap for 2025–2027 was signed in May 2025, as Hungary strived for Belarus' support on the completion of Rosatom's Paks II newbuild project.²⁶¹⁷ The strengthening of this cooperation was also supported by Rosatom's appointment of Vitaly Polyanin as director of the Paks II construction project in November 2023; prior to this, he led the construction of the Belarusian plant.²⁶¹⁸

In response to the war in Ukraine, electricity imports from Russia into E.U. member states have come under scrutiny, and in May 2022, the power exchange Nord Pool decided to stop trading Russian electricity.²⁶¹⁹ Further Baltic grid synchronization with the rest of Europe will physically exclude the import of electricity from Belarus. In February 2025, Estonia, Latvia,

²⁶¹³ - Parties to the Espoo Convention, “Compliance by Belarus with its Obligations under the Convention in Respect of the Belarusian Nuclear Power Plant in Ostrovets”, Excerpt from ECE/MP.EIA/27/Add.1 - ECE/MP.EIA/SEA/11/Add.1, United Nations Economic Commission for Europe, February 2019, see https://unece.org/DAM/env/eia/meetings/2019/IS_MOP_5-7_February_2019___Geneva/Decision_IS.id_.pdf, accessed 21 July 2025.

²⁶¹⁴ - State Nuclear Power Safety Inspectorate of Lithuania, “Belarusian NPP Unit 2 Goes Into Industrial Operation Without Resolving All Safety Issues”, 25 October 2023, see http://www.vatesi.lt/index.php?id=551&L=1&tx_news_pi1%Bnews%5D=1154&tx_news_pi1%Bcontroller%5D=News&tx_news_pi1%Baction%5D=detail&cHash=1c7e12aaf3801051716334bfe7382dob, accessed 29 October 2023; also State Nuclear Power Safety Inspectorate of Lithuania, “Belarusian NPP Continues to Operate with Disruptions, Safety Problems Remain Unresolved”, 23 January 2025, see <https://vatesi.lrv.lt/en/news/belarusian-npp-continues-to-operate-with-disruptions-safety-problems-remain-unresolved/>; and State Nuclear Power Safety Inspectorate of Lithuania, “Belarusian NPP Nuclear Safety Issues Remain Unresolved”, 23 May 2024, see <https://vatesi.lrv.lt/en/news/belarusian-npp-nuclear-safety-issues-remain-unresolved/>; both accessed 10 July 2025.

²⁶¹⁵ - European Council, “EU Sanctions Against Belarus”, Consilium, 13 August 2024, see <https://www.consilium.europa.eu/en/policies/sanctions-against-belarus/>, accessed 13 August 2024.

²⁶¹⁶ - Ministry of Foreign Affairs, “Foreign Minister of Belarus S.Aleinik pays a visit to Hungary”, Press Release, Government of Belarus, 12 April 2023, see https://mfa.gov.by/en/press/news_mfa/ba4cff7f5312bd12.html, accessed 7 June 2025.

²⁶¹⁷ - *Euractiv*, “Hungary Breaks the Diplomatic Isolation of Belarus by Seeking Help for Nuclear Plant”, 30 May 2024, see <https://www.euractiv.com/section/global-europe/news/hungary-breaks-the-diplomatic-isolation-of-belarus-by-seeking-help-for-nuclear-plant/>, accessed 13 August 2024; and Ministry of Energy, “A Roadmap for Cooperation Between Nuclear Power Plants of Belarus and Hungary Was Signed”, Government of Belarus, as published by Belarusian Nuclear Power Plant, 29 May 2024, see <https://www.belaes.by/en/news/item/4365-podpisana-dorozhnaya-karta-sotrudnichestva-aes-belarusi-i-vengrii.html>, accessed 1 September 2024; and *BelTA*, “Belarus, Hungary Sign Roadmap for Nuclear Energy Cooperation for 2025-2027”, 22 May 2025, see <https://eng.belta.by/economics/view/belarus-hungary-sign-roadmap-for-nuclear-energy-cooperation-for-2025-2027-168258-2025/>, accessed 21 July 2025.

²⁶¹⁸ - *MTI*, “New Head of the Paks II Nuclear Power Plant Project Revealed”, as published on *Hungary Today*, 22 November 2023, see <https://hungarytoday.hu/new-head-of-the-paks-ii-nuclear-power-plant-project-revealed/>, accessed 30 May 2025.

²⁶¹⁹ - *CEE Energy News*, “Lithuania Completely Cuts Imports of Russian Energy Supplies”, 23 May 2022, see <https://ceenergynews.com/ukraine-russia-crisis/lithuania-completely-cuts-imports-of-russian-energy-supplies/>, accessed 14 August 2024.

and Lithuania successfully connected to continental European electricity grids.²⁶²⁰ The loss of access to the Western European power market is significant, as higher revenues from the sale of electricity to the West improved the profitability of Ostrovets.

Russia and Belarus seek to develop a unified power market, and in December 2024, Putin and Lukashenko signed a treaty laying out the legal framework for the operation and regulation of a common market.²⁶²¹ According to the Belarusian Minister of Energy, the unified electricity market will be developed in stages. The rules for the market's operation were expected to be finalized and approved in the first half of 2025, with all interactions to be managed through authorized grid operators from both countries. However, as of July 2025, there have been no updates on progress toward this milestone.

Russia

See Focus Countries – [Russia Focus](#).

Ukraine

See Focus Countries – [Ukraine Focus](#).

²⁶²⁰ - Government of Lithuania, “Baltic Countries Successfully Connected to Continental European Electricity Grids”, 9 February 2025, see <https://lrv.lt/en/news/baltic-countries-successfully-connected-to-continental-european-electricity-grids/>, accessed 30 May 2025.

²⁶²¹ - BelTA, “Belarus, Russia Sign Agreement on Union State Unified Electricity Market”, 6 December 2024, see <https://eng.belta.by/society/view/belarus-russia-sign-agreement-on-union-state-unified-electricity-market-163707-2024/>, accessed 10 July 2025.

ANNEX 2 – CHINESE NUCLEAR REACTOR FLEET

Table 23 · Chinese Nuclear Reactors in Operation (as of 1 July 2025)

Reactor	Model	Net Capacity (MWe)	Construction Start	Grid Connection	Commercial Operation
Changjiang-1	CNP-600	601	25/04/2010	07/11/2015	25/12/2015
Changjiang-2	CNP-600	601	21/11/2010	20/06/2016	12/08/2016
Daya Bay-1	M310	944	07/08/1987	31/08/1993	01/02/1994
Daya Bay-2	M310	986	07/04/1988	07/02/1994	06/05/1994
Fangchenggang-1	CPR-1000	1000	30/07/2010	25/10/2015	01/01/2016
Fangchenggang-2	CPR-1000	1000	23/12/2010	15/07/2016	01/10/2016
Fangchenggang-3	HPR-1000 ^(a)	1000	24/12/2015	10/01/2023	25/03/2023
Fangchenggang-4	HPR-1000	1000	23/12/2016	09/04/2024	25/05/2024
Fangjiashan-1	CPR-1000	1012	26/12/2008	04/11/2014	15/12/2014
Fangjiashan-2	CPR-1000	1012	17/07/2009	12/01/2015	12/02/2015
Fuqing-1	CPR-1000*	1000	21/11/2008	20/08/2014	22/11/2014
Fuqing-2	CPR-1000*	1000	17/06/2009	06/08/2015	16/10/2015
Fuqing-3	CPR-1000*	1000	31/12/2010	07/09/2016	24/10/2016
Fuqing-4	CPR-1000*	1000	17/11/2012	29/07/2017	17/09/2017
Fuqing-5	HPR-1000	1075	07/05/2015	27/11/2020	30/01/2021
Fuqing-6	HPR-1000	1075	22/12/2015	01/01/2022	25/03/2022
Haiyang-1	AP-1000	1170	24/09/2009	17/08/2018	22/10/2018
Haiyang-2	AP-1000	1170	20/06/2010	13/10/2018	09/01/2019
Hongyanhe-1	CPR-1000	1061	18/08/2007	17/02/2013	06/06/2013
Hongyanhe-2	CPR-1000	1061	28/03/2008	23/11/2013	13/05/2014
Hongyanhe-3	CPR-1000	1061	07/03/2009	23/03/2015	16/08/2015
Hongyanhe-4	CPR-1000	1061	15/08/2009	01/04/2016	08/06/2016
Hongyanhe-5	ACPR-1000	1061	29/03/2015	25/06/2021	31/07/2021
Hongyanhe-6	ACPR-1000	1061	24/07/2015	02/05/2022	23/06/2022
Ling Ao-1	M310	950	15/05/1997	26/02/2002	28/05/2002
Ling Ao-2	M310	950	28/11/1997	14/09/2002	08/01/2003
Ling Ao-3	CPR-1000	1007	15/12/2005	15/07/2010	15/09/2010
Ling Ao-4	CPR-1000	1007	15/06/2006	03/05/2011	07/08/2011
Ningde-1	CPR-1000	1018	18/02/2008	28/12/2012	15/04/2013
Ningde-2	CPR-1000	1018	12/11/2008	04/01/2014	04/05/2014
Ningde-3	CPR-1000	1018	08/01/2010	21/03/2015	10/06/2015
Ningde-4	CPR-1000	1018	29/09/2010	29/03/2016	21/07/2016
Qinshan-1	CNP-300	326	20/03/1985	15/12/1991	01/04/1994
Qinshan 2-1	CNP-600	623	02/06/1996	06/02/2002	15/04/2002

Reactor	Model	Net Capacity (MWe)	Construction Start	Grid Connection	Commercial Operation
Qinshan 2-2	CNP-600	623	01/04/1997	11/03/2004	03/05/2004
Qinshan 2-3	CNP-600	623	28/04/2006	01/08/2010	05/10/2010
Qinshan 2-4	CNP-600	623	28/01/2007	25/11/2011	30/12/2011
Qinshan 3-1	CANDU 6	677	08/06/1998	19/11/2002	31/12/2002
Qinshan 3-2	CANDU 6	677	25/09/1998	12/06/2003	24/07/2003
Sanmen-1	AP-1000	1157	29/03/2009 ^(b)	30/06/2018	21/09/2018
Sanmen-2	AP-1000	1157	15/12/2009	24/08/2018	05/11/2018
Shidao Bay 1-1 ^(c)	HTR-PM	75 ^(c)	09/12/2012	20/12/2021	06/12/2023
Shidao Bay 1-2 ^(c)	HTR-PM	75 ^(c)	09/12/2012	12/2022?	06/12/2023
Shidaowan Guohe One-1 ^(d)	CAP1400	1400	06/04/2019 ^(e)	31/10/2024 ^(f)	
Taishan-1	EPR-1750	1660	28/10/2009 ^(g)	29/06/2018	13/12/2018
Taishan-2	EPR-1750	1660	15/04/2010	23/06/2019	07/09/2019
Tianwan-1	VVER V-428	1000	20/10/1999	12/05/2006	17/05/2007
Tianwan-2	VVER V-428	1000	20/10/2000 ^(h)	14/05/2007	16/08/2007
Tianwan-3	VVER V-428M	1060	27/12/2012	30/12/2017	14/02/2018
Tianwan-4	VVER V-428M	1060	27/09/2013	27/10/2018	22/12/2018
Tianwan-5	ACPR-1000*	1060	27/12/2015	08/08/2020	08/09/2020
Tianwan-6	ACPR-1000*	1060	07/09/2016	11/05/2021	02/06/2021
Yangjiang-1	CPR-1000	1000	16/12/2008	31/12/2013	25/03/2014
Yangjiang-2	CPR-1000	1000	04/06/2009	10/03/2015	05/06/2015
Yangjiang-3	CPR-1000	1000	15/11/2010	18/10/2015	01/01/2016
Yangjiang-4	CPR-1000	1000	17/11/2012	08/01/2017	15/03/2017
Yangjiang-5	ACPR-1000	1000	18/09/2013	23/05/2018	12/07/2018
Yangjiang-6	ACPR-1000	1000	23/12/2013	29/06/2019	24/07/2019
Zhangzhou-1	HPR-1000	1126	16/10/2019	28/11/2024	01/01/2025
Total Reactors in Operation: 59 Reactors / 56.7 GWe					

Sources: Various, compiled by WNISR, mainly based on IAEA-PRIS, with WNA, 2025

Notes and references:

- All information on this table from IAEA-PRIS database as of 1 July 2025, unless otherwise referenced.

- Net capacity refers to the Reference Unit Power (net) as of 1 July 2025.

* WNA data.

(a) HPR-1000 or Hualong One.

(b) Original construction start date from Chinas' Fifth Report to the Convention on Nuclear Safety; see Government of China, "The Fifth National Report Under the Convention on Nuclear Safety", May 2010, see https://www.iaea.org/sites/default/files/china_5th-national-report-china.pdf, accessed 14 July 2025. Confirmed by other sources. Later revised to 19 April 2009.

(c) The IAEA considers the two 100-MW modules as one reactor as they drive a single 200-MW turbine. WNISR counts each module as a separate reactor. Since 2023, the announced reference unit power for both is 150-MW, and has been arbitrarily allocated as half to each of the reactors.

Grid connection of the first unit of the twin reactors officially took place on 20 December 2021. No date was provided for startup of the second reactor, which WNISR considers as operating as of end-2022. See Government of China, "The Ninth National Report for the Convention on Nuclear Safety (2019-2021)", August 2022, see https://www.iaea.org/sites/default/files/24/01/9th_rm_national_report_cns_china.pdf, accessed 7 April 2025.

(d) WNISR previously used Shidao-Bay 2-1 and 2-2 as provisional names for the two CAP1400 at Rongcheng/Shidaowan. As of WNISR2025, it adopted the name Shidaowan Guohe One-1 & -2. They appear under the name "State Nuclear Power Demonstration Project" in China's Ninth Report to the Convention on Nuclear Safety; see Government of China, "The Ninth National Report for the Convention on Nuclear Safety (2019-2021)", August 2022, op. cit.

(e) Government of China, "The Ninth National Report for the Convention on Nuclear Safety (2019-2021)", August 2022, op. cit.

(f) WNN, "China's First CAP1400 Begins Supplying Power", *World Nuclear News*, 4 November 2024, see <https://world-nuclear-news.org/articles/china-first-cap1400-begins-supplying-power>, accessed 4 November 2024.

(g) According to EDF, first concrete at Taishan-1 was poured in October 2009; see for example EDF, “EDF in the UK–Investor Workshop”, 17 December 2010, see https://www.edf.fr/sites/groupe/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/financial-data/investors-analysts/events/investor-day-workshops/investorworkshop_edfuk20101210_2_o.pdf, accessed 29 August 2025.

(h) Original construction start date from China’s Third Report to the Convention on Nuclear Safety; see Government of China, “The Third National Report Under the Convention on Nuclear Safety”, August 2014, see https://www.iaea.org/sites/default/files/china_3rd-national-report-china.pdf, accessed 14 July 2025. Later revised to 20 September 2000.

Table 24 · Chinese Nuclear Reactors in LTO

Reactor	Model	Net Capacity (MWe)	Construction Start	Grid Connection	Commercial Operation
CEFR	BN-20	20	10/05/2000	21/07/2011	

Source: IAEA-PRIS, 2023

Note: The China Experimental Fast Reactor (CEFR) is not primarily a power generating reactor. However, as it was connected to the grid in 2011 at about 40 percent power and achieved full power for 72 hours starting 18 December 2014,¹ it is included in the WNISR. Its current operational status is uncertain. In the absence of operational data, WNISR considers it in LTO as of May 2023.

1 - See *Xinhua*, “China Experimental Fast Reactor Runs at Full Capacity” as published in *China Securities Journal*, 19 December 2014, see http://www.cs.com.cn/english/ei/201412/t20141219_4595461.html, accessed 28 May 2018.

ANNEX 3 – RUSSIA NUCLEAR INTERDEPENDENCIES

Table 25 · Fuel Supply for Soviet-designed Reactors in the E.U. and Ukraine (as of mid-2025)

Country	Nuclear Share 2024 ¹	Unit	Type	TVEL (Russia)	Westinghouse (U.S./Canada)	Framatome (France)
Bulgaria	41%	Kozloduy-5	VVER-1000	- Contract until end-2025², terminated early - Resumption of deliveries (March–April 2025)³	- 10-year supply contract (Dec. 2022)⁴ - First load (May 2024)⁵ - Second load (May 2025)⁶	-
		Kozloduy-6	VVER-1000		Contract for Safety Analysis to License Alternative Nuclear Fuel Design (Dec. 2024)⁷	- Preliminary Agreement for 10-year supply (Dec. 2022)⁸ - Supply contract for 2025–2034 (2023)⁹
Czech Republic	40.2%	Dukovany-1–4	VVER-440	- Fuel reload in Oct-2023 at Dukovany-4¹⁰ - Fuel reserve until approx. 2028¹¹ - Contract until 2028¹²	- 7-year supply contract starting 2024 (April 2023)¹³ - First delivery (June 2025)¹⁴	- Ongoing negotiations as of May 2025 ¹⁵
		Temelín-1–2	VVER-1000	- Supply since 2010¹⁶ - Contract until 2023¹⁷ - Last delivery in 2024¹⁸ - Fuel reload completed in June 2024¹⁹	- Supply 2000–2010²⁰ - 6 lead test assemblies loaded in 2019²¹ - 10+-year contract (June 2022), supply starting 2024²² - First delivery (June 2025)²³	- 10+-year contract (Jun-2022), supply was to begin in 2024;²⁴ ČEZ now expects delivery in 2026²⁵ - MoU on development of Framatome own-design VVER-1000 fuel program (Oct. 2024)²⁶
Finland	39.2%	Loviisa-1	VVER-440	Contract until end 2027 ²⁷	- Supply 2001–2007²⁸ - Supply contract (Nov. 2022)²⁹	
		Loviisa-2	VVER-440	Contract until end 2030 ³²	- Lead test assembly loaded: 2023³⁰ - First reload (Sept. 2024)³¹	
Hungary	42.8%	Paks-1–4	VVER-440	- “Lifetime” supply contract³³ - Fuel reserve until 2026³⁴		- MoU, incl. fuel supply (Sept. 2023)³⁵ - Supply contract for delivery starting 2027 (Oct. 2024)³⁶
Slovakia	61.5%	Bohunice-3–4	VVER-440	- Supply contract 2022–2026, with option until 2030 (June 2019)³⁷	- Supply contract (Aug. 2023)⁴⁰	- MoU, incl. fuel supply (May 2023)⁴² - Supply contract for delivery starting 2027 (July 2024)⁴³
		Mochovce-1–3	VVER-440	- Supply contract extended to 2030³⁸ - Fuel reserve until mid-2027³⁹	- First delivery 2026, first load 2027⁴¹	
Ukraine	52.4%	Rivne-1–2	VVER-440	Supply contract for 8 reactors 2021–2025 (Dec. 2018) ⁴⁴	- Since 2010, fuel supplied to 6 VVER-1000⁴⁵	
		Khmelnyskiy-1–2	VVER-1000		- Full load to South Ukraine-3 (July 2018)⁴⁶	
		Rivne-3–4	VVER-1000		- Supply contract for all Ukrainian reactors (June 2022)⁴⁷	
		South Ukraine-1–3	VVER-1000		- First load Rivne (Sept. 2023)⁴⁸	
		Zaporizhzhia-1–6	VVER-1000		- First delivery Khmelnyskiy (March 2024)⁴⁹	

- 1 - Based on gross production from Energy Institute, “Statistical Review of World Energy—Data”, June 2025, see https://www.energyinst.org/_data/assets/excel_doc/0008/1656215/EI-Stats-Review-ALL-data.xlsx, accessed 27 June 2025.
- 2 - TVEL, “TVEL and Kozloduy NPP Have Contracted Supplies of Russian Nuclear Fuel to Bulgaria through 2025”, 19 December 2019, see https://www.tvcl.ru/en/press-center/news/?ELEMENT_ID=8140, accessed 19 July 2023.
- 3 - Kozloduy NPP, “Annual Separate Management Report—Corporate Governance Statement—Independent Auditors’ Report—Annual Separate Financial Statements”, April 2025, see https://www.kznpp.org/upload/37109/Finacial_Report_2024.pdf, accessed 2 September 2025.
- 4 - Westinghouse, “Westinghouse’s VVER-1000 Nuclear Fuel Fabrication Agreement Helps Cement Bulgaria’s Energy Security”, Press Release, 22 December 2022, see <https://info.westinghousenuclear.com/news/westinghouse-vver-1000-nuclear-fuel-fabrication-agreement-helps-cement-bulgarias-energy>, accessed 7 July 2024.
- 5 - Westinghouse, “Westinghouse Delivers First VVER-1000 Fuel Reload to Bulgaria”, Press Release, 29 May 2024, see <https://info.westinghousenuclear.com/news/westinghouse-delivers-first-vver-1000-fuel-reload-to-bulgaria>, accessed 26 June 2024.
- 6 - Kozloduy Nuclear Power Plant, “Приключи Плановият Годишен Ремонт На Пети Блок На Аец „Козлодуй””, 11 June 2025, see <https://www.kznpp.org/bg/novini/638>, accessed 27 June 2025; and Nuclear Regulatory Agency of Bulgaria, “Приключи второто горивно зареждане на реактора на блок 5 на АЕЦ „Козлодуй” с касети RWFA”, Undated, see <https://bnra.bg/bg/novini-bnra/prikluychi-vtoroto-gorivno-zarezh-dane-na-reaktora-na-blok-5-na-aets-kozloduy-s-kaseti-rwfa/>, accessed 20 July 2025.
- 7 - Westinghouse, “Westinghouse and Kozloduy NPP Sign New Contract for Safety Analysis to License Alternative Nuclear Fuel Design for Unit 6”, Press Release, 20 December 2024, see <https://info.westinghousenuclear.com/news/westinghouse-and-kozloduy-npp-sign-new-contract-for-safety-analysis-to-license-alternative-nuclear-fuel-design-for-unit-6>, accessed 1 May 2025.
- 8 - Ministry of Energy, “Министър Христов: С подписаното споразумение с Фраматом завършва процесът по диверсификация на доставките за българската ядрена централа”, Government of Bulgaria, 30 December 2022, see <https://www.me.government.bg/bg/news/ministar-hristov-s-podpisanoto-sporazumenie-s-framatom-zavarshva-procesat-po-diversifikaciya-na-dostavkite-za-balgarskata-yadrena-centrala-3128.html>, accessed 13 August 2025; and WNN, “Kozloduy and Framatome Sign Nuclear Fuel Agreement”, 4 January 2023, see <https://www.world-nuclear-news.org/Articles/Kozloduy-and-Framatome-sign-nuclear-fuel-agreement>, accessed 4 January 2023.
- 9 - Various inconsistent dates have been communicated; see Council of Ministers, “Bulgaria and France Explore Opportunities for Cooperation in Power and Defense Sectors”, Government of Bulgaria, 12 October 2023, see <https://www.gov.bg/special/en/Press-center/News/Bulgaria-and-France-explore-opportunities-for-cooperation-in-power-and-defense-sectors>; and Framatome, “Framatome and Bulgarian Technical University to Collaborate on Education and Training”, Press Release, 2 May 2024, see <https://www.framatome.com/medias/framatome-and-bulgarian-technical-university-to-collaborate-on-education-and-training/>; both accessed 31 July 2024; also Council of Ministers, “First 43 Cassettes with Alternative Type of Fuel Produced by American Westinghouse Are Loaded at Kozloduy NPP”, Government of Bulgaria, 29 May 2024, see <https://www.gov.bg/en/Press-center/News/First-43-cassettes-with-alternative-type-of-fuel-produced-by-American-Westinghouse-are-loaded-at-Kozloduy-NPP>, accessed 20 July 2025.
- 10 - NEI Magazine, “Dukovany 4 to Switch to New Generation Russian Fuel”, 24 October 2023, see <https://www.neimagazine.com/news/dukovany-4-to-switch-to-new-generation-russian-fuel-11242878/>, accessed 28 June 2024.
- 11 - CEZ Group, “2024 Annual Financial Report”, 7 April 2025, see <https://www.cez.cz/webpublic/file/edee/ospol/fileexport/investori/vz-2024/cez-group-annual-financial-report-2024.pdf>, accessed 20 May 2025.
- 12 - CitiGroup and Deutsche Bank, “Base Prospectus—ČEZ, a. s.—€8,000,000,000 Euro Medium Term Note Programme”, ČEZ, April 2025, see <https://www.cez.cz/webpublic/file/edee/2025/04/cez-entn-base-prospectus-16-april-2025.pdf>, accessed 13 July 2025; and Denisa Funtíková, “Slovensko využilo možnosť odobrať ruské jadrové palivo, ktoré vystačí až do roku 2030. Česi ho začnú brať už tento rok radšej od Američanov”, *Denník E*, 14 November 2024, see <https://e.dennikn.sk/4306174/slovensko-vyuzilo-moznost-odobrat-ruske-jadrove-palivo-ktore-vystaci-az-do-roku-2030-cesi-ho-zacnu-brat-uz-tento-rok-radsej-od-americanov/>, accessed 1 July 2025.
- 13 - Westinghouse, “Westinghouse Reinforces its Commitment to Energy Security in Czech Republic”, Press Release, 29 March 2023, see <https://info.westinghousenuclear.com/news/westinghouse-reinforces-its-commitment-to-energy-security-in-czech-republic>, accessed 26 June 2024.
- 14 - CEZ Group, “First Westinghouse Nuclear Fuel Arrives in Dukovany”, 16 June 2025, see <http://www.cez.cz/en/media/press-releases/first-westinghouse-nuclear-fuel-arrives-in-dukovany-1-222263>, accessed 27 June 2025; and Westinghouse, “Westinghouse Completes First VVER Fuel Deliveries to Temelín and Dukovany Nuclear Power Plants”, Press Release, 16 June 2025, see <https://info.westinghousenuclear.com/news/westinghouse-completes-first-vver-fuel-deliveries-to-temelin-and-dukovany-nuclear-power-plants>, accessed 19 June 2025.
- 15 - Daniel Beneš, “Board of Directors’ Report on the Company’s Business Activities”, Chairman of the Board of Directors, and Chief Executive Officer, ČEZ, 14 May 2025, see https://www.cez.cz/webpublic/file/edee/ospol/fileexport-s/pro-investory/investor-relations/vh2025/aj/1a_en_zprava-pas-o-podnikatelske-cinnosti.pdf, accessed 12 July 2025.
- 16 - ČEZ, “Temelin Will Buy Fissionable Fuel from the Russian TVEL”, Press Release, 17 May 2006, see <https://www.cez.cz/en/media/press-releases/temelin-will-buy-fissionable-fuel-from-the-russian-tvel-70158>, accessed 8 July 2024.
- 17 - ČEZ, “Refueling Will Start at Temelín. Six Fuel Assemblies Made by Westinghouse Electric Sweden Will Be Tested”, Press Release, 4 April 2019, see <https://www.cez.cz/en/media/press-releases/refueling-will-start-at-temelin-six-fuel-assemblies-made-by-westinghouse-electric-sweden-will-be-tested-69837>, accessed 8 July 2024.
- 18 - CitiGroup and Deutsche Bank, “Base Prospectus—ČEZ, a. s.—€8,000,000,000 Euro Medium Term Note Programme”, ČEZ, April 2025, op. cit.

- 19 - CEZ Group, “The First Temelín Unit Produces Electricity Again. It Has Been Shut Down for Two Months to Inspect and Replace Fuel Assemblies”, Press Release, 12 June 2024, see <http://www.cez.cz/en/media/press-releases/the-first-temelin-unit-produces-electricity-again-it-has-been-shut-down-for-two-months-to-inspect-and-replace-fuel-assemblies-192183>, accessed 8 July 2024.
- 20 - Daniel Ernst and Lukáš Milisdörfer, “10 Years of Experience with Westinghouse Fuel at NPP Temelín”, ČEZ, as presented at the VVER 2010 Conference, 1–3 November 2010, see https://inis.iaea.org/collection/NCLCollectionStore/_Public/42/016/42016135.pdf, accessed 2 August 2023.
- 21 - Jan Höglund and Ulf Benjaminsson, “New Fuel for Temelín 1”, Technical Lead for Fuel Engineering, and Fuel Marketing Manager, Westinghouse, published in Nuclear Engineering International, 3 October 2019, see <https://www.neimagazine.com/analysis/new-fuel-temelin-1-7436970/>, accessed 29 June 2024; and ČEZ, “Temelín’s Unit 1 Restored The Electricity Production”, Press Release, 29 April 2019, see <https://www.cez.cz/en/media/press-releases/temelins-unit-1-restored-the-electricity-production-69835>, accessed 8 July 2024.
- 22 - ČEZ, “We Are Strengthening the Energy Security of the Czech Republic: We Have Signed Contracts for the Supply of Fuel Assemblies with Westinghouse and Framatome”, Press Release, 28 June 2022, see <https://www.cez.cz/en/media/press-releases/we-are-strengthening-the-energy-security-of-the-czech-republic-we-have-signed-contracts-for-the-supply-of-fuel-assemblies-with-westinghouse-and-framatome-160156>, accessed 26 July 2023; and Westinghouse, “Westinghouse Advances Energy Security in Czech Republic”, 28 June 2022, see <https://info.westinghousenuclear.com/news/westinghouse-advances-energy-security-in-cz>, accessed 26 June 2024.
- 23 - Westinghouse, “Westinghouse Completes First VVER Fuel Deliveries to Temelín and Dukovany Nuclear Power Plants”.
- 24 - ČEZ, “We Are Strengthening the Energy Security of the Czech Republic: We Have Signed Contracts for the Supply of Fuel Assemblies with Westinghouse and Framatome”, 28 June 2022, op. cit.
- 25 - CitiGroup and Deutsche Bank, “Base Prospectus—ČEZ, a. s.—€8,000,000,000 Euro Medium Term Note Programme”, ČEZ, April 2025, op. cit.
- 26 - Framatome, “Framatome Signs Memorandum of Understanding with ČEZ on Framatome Own Design VVER-1000 Fuel Program”, Press Release, 1 October 2024, see <https://www.framatome.com/medias/framatome-signs-memorandum-of-understanding-with-cez-on-framatome-own-design-vver-1000-fuel-program/>, accessed 5 May 2025.
- 27 - Fortum, “Sustainability 2023”, March 2024, see <https://www.fortum.com/files/fortum-sustainability-2023/download>, accessed 8 July 2024.
- 28 - Mark Dye, Jan Höglund and Ulf Benjaminsson, “Diversification of the VVER Fuel Market”, Nuclear Engineering International, September 2015, see <https://westinghousenuclear.com/media/15pjkvtk/westinghouse-reprint-vver-fuel-nei.pdf>, 29 June 2024.
- 29 - Westinghouse, “Helping Finland to Secure Its Energy Future”, Press Release, 22 November 2022, see <https://info.westinghousenuclear.com/news/helping-finland-secure-energy-future>, accessed 26 June 2024.
- 30 - Fortum, “Fortum’s Loviisa Nuclear Power Plant Generated 8.09 Terawatt-Hours of Carbon-Free Electricity in 2023”, Press Release, 4 January 2024, see <https://www.fortum.com/media/2024/01/fortums-loviisa-nuclear-power-plant-generated-809-terawatt-hours-carbon-free-electricity-2023>, accessed 4 June 2024.
- 31 - Westinghouse, “Westinghouse Completes First VVER-440 Fuel Reload at Finland’s Loviisa Nuclear Power Plant”, Press Release, 2 September 2024, see <https://info.westinghousenuclear.com/news/westinghouse-completes-first-vver-440-fuel-reload-at-finlands-loviisa-nuclear-power-plant>, accessed 1 May 2025.
- 32 - Fortum, “Sustainability 2023”, March 2024, op. cit.
- 33 - Rosatom, “TVEL Fuel Company of Rosatom Will Develop a Unique Modification of Nuclear Fuel for Paks NPP (Hungary)”, 13 November 2017, see <https://www.rusatom-energy.ru/en/media/rosatom-news/tvel-fuel-company-of-rosatom-will-develop-a-unique-modification-of-nuclear-fuel-for-paks-npp-hungary/>, accessed 8 July 2024.
- 34 - Charles Digges, “Europe Doubled Its Import of Russian Nuclear Fuel for 2023, Data Say”, Bellona, 15 March 2024, see <https://bellona.org/news/nuclear-issues/2024-03-europe-russian-nuclear-fuel>, accessed 27 June 2024.
- 35 - Framatome, “Framatome signs Memorandum of Understanding with Hungary to Extend Long-Term Cooperation in Nuclear Power”, Press Release, 12 September 2023, see <https://www.framatome.com/medias/framatome-signs-memorandum-of-understanding-with-hungary-to-extend-long-term-cooperation-in-nuclear-power/>, accessed 25 June 2024.
- 36 - Framatome, “Framatome to Supply Fuel to Hungarian VVER Reactors”, Press Release, 25 October 2024, see <https://www.framatome.com/medias/framatome-to-supply-fuel-to-hungarian-vver-reactors/?lang=en>, accessed 30 April 2025.
- 37 - SE, “Palivo pre jadrové elektrárne na Slovensku dodá spoločnosť TVEL”, Press Release, Slovenské elektrárne, 5 June 2019, see <https://www.seas.sk/tlacove-spravy/palivo-pre-jadrove-elektrarne-na-slovensku-doda-spolocnost-tvel/>, accessed 26 June 2024.
- 38 - Denisa Funtíková, “Slovensko využilo možnosť odobrať ruské jadrové palivo, ktoré vystačí až do roku 2030. Česi ho začnú brať už tento rok radšej od Američanov”, *Denník E*, 14 November 2024, op. cit.; and TASR, “Saková: Elektrárne majú zásoby jadrového paliva na ďalšieho 2,5 roka”, as published on *TERAZ.sk*, 14 November 2024, see <https://www.teraz.sk/priame-prenosy-a-videa-tasr-tv/sakova-elektrarne-maju-zasoby-jadro/836311-clanok.html>, accessed 18 May 2025.
- 39 - Ibidem.
- 40 - Westinghouse, “Westinghouse Strengthens Energy Security in Slovakia”, Press Release, 25 August 2023, see <https://info.westinghousenuclear.com/news/westinghouse-strengthens-energy-security-in-slovakia>, accessed 26 June 2024.
- 41 - Denisa Funtíková, “Slovensko využilo možnosť odobrať ruské jadrové palivo, ktoré vystačí až do roku 2030. Česi ho začnú brať už tento rok radšej od Američanov”, *Denník E*, 14 November 2024, op. cit.

42 - Framatome, “Framatome signs Memorandum of Understanding with Slovenské Elektrárne to Extend Long-Term Partnership”, Press Release, 31 May 2023, see <https://www.framatome.com/medias/framatome-signs-memorandum-of-understanding-with-slovenske-elektrarne-to-extend-long-term-partnership/>, accessed 25 June 2024.

43 - Framatome, “Framatome to Supply Fuel to VVER Reactors in Slovakia”, Press Release, 23 July 2024, see <https://www.framatome.com/medias/framatome-to-supply-fuel-to-vver-reactors-in-slovakia/>, accessed 30 April 2025.

44 - WNA, “Nuclear Power in Ukraine”, World Nuclear Association, Updated 25 March 2024, see <https://world-nuclear.org/Information-Library/Country-Profiles/Countries-T-Z/Ukraine>, accessed 28 June 2024.

45 - Ibidem.

46 - Westinghouse, “Full Core of Westinghouse Fuel Achieved at South-Ukraine Nuclear Power Plant Unit 3”, 19 July 2018, see <https://info.westinghousenuclear.com/news/full-core-of-westinghouse-fuel-achieved-at-south-ukraine-nuclear-power-plant-unit-3>, accessed 24 June 2024.

47 - Westinghouse, “Energoatom and Westinghouse Reaffirm Clean Energy Partnership, Announce Expanded Cooperation on Westinghouse-supplied VVER Fuel and AP1000® Plants to be Built in Ukraine”, 3 June 2022, see <https://info.westinghousenuclear.com/news/energoatom-and-westinghouse-reaffirm-clean-energy-partnership>, accessed 9 July 2024.

48 - Westinghouse, “Westinghouse Delivers First VVER-440 Fuel Assemblies to Energoatom”, Press Release, 12 September 2023, see <https://info.westinghousenuclear.com/news/westinghouse-delivers-first-vver-440-fuel-assemblies-to-energoatom>, accessed 17 November 2023.

49 - Energoatom, “The First Batches Of Westinghouse Nuclear Fuel Delivered To Khmelnytsky NPP”, 8 March 2024, see <https://energoatom.com.ua/en/news/na-hmelnicku-aes-zavezli-pershi-partiyi-yadernogo-paliva-westinghouse>, accessed 15 August 2025.

ANNEX 4 - STATUS OF NUCLEAR POWER IN THE WORLD

Table 26 · Status of Nuclear Power in the World (as of 1 July 2025)

Country	Nuclear Fleet					Power	Energy
	Operating		LTO	Mean Age ^(a)	Under Construction	Share of Commercial Electricity ^(b) (2024)	Share of Commercial Primary Energy ^(b) (2024)
	Units	Capacity ^(a) (MW)	Units	Years	Units		
Argentina	3	1 641		34.8		6.9% (=)	2.6% (=)
Armenia	1	416		45.5		30.8% (=)	N/A
Bangladesh	-	-		-	2		
Belarus	2	2 220		3.4		35.8% (+)	12.4% (+)
Belgium	4	3 463		45.1		41.4% (+)	12% (=)
Brazil	2	1 884		34.1		2.1% (=)	1% (=)
Bulgaria	2	2 006		35.8		41% (=)	N/A
Canada	15	11 066	2	40.7/40.8		13.4% (=)	5.5% (=)
China	59	56 720	1	11.1	32	4.5% (=)	2.3% (=)
Czech Republic	6	3 963		34		40.2% (=)	18.8% (=)
Egypt					4		
Finland	5	4 369		37.7		39.2% (-)	24.2% (-)
France	57	63 000		39.4		67.8% (+)	37.5% (+)
Hungary	4	1 916		40		42.8% (-)	15.3% (=)
India	21	7 550	3	25/21.2	6	2.7% (=)	1.2% (=)
Iran	1	915		13.8	1	1.9% (=)	0.5% (=)
Japan	14	12 631	19	34.5/38.7		8.4% (=)	4.4% (=)
Mexico	2	1 552		33.4		3.5% (=)	1.3% (=)
Netherlands	1	482		52		2.9% (=)	1% (=)
Pakistan	6	3 262		10.6	1	17% (=)	6.4% (=)
Romania	2	1 300		23.5		20.1% (=)	7.6% (=)
Russia	36	26 802		31.5	7	17.8% (=)	5.9% (=)
Slovakia	5	2 302		27.1	1	61.5% (=)	N/A
Slovenia	1	688		43.7		33.1% (-)	N/A
South Africa	2	1 854		40.6		3.3% (=)	1.4% (=)
South Korea	24	23 973	2	24.2/22.8	3	30.2% (=)	13% (=)
Spain	7	7 123		40.4		19.1% (=)	8.4% (=)
Sweden	6	7 008		43		29.4% (=)	20.6% (=)
Switzerland	4	2 973		49.3		28.6% (-)	16.8% (-)
Taiwan	-	-		-		4.2% (-)	2.4% (-)
Türkiye	-	-		-	4		
UAE	4	5 348		3.2		22.9% (+)	6.6% (=)
U.K.	9	5 883		38.1	2	14.2% (=)	5.2% (=)
Ukraine	9	7 407	6	36.4/36		52.4% (+)	21.9% (=)
U.S.	94	96 952		43.7		17.8% (=)	7.7% (=)
EU27	100	97 620		38.7	1	23.2 (=)	10.1% (=)
World	408	368 669	33	32.6/32.4	63	9.01% (=)	4% (=)

Notes: LTO=Long-Term Outage.

(a) – Including reactors in LTO/Excluding reactors in LTO.

(b) – All shares for 2024, from Energy Institute, “Statistical Review of World Energy”, 2025, except Armenia (IAEA-PRIS data). Energy share based on Energy Institute’s fossil-fuel equivalent or substitution method.

Sources: WNISR with Energy Institute and IAEA-PRIS, 2025

ANNEX 5 – NUCLEAR REACTORS IN THE WORLD “UNDER CONSTRUCTION”

Table 27 · Nuclear Reactors in the World “Under Construction” (as of 1 July 2025)

Country / Reactors	Qty	Capacity MW net ¹	Model	Initial Construction Start	Scheduled Startup at Construction Start ²	Scheduled Startup as of mid-2025 ³	Delayed ⁴
Bangladesh	2	2 160					
Rooppur-1		1 080	VVER V-523	30/11/2017	2023 ⁵	2025 ⁶	Further delayed
Rooppur-2		1 080	VVER V-523	14/07/2018	2024 ⁷	2027 ⁸	Further delayed
China	32	34 512					
Changjiang SMR-1 ⁹		100	ACP100 ¹⁰	13/07/2021	2026 ¹¹	2026	
Changjiang-3		1 000	HPR-1000 ¹²	31/03/2021	2026 ¹³	2026	
Changjiang-4		1 000	HPR-1000	28/12/2021	2026 ¹⁴	2026	
Haiyang-3		1 161	CAP1000	07/07/2022	2027 ¹⁵	2027	
Haiyang-4		1 161	CAP1000	22/04/2023	2027 ¹⁶	2027	
Lianjiang-1		1 224 ¹⁷	CAP1000	29/09/2023	2028 ¹⁸	2028	
Lianjiang-2		1 224 ¹⁹	CAP1000	26/04/2024	2028 ²⁰	2028	
Lufeng-1		1 224 ²¹	CAP1000	24/02/2025 ²²	2030 ²³	2030 ²⁴	
Lufeng-5		1 116	HPR-1000	08/09/2022	2027 ²⁵	2027 ²⁶	
Lufeng-6		1 116	HPR-1000	26/08/2023	2028 ²⁷	2028 ²⁸	
Ningde-5		1 200	HPR-1000	28/07/2024	2029 ²⁹	2029 ³⁰	
Sanao-1 ³¹		1 117	HPR-1000	31/12/2020	2026 ³²	2026 ³³	
Sanao-2		1 117	HPR-1000	30/12/2021	2027 ³⁴	2027 ³⁵	
Sanmen-3		1 163	CAP1000	28/06/2022	2027 ³⁶	2027 ³⁷	
Sanmen-4		1 163	CAP1000	23/03/2023	2027 ³⁸	2027 ³⁹	
Shidaowan Guohe One-2 ⁴⁰		1 400 ⁴¹	CAP1400	2/11/2019 ⁴²	2024 ⁴³	2025?	Delayed
Shidaowan-1		1 134	HPR-1000	28/07/2024	2029 ⁴⁴	2029	
Shidaowan-2		1 134	HPR-1000	08/05/2025	2030 ⁴⁵	2030	
Taipingling-1 ⁴⁶		1 116	HPR-1000	26/12/2019	2025 ⁴⁷	2025 ⁴⁸	
Taipingling-2		1 116	HPR-1000	15/10/2020	2026 ⁴⁹	2026 ⁵⁰	
Taipingling-3		1 116	HPR-1000	10/06/2025	2030 ⁵¹	2030	
Tianwan-7		1 171	VVER V-491	19/05/2021	2026 ⁵²	2026	
Tianwan-8		1 171	VVER V-491	15/02/2022	2027 ⁵³	2027	
Xiapu-1		642	CFR-600	29/12/2017	2023 ⁵⁴	2025 ⁵⁵	Delayed?
Xiapu-2		642	CFR-600	27/12/2020	2026 ⁵⁶	2026	

Country / Reactors	Qty	Capacity MW net ¹	Model	Initial Construction Start	Scheduled Startup at Construction Start ²	Scheduled Startup as of mid-2025 ³	Delayed ⁴
Xudapu-1 ⁵⁷		1 000	CAP1000	15/11/2023	2028 ⁵⁸	2028	
Xudapu-2		1 000	CAP1400	17/07/2024	2029 ⁵⁹	2029	
Xudapu-3		1200	VVER V-491	19/05/2021	2027 ⁶⁰	2027	
Xudapu-4		1200	VVER V-491	19/05/2022	2028 ⁶¹	2028	
Zhangzhou-2		1 126	HPR-1000	04/09/2020	2025 ⁶²	2025 ⁶³	
Zhangzhou-3		1 129	HPR-1000	22/03/2024	2028/2029 ⁶⁴	2028/2029	
Zhangzhou-4		1 129	HPR-1000	27/09/2024	2029 ⁶⁵	2029	
Egypt	4	4 400					
El Dabaa-1		1100	VVER-1200	20/07/2022	2028 ⁶⁶	2028 ⁶⁷	
El Dabaa-2		1100	VVER-1200	19/11/2022	2029 ⁶⁸		
El Dabaa-3		1100	VVER-1200	03/05/2023	2030 ⁶⁹		
El Dabaa-4		1100	VVER-1200	23/02/2024	2030/2031 ⁷⁰		
India	6	4 768					
Kudankulam-3		917	VVER V-412	29/06/2017	2023 ⁷¹	2026 ⁷²	Further delayed
Kudankulam-4		917	VVER V-412	23/10/2017	2023 ⁷³	2027 ⁷⁴	Further delayed
Kudankulam-5		917	VVER V-412	29/06/2021	2026 ⁷⁵	2027 ⁷⁶	Delayed
Kudankulam-6		917	VVER V-412	20/12/2021	2027 ⁷⁷	2028 ⁷⁸	Delayed
PFBR		470	FBR	23/10/2004	2010 ⁷⁹	2026 ⁸⁰	Further delayed
Rajasthan-8		630	PHWR	30/09/2011	2016 ⁸¹	2026 ⁸²	Delayed several times
Iran	1	974					
Bushehr-2		974	VVER V-446	02/1976 ⁸³	?	2029 ⁸⁴	Further delayed
Pakistan	1	1 117					
Chasnupp-5 ⁸⁵		1 117	HPR1000	30/12/2024	2030 ⁸⁶	2030	
Russia	7	5 110					
BREST-OD-300		300	FBR	08/06/2021	2026? ⁸⁷	2028 ⁸⁸	Delayed
Kursk 2-1		1200	VVER V-510	29/04/2018	2022 ⁸⁹	2025 ⁹⁰	Further delayed
Kursk 2-2		1200	VVER V-510	15/04/2019	2023 ⁹¹	2027 ⁹²	Delayed
Leningrad 2-3 ⁹³		1 150	VVER V-491	14/03/2024	01/2030 ⁹⁴	12/2030 ⁹⁵	Delayed?
Leningrad 2-4 ⁹⁶		1 150	VVER V-491	20/03/2025	2032 ⁹⁷		
Cape Nagloynyn 1-1 ⁹⁸		55	RITM-200S	30/08/2022	2027 ⁹⁹	2028 ¹⁰⁰	Delayed?
Cape Nagloynyn 1-2		55	RITM-200S	30/08/2022	2027 ¹⁰¹	2028 ¹⁰²	Delayed?
Slovakia	1	440					
Mochovce-4		440	VVER V-213	01/01/1985 ¹⁰³	1992 ¹⁰⁴	2025 ¹⁰⁵	Further delayed
South Korea	3	4 020					
Saeul-3 ¹⁰⁶		1340	APR-1400	03/04/2017 ¹⁰⁷	10/2021 ¹⁰⁸	02/2026 ¹⁰⁹	Further delayed
Saeul-4		1340	APR-1400	19/09/2018 ¹¹⁰	03/2023 ¹¹¹	11/2026 ¹¹²	Further delayed
Shin-Hanul-3		1340	APR-1400	20/05/2025	10/2032 ¹¹³ (commercial operation)		

Country / Reactors	Qty	Capacity MW net ¹	Model	Initial Construction Start	Scheduled Startup at Construction Start ²	Scheduled Startup as of mid-2025 ³	Delayed ⁴
Türkiye	4	4 456					
Akkuyu-1		1 114	VVER V-509	03/04/2018	2023 ¹¹⁴	2026 ¹¹⁵	Further delayed
Akkuyu-2		1 114	VVER V-509	08/04/2020	2024 ¹¹⁶	2027 ¹¹⁷	Further delayed
Akkuyu-3		1 114	VVER V-509	10/03/2021	2025 ¹¹⁸	2028 ¹¹⁹	Further delayed
Akkuyu-4		1 114	VVER V-509	21/07/2022	2026	2029 ¹²⁰	Further delayed
U.K.	2	3 260					
Hinkley Point C-1		1 630	EPR-1750	11/12/2018 ¹²¹	2025 ¹²²	2030? ¹²³	Delayed several times
Hinkley Point C-2		1 630	EPR-1750	10/12/2019 ¹²⁴	2026	2031? ¹²⁵	Delayed several times
World	63	65 217		1976–2025		2025–2031	22–26

Notes

1 - As declared in the IAEA-PRIS database, unless otherwise noted.

2 - This scheduled startup date is the date provided or in use at **construction start** when available, i.e., NOT projected date at any stage prior to construction start; when possible, this refers to grid connection, alternatively to commercial operation, completion, or commissioning information or is based on expected construction duration or WNISR estimates from authoritative sources (as referenced).

3 - Expected grid connection date or other “startup date” based on official announcements or WNISR estimates from authoritative sources (as referenced), as of 1 July 2025.

4 - “Further delayed” indicates that a construction is delayed (startup pushed back) compared to the date indicated in WNISR2024.

5 - Rosatom, “First Concrete Poured at the Constructed Rooppur NPP Site (Bangladesh)”, Press Release, 30 November 2017, see <http://www.rusatom-overseas.com/media/news/first-concrete-poured-at-the-site-constructed-npp-rooppur-bangladesh.html>, accessed 17 August 2020.

6 - Grid connection of Rooppur-1 is presented as one of the “priorities for Rosatom” for 2025, but questions remain. See *Страна РОСАТОМ*, “Шесть вызовов ближайших шести лет: в «Росатоме» прошел день информирования”, Rosatom, 10 March 2025, see <https://strana-rosatom.ru/2025/03/10/shest-vyzovov-blizhajshih-shesti-let-v-r/>, accessed 18 March 2025; and *The Financial Express*, “Bangladesh Unlikely to Get Electricity From Rooppur Power Plant Before 2026”, 6 March 2025, see <https://thefinancialexpress.com.bd/trade/bangladesh-unlikely-to-get-electricity-from-rooppur-power-plant-before-2026>, accessed 15 March 2025.

7 - Rosatom, “Main Construction of the 2nd Unit of Rooppur NPP Begins with the ‘First Concrete’ Ceremony”, Press Release, 14 July 2018, see <http://rosatom.ru/en/press-centre/news/main-construction-of-the-2nd-unit-of-rooppur-npp-begins-with-the-first-concrete-ceremony/>, accessed 15 July 2018.

8 - In 2024, commercial operation was pushed back to 2026. See *The Business Standard*, “PM Hasina Wants Russian Rosatom To Build Another Nuclear Power Plant At Rooppur”, 2 April 2024, see <https://www.tbsnews.net/bangladesh/energy/pm-hasina-wants-russian-rosatom-build-another-nuclear-power-plant-rooppur-821276>, accessed 3 May 2024.

Shortly after, the project’s deadline was extended by two years to end of 2027, and Unit 2 “is now expected to begin production no earlier than 2027.” See *Prothomalo*, “Transmission Line Commissioned, Yet Rooppur Not Ready”, 16 June 2025, see <https://en.prothomalo.com/bangladesh/5nclaklsd>, accessed 27 June 2025.

9 - The Changjiang SMR is listed as Linglong-1 (Hainan Changjiang SMR) in IAEA-PRIS statistics.

10 - The ACP100 also goes by the name Linglong One.

11 - No official startup date as of construction start. According to WNN, “Construction time is expected to be 58 months.” See WNN, “China Starts Construction of Demonstration SMR”, 13 July 2021, see <https://www.world-nuclear-news.org/Articles/China-starts-construction-of-demonstration-SMR>, accessed 16 July 2021; and CNNC, “Workshop on the Application of Small Modular Reactor held in Hainan”, 8 September 2023, see https://en.cnncc.com.cn/2023-09/08/c_1023349.htm, accessed 5 April 2025.

12 - The HPR-1000 also goes by the name Hualong One.

13 - Construction period is expected to be 60 months. See *NEI Magazine*, “First Concrete Poured for China’s Changjiang 3”, *Nuclear Engineering International*, 1 April 2021, see <https://www.neimagazine.com/news/newsfirst-concrete-poured-for-chinas-changjiang-3-8644649>, accessed 2 April 2021.

14 - WNN, “Construction Begins at Second Changjiang Hualong One”, 29 December 2021, see <https://world-nuclear-news.org/Articles/Construction-begins-at-second-Changjiang-Hualong-O>, accessed 30 December 2021.

15 - No official startup date provided at construction start. WNISR used 2027, confirmed at construction start of Haiyang-4. See following note.

- 16 - According to Shanghai Nuclear Engineering Research and Design Institute (SNERDI), construction time of Haiyang-3 and -4 is expected to be 56 months, with both units to be in operation in 2027.
See SNERDI, “海阳核电4号机组顺利实现FCD”, Press Release, Shanghai Nuclear Engineering Research & Design Institute Co, LTD., 22 April 2023, see <https://www.snerdi.com.cn/newsdetail?id=9277>, accessed 28 April 2023.
- 17 - As of July 2025, IAEA-PRIS uses 1224 MW for both Gross and Net capacity.
- 18 - CCNP, “国家电投广东廉江核电一期工程开工”, 8 October 2023, see <https://www.cnnpn.cn/article/39053.html>, accessed 29 August 2025; and State Nuclear Zhanjiang Nuclear Power Company Ltd, “广东廉江核电厂 1、2 号机组环境影响报告书” June 2022, see https://www.mee.gov.cn/ywdt/gsgg/gongshi/wqgs_1/202210/W020230110587145294082.pdf, accessed 28 August 2025.
- 19 - As of July 2025, IAEA-PRIS uses 1224 MW for both Gross and Net capacity.
- 20 - State Nuclear Zhanjiang Nuclear Power Company Ltd, “广东廉江核电厂 1、2 号机组环境影响报告书” June 2022, op. cit.
- 21 - As of July 2025, Lufeng-1 is not counted as under construction in IAEA-PRIS, WNISR2025 uses capacity provided for CAP1000 reactors at Lianjiang.
- 22 - CGN Power, “Immediate Commencement of Full Construction of Lufeng 1 Unit”, China General Nuclear Power Corporation, 21 February 2025, see <http://en.cgnp.com.cn/encgnp/c2025-02/21/47394a317bca4adaa26876c03ffe9900/files/d5704e3b956b44bda6611288634da712.pdf> accessed 21 February 2025.
- 23 - CGN Power, “Inside Information Operation Briefings for the First Quarter of 2025”, April 2025, see <http://en.cgnp.com.cn/encgnp/c2025/2025-04/09/16088034f34047849e456267869683c2/files/4200560372aa4e73b931c5b30f6343ee.pdf>, accessed 11 April 2025.
- 24 - CGN Power, “Inside Information Operation Briefings for the Second Quarter of 2025”, 7 July 2025, see <http://en.cgnp.com.cn/encgnp/c2025/2025-07/07/64d180dd90f74dde9e608cf61aa26d77/files/4251705d6cb5475788eb167d9593d775.pdf>, accessed 10 July 2025.
- 25 - CGN Power, “Inside Information - Operation Briefings for the Fourth Quarter of 2022”, 9 January 2023, see <http://en.cgnp.com.cn/encgnp/c22122503/2023-01/09/5dea667175824ede9c0ff34882623bec/files/2537af48e9584a85bdd4130e23b7c749.pdf>, accessed 11 January 2023.
- 26 - CGN Power, “Inside Information Operation Briefings for the Second Quarter of 2025”, 7 July 2025, op. cit.
- 27 - CGN Power, “2023 Annual Report”, April 2024, see <http://en.cgnp.com.cn/encgnp/c100882/2024-04/11/cb76379ce6e04b15829f4f8686032e0e/files/e0670ca0ee664b9a977afc238c6e47f4.pdf>, accessed 13 May 2024.
- 28 - CGN Power, “Inside Information Operation Briefings for the Second Quarter of 2025”, 7 July 2025, op. cit.
- 29 - CGN Power, “2024 Interim Report”, August 2024, see <http://en.cgnp.com.cn/encgnp/c100882/2024-08/26/2ac413a6c41e49909doe738b8ed46956/files/d83c3e5adff8944b4baa997471836e494.pdf>.
- 30 - CGN Power, “Inside Information Operation Briefings for the Second Quarter of 2025”, 7 July 2025, op. cit.
- 31 - Sanao reactors (also called San’ao or Cangnan) previously appeared under the name Sanaocun.
- 32 - CGN Power, “2020 Annual Report”, April 2021, see <http://en.cgnp.com.cn/encgnp/c100882/2021-04/08/c95f2296e95a4aab8a1d7b749996bb43/files/72fd1f144fa44cefb5496fb45eaaab6.pdf>, accessed 1 June 2021.
- 33 - CGN Power, “Inside Information Operation Briefings for the Second Quarter of 2025”, 7 July 2025, op. cit.
- 34 - CGN Power, “2021 Annual Report”, April 2022, see <http://en.cgnp.com.cn/encgnp/c100882/2022-04/07/c458fe3cfd6e4e93950b586f499ce402/files/8787336618b24d2090doeae9e1554d6.pdf>, accessed 7 April 2022.
- 35 - CGN Power, “Inside Information Operation Briefings for the Second Quarter of 2025”, 7 July 2025, op. cit.
- 36 - No official information on expected startup date at construction start. WNISR uses the 56-month construction period announced for other CAP1000 reactors.
- 37 - CNNPN, “国内核电运营商新建项目建设进展, CNNC, 23 December 2024, see <https://www.cnnpn.cn/article/45423.html>, accessed 29 August 2025.
- 38 - No official information on expected startup date at construction start. WNISR uses the 56-month construction period announced for other CAP1000 reactors.
- 39 - CNNPN, “国内核电运营商新建项目建设进展, 23 December 2024, op. cit.
- 40 - Construction of two CAP1400 reactors at Rongcheng/Shidaowan was introduced in WNISR statistics in 2020 following *Nuclear Intelligence Weekly* (NIW) articles (in particular July 2019) and confirmation from sources in China. In July 2019, NIW classified the two units as “under construction” on the basis of the Chinese National Nuclear Safety Administration (NNSA) map as of June 2019. See NIW, “Chinese Power Reactor Project Wrapped in Secrecy”, *Nuclear Intelligence Weekly*, 12 July 2019. Those reactors now appear in the Chinese National Report to the Convention on Nuclear Safety under the name “State Nuclear Power Demonstration Project”; see The People’s Republic of China, “The Ninth National Report for the Convention on Nuclear Safety (2019-2021)”, August 2022, see https://www.iaea.org/sites/default/files/24/01/9th_rm_national_report_cns_china.pdf, accessed 7 April 2025.
- 41 - No net capacity available.
- 42 - The People’s Republic of China, “Appendix 1: List of NPPs in China (As of December 31, 2021)”, in The Ninth National Report for the Convention on Nuclear Safety (2019-2021), 2022, op. cit.
- 43 - No official information. WNISR used the 56-month expected construction duration of CAP1400.
- 44 - WNN, “Construction Starts on Two New Chinese Units”, 29 July 2024, see <https://www.world-nuclear-news.org/Articles/Construction-starts-on-two-new-Chinese-units>, accessed 29 July 2024.
- 45 - No official startup date provided at construction start. WNISR uses the same construction duration as Unit 1.

46 - Also known as Huizhou.

47 - CGN Power, “2020 Interim Report”, August 2020 see <http://en.cgnp.com.cn/encgnp/c100882/2020-08/28/65c9960544a4422689f657433efe105b/files/01b7e4aee8204dfda4b823a416a196c8.pdf>.

48 - CGN Power, “Inside Information Operation Briefings for the Second Quarter of 2025”, 7 July 2025, op. cit.

49 - CGN Power, “2020 Annual Report”, 2021, op. cit.

50 - CGN Power, “Inside Information Operation Briefings for the Second Quarter of 2025”, 7 July 2025, op. cit.

51 - Ibidem.

52 - According to sources in China, the contract between China and Russia stipulated a construction duration of 65 months. Rosatom stated about the Tianwan-7 and -8 project “the units are scheduled to be commissioned in 2026-2027”. See Rosatom, “Start of New Unit Construction at China’s Tianwan and Xudapu Nuclear Power Plants”, Press Release, 19 May 2021, see <https://rosatom.ru/en/press-centre/news/start-of-new-unit-construction-at-china-s-tianwan-and-xudapu-nuclear-power-plants>, accessed 14 June 2021.

53 - ASE Rosatom, “The First Concrete Has Been Laid at Tianwan NPP Power Unit 8 in China”, 28 February 2022, see <https://ase-ec.ru/en/for-journalists/news/2022/feb/the-first-concrete-has-been-laid-at-tianwan-npp-power-unit-8-in-china/>, accessed 28 February 2022.

54 - Commercial operation at construction start was expected in 2023. See WNN, “China Begins Building Pilot Fast Reactor”, 29 December 2017, see <http://www.world-nuclear-news.org/NN-China-begins-building-pilot-fast-reactor-2912174.html>, accessed 30 December 2017.

55 - Operating? Grid connection delayed? According to Chinese sources, reported by IPFM, as of mid-2023, the CFR-600 was operating at low power but no information on electricity production or grid connection had been provided. See Hui Zhang, “China started operation of its first CFR-600 breeder reactor”, IPFM Blog, 15 December 2023, see https://fissilematerials.org/blog/2023/12/china_started_operation_o.html, accessed 3 May 2024.

56 - No official information about expected grid connection. WNISR2024 uses 2026 (same originally expected duration as Xiapu-1).

57 - Also known as Xudabu or Xudabao.

58 - CNNC, “助力东北全面振兴 辽宁徐大堡核电站1号机组核岛开工”, 16 November 2023, see <https://www.cnncc.com.cn/cnncc/xwzx65/ttywo1/1380782/index.html>, accessed 30 August 2025.

59 - CNNC, “刚刚，中核又一台核电机组开工！”, 17 July 2024, see <https://www.cnncc.com.cn/cnncc/xwzx65/zhyywo/1442392/index.html>, accessed 30 August 2025.

60 - According to sources in China, the expected construction duration of VVER-1200/V-491 is 69 months. At construction start, Rosatom stated about the Xudapu/Xudabu Project, “the units are expected to be commissioned in 2027-2028.” See Rosatom, “Start of New Unit Construction at China’s Tianwan and Xudapu Nuclear Power Plants”, Press Release, 19 May 2021, see <https://rosatom.ru/en/press-centre/news/start-of-new-unit-construction-at-china-s-tianwan-and-xudapu-nuclear-power-plants/>, accessed 14 June 2021.

61 - According to Rosatom at construction start of Unit 4, commissioning of Xudabu-3 and -4 is scheduled for 2027-2028. See ASE-Rosatom, “First Concrete Laid at Xudapu NPP Power Unit 4 in China”, Press Release, 19 May 2022, see <https://ase-ec.ru/en/for-journalists/news/2009/may/first-concrete-laid-at-xudapu-npp-power-unit-4-in-china/>, accessed 19 May 2022.

62 - WNN, “Zhangzhou Unit 2 Construction Starts”, 4 September 2020, see <https://www.world-nuclear-news.org/Articles/Construction-starts-of-second-Zhangzhou-unit>, accessed 4 September 2020. Construction duration of Hualong One design is given as 60 months.

63 - CNNC, “No. 2 Unit of Zhangzhou Nuclear Power Plant Passes Hot Functional Test”, 11 April 2025, see https://en.cnncc.com.cn/2025-04/11/c_1085304.htm, accessed 30 August 2025.

64 - No official startup date at construction start. Construction duration of Hualong One design is given as 60 months. However, *China Global Television Network (CGTN)* quotes 2028 for commencement of operation. See CGTN, “Construction on New Unit of Zhangzhou Nuclear Power Plant Underway in Fujian”, 23 February 2024, see <https://news.cgtn.com/news/2024-02-23/Construction-on-new-unit-of-Zhangzhou-nuclear-power-plant-underway-1rqt4dAP1Li/p.html>, accessed 10 May 2024.

65 - No official startup date at construction start. Construction duration of Hualong One design is given as 60 months.

66 - *EgyptToday*, “Egypt’s Nuclear Plants Authority, Rosatom Committed to Dabaa Plant Construction Schedule: Official”, 9 May 2022, see <https://www.egypttoday.com/Article/3/115597/Egypt's-Nuclear-Plants-Authority-Rosatom-committed-to-Dabaa-plant-construction>, accessed 17 July 2022.-

67 - *CairoScene*, “First Unit of El Dabaa Nuclear Power Plant to Begin Operation in 2028”, 26 January 2025, see <https://cairosce.com/Buzz/First-Unit-of-El-Dabaa-Nuclear-Power-Plant-to-Begin-Operation-in-2028>, accessed 3 April 2025.

68 - No official specific startup date for El Dabaa-2 as of construction start. WNISR uses 2029 as previously announced, see *EgyptToday*, “Egypt’s Nuclear Plants Authority, Rosatom Committed to Dabaa Plant Construction Schedule: Official”, 9 May 2022, op. cit. (WNA uses 2030 for El Dabaa 2-4).

69 - No official specific startup date for El Dabaa-3 as of construction date; however, according to the Ministry of Electricity as of June 2023, all four units are to be completed by 2030 or 2031. “Dabaa nuclear plant project progresses according to schedule: Minister of Electricity”, *Daily News Egypt*, 14 June 2023, see <https://www.dailynewsegypt.com/2023/06/14/dabaa-nuclear-plant-project-progresses-according-to-schedule-minister-of-electricity/>, accessed 22 August 2023. WNISR uses 2030 (WNA uses 2030 for El Dabaa 2-4).

70 - No official specific startup date for El Dabaa-4 as of construction date. As all four units are expected online by 2030 or 2031 (see previous note), WNISR uses 2031. In February 2025, Rosatom’s CEO Likachev told TASS that Rosatom still expects to complete all four

units by 2030. See TASS, “Rosatom Plans to Begin Physical Start-up Procedures at Egypt’s El Dabaa NPP in 2027”, as published by *Pravda Egypt*, 18 February 2025, see <https://egypt.news-pravda.com/en/world/2025/02/18/1689.html>, accessed 27 June 2025.

71 - Department of Atomic Energy, “Rajya Sabha: Unstarred Question No. 2723– Commissioning of Unit-3 of Kudankulam NPP–Answered on 10.08.2017”, Government of India, see <http://dae.nic.in/writereaddata/parl/monsoon2017/rsus2723.pdf>, accessed 6 November 2017.

72 - “Expected completion”, as provided by Department of Atomic Energy, “Lok Sabha: Unstarred Question No 2155–Nuclear Power Generation–Answered on 12.03.2025”, Government of India, 12 March 2025, see https://sansad.in/getFile/loksabhaquestions/annex/184/AU2155_UqC3nk.pdf?source=pqals, accessed 3 June 2025.

73 - Department of Atomic Energy, “Lok Sabha: Unstarred Question No. 4226–Issues Concerning Installation of New NPPs–Answered on 21.03.2018”, Government of India, see <http://dae.nic.in/writereaddata/parl/budget2018/lsus4226.pdf>, accessed 15 May 2018. Other sources also used 2024.

74 - “Expected completion”, as provided by Department of Atomic Energy, “Lok Sabha: Unstarred Question No 2155–Nuclear Power Generation–Answered on 12.03.2025”, Government of India, 12 March 2025, op. cit.

75 - Expected construction duration of Kudankulam-5 given as 66 months. See Government of India “Lok Sabha: Unstarred Question No. 2756–Kudankulam Nuclear Power Plant–Answered on 10.03.2021”, Government of India, March 2021, see <https://dae.gov.in/writereaddata/lsusq%202756.pdf>, accessed 30 June 2021.

76 - Department of Atomic Energy, “Lok Sabha: Unstarred Question No- 2155–Nuclear Power Generation–Answered on 12.03.2025”, 12 March 2025, op. cit.

77 - Department of Atomic Energy, “Rajya Sabha: Unstarred Question No. 3203–Status of Under Construction and Planned Nuclear Power Plants–Answered on 31.03.2022”, Government of India, March 2022, see <http://dae.gov.in/writereaddata/rsusq3203.pdf>, accessed 6 April 2022.

78 - Department of Atomic Energy, “Lok Sabha: Unstarred Question No 2155–Nuclear Power Generation–Answered on 12.03.2025”, March 2025, op. cit.

79 - MoSPI, “Project Implementation on Central Sector Projects (Costing Rs.20 Crores & Above) October–December, 2004”, Ministry of Statistics and Programme Implementation, Government of India, 2004, see <http://www.cspm.gov.in/english/qr/oct-dec-04.pdf>, accessed 24 August 2025.

80 - Fuel loading started in March 2024, with grid connection expected by the end of 2024. As of July 2025, completion is expected at the end of 2026. See Office of the Prime Minister of India, “PM Witnesses the Historic ‘Commencement of Core Loading’ at India’s First Indigenous Fast Breeder Reactor (500 MWe) at Kalpakkam, Tamil Nadu”, Government of India, 4 March 2024, see https://www.pmindia.gov.in/en/news_updates/pm-witnesses-the-historic-commencement-of-core-loading-at-indias-first-indigenous-fast-breeder-reactor-500-mwe-at-kalpakkam-tamil-nadu/, accessed 19 March 2024; and Department of Atomic Energy, “Lok Sabha: Unstarred Question No 2155–Nuclear Power Generation–Answered on 12.03.2025”, March 2025, op. cit.

81 - NPCIL, “Plants Under Construction - Rajasthan”, Nuclear Power Corporation of India Limited, as of 3 April 2013, see <http://www.npcil.nic.in/main/ConstructionDetail.aspx?ReactorID=87>, accessed 3 April 2013.

82 - Department of Atomic Energy, “Lok Sabha: Unstarred Question No 2155–Nuclear Power Generation–Answered on 12.03.2025”, March 2025, op. cit.

83 - Original construction of Bushehr-2 had started in February 1976 before it was halted in 1978. The reactor was listed as “under construction” in IAEA, “Nuclear Power Reactors in the World”, from 1986 to 2004. Currently, IAEA-PRIS indicates September 2019 as construction start, when construction work resumed, and a new concrete slab was poured. See WNISR, “Iran: Construction Restart of Busheer-2”, 14 November 2019, see <https://www.worldnuclearreport.org/Iran-Construction-Restart-of-Busheer-2.html>, accessed 18 May 2020.

84 - The 2024 startup date announced when construction resumed in 2019 was pushed back several times since. The latest announced date is now 2029 for “commercial operation”. See Judith Perera, “Iran’s Nuclear Development”, *NEI Magazine*, 9 January 2025, see <https://www.neimagazine.com/analysis/irans-nuclear-development/> accessed 8 April 2025.

85 - Also known as Chashma Unit 5.

86 - David Dalton, “Construction Begins of China-Supplied Hualong One Nuclear Plant At Chasnupp”, *NucNet*, 20 June 2023, see <https://www.nucnet.org/news/construction-begins-of-china-supplied-hualong-one-nuclear-plant-at-chasnupp-7-1-2023>, accessed 24 August 2025 and Raja Ali Raza Anwar, “National Statement of Pakistan”, Chairman, Pakistan Atomic Energy Commission, 16 September 2024, delivered at 68th Regular Session of the General Conference of the International Atomic Energy Agency, 16–18 September 2024, as released by the IAEA, see <https://www.iaea.org/sites/default/files/24/09/pakistan-gc68.pdf>, accessed 1 May 2025.

87 - As of construction start, BREST-OD was to start operating in 2026, and shortly after, in 2027. See Rosatom, “ROSATOM Starts Construction of Unique Power Unit with BREST-OD-300 Fast Neutron Reactor”, Press Release, 8 June 2021, see <https://rosatom-europe.com/press-centre/news/rosatom-starts-construction-of-unique-power-unit-with-brest-od-300-fast-neutron-reactor/>, accessed 19 August 2022; and Rosatom, “Newsletter #247—Proryv: Breaking Through”, November 2021, see <https://rosatomnewsletter.com/2021/12/01/proryv-breaking-through/>, accessed 8 August 2024.

88 - TASS, “Росатом в 2028 году может выйти на физический пуск реактора БРЕСТ в Северске”, 21 May 2025, see <https://tass.ru/ekonomika/24003849>, accessed 21 May 2025; and Rosatom, “В Северске запустили завод по производству топлива для реактора БРЕСТ-ОД-300”, 25 December 2024, see <https://strana-rosatom.ru/2024/12/25/v-severske-zapustili-zavod-po-proizvozu/>, accessed 27 August 2025.

89 - Startup dates for Kursk 2-1 and 2-2 at construction start were never very explicit, with 2022 often quoted for Unit 1, while others used 2023. However, in the 2019 edition of IAEA’s “Nuclear Power Reactors in the World”, Kursk 2-1 is the only ‘Construction Start During 2018’ to have a grid connection date, set to June 2022. In the 2022 edition, Kursk 2-1 was listed in the “Scheduled connections to the grid during 2022”.

- 90 - TASS, “Rosatom Plans to Connect New Power Unit at Kursk NPP-2 to Grid in 2025”, 21 May 2025, see <https://tass.com/economy/1961367>, accessed 6 September 2025.
- 91 - In the 2020 edition of IAEA’s “Nuclear Power Reactors in the World”, Kursk 2-2 is the only ‘Construction Start During 2019’ to have a grid connection date, set to December 2023.
- 92 - As of the 2023 edition of IAEA’s “Nuclear Power Reactors in the World”, grid connection was pushed back to March 2027.
- 93 - Also known as Leningrad-7.
- 94 - According to PRIS database at construction start, startup date was January 2030 (for both grid connection and commercial operation), see IAEA, “Reactor Basic Information–Leningrad 2-3”, PRIS Database, 5 April 2024; and WNN, “First Concrete Poured at Leningrad 7”, 14 March 2024, see <https://www.world-nuclear-news.org/Articles/First-concrete-poured-at-Leningrad-7>, accessed 14 March 2024.
- 95 - As of July 2025, grid connection date has been pushed back from January to December 2030, and Commercial operation to 2031 in the PRIS database, see IAEA, “Reactor Basic Information–Leningrad 2-3”, PRIS Database, last accessed 24 July 2025.
- 96 - Also known as Leningrad-8
- 97 - Government of Russia, “РАСПОРЯЖЕНИЕ от 30 декабря 2024 г. № 4153-п”, 30 December 2024, see <http://static.government.ru/media/files/Rwf9AkjfsFwAnustDEL2m7PEvZ26i7k3.pdf>, accessed 24 April 2025, and WNN, “First Concrete Poured for Leningrad’s Eighth Unit”, 20 March 2025, see <https://world-nuclear-news.org/articles/first-concrete-poured-for-leningrads-eighth-unit>, accessed 20 March 2025.
- 98 - Status of the project unclear. In August 2022, Rosatom announced the keel-laying ceremony in China of the first Arctic-type Nuclear Floating Power Unit (NFPU) to be equipped with two RITM-200C reactors and to be deployed in Russia. As there is no official name yet for the reactors, those units are provisionally named Cape Nagloynyn 1-1 and 1-2 according to the overall project name Cape Nagloynyn. See Rosatom, “Keel-Laying Ceremony for the First Arctic-Type Floating Power Unit With RITM-200 Transport Reactor Vessels”, Press Release, 30 August 2022, see <https://rosatom-mena.com/press-centre/news/keel-laying-ceremony-for-the-first-arctic-type-floating-power-unit-with-ritm-200-transport-reactor-v/>, accessed 5 October 2022, and WNN, “Construction Starts on Russia’s Next Floating Nuclear Power Plant”, 31 August 2022, see <https://www.world-nuclear-news.org/Articles/Construction-starts-on-Russia-s-next-floating-nucl>, accessed 20 September 2022.
- 99 - WNN, “Construction starts on Russia’s next floating nuclear power plant”, 31 August 2022, op. cit.
- 100 - Government of Russia, “РАСПОРЯЖЕНИЕ от 30 декабря 2024 г. № 4153-п”, 30 December 2024, op. cit.
- 101 - See previous notes.
- 102 - See previous notes.
- 103 - Mochovce-4 was listed as “under construction” in IAEA “Nuclear Power Reactors in the World” until the 2004 edition, with a construction start date of 1985 (or January 1985); it was then retrieved, and reintroduced in the 2020 edition with a new construction start date (1987).
- 104 - IAEA “Nuclear Power Reactors in the World–1986 Edition”, International Atomic Energy Agency, 1986, see <https://inis.iaea.org/records/z79q8-tze6o>, accessed 6 September 2025.
- 105 - As of end of 2023, fuel loading and grid connection were expected in the first quarter of 2025. See TREND, “Palivo do 4. bloku Mochoviec zavezu v roku 2025”, 6 November 2023, see <https://www.trend.sk/spravy/zavezenie-paliva-stvrteho-bloku-jadrovej-elektrarne-mochovce-caka-roku-2025>, accessed 5 July 2024. Hot hydro test started in March 2025, when Branislav Strýček, president and chief executive of Slovenské Elektrárne stated: “Our goal is to load nuclear fuel into the reactor this year once all the necessary tests and revisions have been carried out.” See Slovenské Elektrárne, “Slovenské elektrárne Started Hot Hydro Test at Mochovce 4”, 21 March 2025, see <https://www.seas.sk/en/press-releases/mochovce-4-hot-hydro-test/>, accessed 3 April 2025. No update has been provided since.
- 106 - In late 2022, two reactors under construction, Shin-Kori Unit 5 and 6, were renamed Saeul-3 and -4. See KHNP, “Saeul NPP Renames as Saeul Units 1, 2, 3 and 4”, Press Release, Korea Hydro & Nuclear Power, 1 November 2022, see https://cms.khnp.co.kr/eng/selectBbsNttView.do?WCN_KHNPHOME=30yVBQtmOX8ttEVoH9XYo11xjJSy2XlO2nToY1Bfoo61Doij-Acfl-1320158464?key=565&bbsNo=84&nttNo=46397&searchCtgr=&searchCnd=all&searchKwd=&integrDeptCode=&pageIndex=1, accessed 3 November 2022.
- 107 - Construction officially started in April 2017, suspended in July to resume in October of the same year. Construction start date in the PRIS Database slightly different (1 April 2017). KXP, “발전소 건설사업 추진현황 17년도 2분기”, 20 July 2017, see https://www.kpx.or.kr/boardDownload.es?bid=0040&list_no=4896600020170720105802282&seq=28135, accessed 15 April 2025 and KHNP, “Nuclear Power Construction - Shin-Kori #5,6”, Updated as of 30 September 2017, see <http://cms.khnp.co.kr/eng/content/548/main.do?mnCd=EN03020304>, accessed 18 October 2017.
- 108 - KHNP, “Nuclear Power Construction - Shin-Kori #5,6”, Updated as of 30 September 2017, see <http://cms.khnp.co.kr/eng/content/548/main.do?mnCd=EN03020304>, accessed 18 October 2017.
- 109 - The timeline on the dedicated webpage has been updated as of March 2025, and commercial operation pushed back to February 2026 (compared to October 2024 in previous timeline). See KHNP, “Nuclear Power Construction—Saeul #3,4”, Updated as of 30 April 2025, see <https://cms.khnp.co.kr/eng/contents.do?key=525>, last accessed 24 July 2025.
- 110 - According to KHNP data, the first concrete was poured on 19 September 2018, whereas PRIS indicates 20 September 2018. See KHNP, “Nuclear Power Construction - Shin-Kori #5,6”, Updated 31 October 2018, see <http://cms.khnp.co.kr/eng/content/548/main.do?mnCd=EN03020304>, accessed 16 January 2019.
- 111 - Commercial operation. See KHNP, “Nuclear Power Construction - Shin-Kori #5,6”, Updated 31 October 2018.

112 - The timeline on the dedicated webpage has been updated as of March 2025, and commercial operation pushed back to November 2026 (compared to October 2025 in previous timeline). See KHNP, “Nuclear Power Construction – Saeul #3,4”, Korea Hydro & Nuclear Power, Updated as of 31 March 2025, op.cit.

113 - KHNP, “Nuclear Power Construction - Shin-hanul #3,4”, 30 May 2025, see <https://cms.khnp.co.kr/eng/contents.do?key=3447>, accessed 30 May 2025.

114 - Rosatom, “Presidents of Russia and Turkey Vladimir Putin and Recep Tayyip Erdoğan Kicked Off Large-Scale Construction of Akkuyu NPP”, Press Release, 4 April 2018, see <http://rosatom.ru/en/press-centre/news/presidents-of-russia-and-turkey-vladimir-putin-and-recep-tayyip-erdo-an-kicked-off-large-scale-const/>, accessed 4 April 2018.

115 - Commissioning of Akkuyu-1 has been pushed back several times. As of early 2025, it was presented as one of the “priorities for Rosatom” for 2025. As of early July, Anton Dedusenko, chairman of the Board of Directors of Akkuyu Nuclear JSC indicated 2026 as an expected date for the launch of electricity production.

See *Türkiye Today*, “Russia Signals Investor Confidence in Türkiye’s Flagship Nuclear Project”, 2 July 2025, see <https://www.turkiyetoday.com/business/russian-signals-investor-confidence-in-turkiyes-flagship-nuclear-project-3203728>, accessed 7 July 2025.

116 - Türkiye’s Minister of Energy and Natural Resources indicated 2024 as a startup date for Akkuyu-2.

See *Daily Sabah*, “Construction Starts on 2nd Unit of Turkey’s 1st Nuclear Power Plant Akkuyu”, 28 June 2020, see <https://www.dailysabah.com/business/energy/construction-starts-on-2nd-unit-of-turkeys-1st-nuclear-power-plant-akkuyu>, accessed 28 June 2020. As it seemed rather impossible, WNISR2020 used a 5-year construction period or one-year interval with Unit 1 which was already delayed to 2024.

117 - While startup of Unit 1 has been pushed back several times, there is no specific information on the impact for the other units. In the absence of any official statement, WNISR assumes a one-per-year startup frequency.

118 - WNN, “Akkuyu Construction to Be Completed by 2026, Says Project CEO”, 10 February 2021, see <https://www.world-nuclear-news.org/Articles/Akkuyu-fully-operational-by-2026-says-project?feed=feed>, accessed 10 April 2021.

119 - While startup of Unit 1 has been pushed back several times, there is no specific information on the impact for the other units. In the absence of any official statement, WNISR assumes a one-per-year startup frequency.

120 - While startup of Unit 1 has been pushed back several times, there is no specific information on the impact for the other units. In the absence of any official statement, WNISR assumes a one-per-year startup frequency.

121 - WNISR, “The Oddly Discreet Construction Start of Hinkley Point C”, 29 December 2018, see <https://www.worldnuclearreport.org/The-Oddly-Discreet-Construction-Start-of-Hinkley-Point-C.html>, accessed 24 August 2019.

122 - EDF, “Clarifications on Hinkley Point C Project”, 3 July 2017, see <https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/clarifications-on-hinkley-point-c-project>, accessed 7 May 2018, and EDF, “Reference Document 2018 including the Annual Financial Report”, 2019, see <https://www.edf.fr/sites/groupe/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/financial-information/regulated-information/reference-document/edf-ddr-2018-en.pdf>, accessed 7 April 2025.

123 - On 23 January 2024, EDF presented three scenarios for the startup of Unit 1. The first would see startup in 2029, the second in 2030 (“base case”), and the third in 2031, compared to 2027 in WNISR2023. See EDF, “Hinkley Point C Update”, Press Release, 23 January 2024, see <https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/hinkley-point-c-update-1>, accessed 23 January 2024; and EDF, “Universal Registration Document 2024 Including the Annual Financial Report”, April 2025, see <https://www.edf.fr/sites/groupe/files/2025-04/2025-04-24-edf-urd-2024-en.pdf>, accessed 13 May 2025.

124 - WNISR, “Strangely Belated Announcement of Hinkley Point C-2 Construction Start”, 18 March 2020, see <https://www.worldnuclearreport.org/Strangely-Belated-Announcement-of-Hinkley-Point-C-2-Construction-Start.html>, accessed 21 May 2020.

125 - Scenarios presented by EDF in January 2024 put grid connection of Unit 1 within the period between 2029 and 2031, no date has been indicated for Unit 2. WNISR assumes grid connection for Unit 2 will take place with the same time lag as for the construction start. See EDF, “Hinkley Point C Update”, Press Release, 23 January 2024, op. cit.; and EDF, “Universal Registration Document 2024 Including the Annual Financial Report”, April 2025, op. cit.

ANNEX 6 – ABBREVIATIONS

ELECTRICAL AND OTHER UNITS

KW	kilowatt (unit of installed electric power capacity)
kWh	kilowatt hour (unit of electricity production or consumption)
MW	megawatt (10^6 watts)
MWe	megawatt electric
MWt	megawatt thermal
GW	gigawatt (10^9 watts)
GWe	gigawatt electric
TWh	terawatt hour (10^{12} watt-hours)
W_p	Watt peak
Bq	Becquerel
mSv	millisievert
Sv	Sievert
Sv/h	Sievert per hour
tSWU	Thousand Separative Work Units

ACRONYMS

3/11	“Great East Japan Earthquake”; beginning of the Fukushima nuclear disaster (11 March 2011)
ABWR	Advanced Boiling Water Reactor (Reactor design)
AGR	Advanced Gas-cooled Reactor (Reactor design)
ALPS	Advanced Liquid Processing Systems
ANF	Advanced Nuclear Fuels (Framatome subsidiary, Germany)
ASN	<i>Autorité de Sûreté Nucléaire</i> – former Nuclear Safety Authority (France)
ASNR	<i>Autorité de Sûreté Nucléaire et de Radioprotection</i> – Nuclear Safety and Radiation Protection Authority (France)
BESS	Battery Energy Storage System
BNDES	<i>Banco Nacional de Desenvolvimento Econômico e Social</i> – Brazilian Development Bank
BPE	Basic Plan for Long-term Electricity Supply and Demand (South Korea)
BRL	Brazilian real (Currency)
BWR	Boiling Water Reactor (Reactor design)
CAD	Canadian dollar (Currency)
CANDU	CANadian Deuterium Uranium (Reactor design, Canada)
CAPEX	Capital Expenditure
CAREM	<i>Central Argentina de Elementos Modulares</i> – Small Modular PWR Design (under construction in/by Argentina)
CDU	<i>Christlich Demokratische Union Deutschlands</i> (Political Party, Germany)
CEFR	China Experimental Fast Reactor
ČEZ	<i>České Energetické Závody</i> (Conglomerate, Czech Republic)
CfD	Contract for Difference
CGN	China General Nuclear Power Corporation

CNEA	<i>Comisión Nacional de Energía Atómica</i> – National Atomic Energy Commission (Argentina)
CNEN	<i>Comissão Nacional de Energia Nuclear</i> – Federal Commission on Nuclear Energy (Brazil)
CNNC	China National Nuclear Corporation
CNSC	Canadian Nuclear Safety Commission
CNY	Chinese yuan renminbi (Currency)
COP	Conference of the Parties (of the United Nations Framework Convention on Climate Change)
CPA	Construction Permit Application (U.S. Nuclear Regulatory Commission)
CPN	<i>Conseil de Politique Nucléaire</i> – Nuclear Policy Council (France)
CWIP	Construction Work In Progress
CZK	Czech Koruna (Currency)
[U.S.] DOE	Department of Energy (United States)
DPP	Democratic Progressive Party (Taiwan)
EDF	<i>Électricité de France</i> – Power Utility (France)
EIA	Environmental Impact Assessment or Energy Information Administration (United States Department of Energy)
EL-4	Reactor (France)
EMEA	Europe, Middle East and Africa
EnBW	Energie Baden-Württemberg AG.
Enresa	<i>Empresa Nacional de Residuos Radiactivos S.A.</i> – Radioactive Waste Management Agency (Spain)
EPC	Engineering, Procurement and Construction
EPR	European Pressurized Water Reactor or Evolutionary Power Reactor (Reactor Design)
E.U.	European Union
FBR	Fast Breeder Reactor
FDP	<i>Freie Demokratische Partei</i> – Free Democratic Party (Germany)
FID	Final Investment Decision
FL3	Flamanville-3 (Reactor, France)
FNPP	Floating Nuclear Power Plant
FY	Financial Year
GCR	Gas-Cooled Reactor
GDA	Generic Design Assessment
GE	General Electric
GEH	GE Hitachi
GEN III	Generation III – “Advanced” Nuclear Power Reactor designs
HAEA	Hungarian Atomic Energy Authority
HB	House Bill (United States)
HDR	Heißdampfreaktor (Reactor, Germany)
HPC	Hinkley Point C (Nuclear power plant construction project, United Kingdom)
HTR	High Temperature (Gas-Cooled) Reactor or High Temperature Reactor
HTR-PM	High-Temperature gas-cooled Reactor Pebble-bed Module (Demonstration plant, China)
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
ILR	Initial License Renewal (operating license extension beyond 40 years, U.S. Nuclear Regulatory Commission)
IRA	Inflation Reduction Act (U.S. Federal legislation, 2022)
IRENA	International Renewable Energy Agency
JAIF	Japan Atomic Industrial Forum
JANSI	Japan Nuclear Safety Institute
JAPC	Japan Atomic Power Company
JAVYS	Jadrová a vyřad’ovací společnost (Nuclear decommissioning company, Slovakia)

JPDR	Japan Power Demonstration Reactor
KEPCO	Kansai Electric Power Company (Japan) or Korea Electric Power Corporation (South Korea)
KHNP	Korea Hydro & Nuclear Power (operator, subsidiary of Korea Electric Power Corporation, South Korea)
KMT	Kuomintang (Nationalist Party of China)
KRW	Korean won (Currency)
LCOE	Levelized Cost of Energy
LNG	Liquefied Natural Gas
LTE	Long-Term Enclosure (Reactor status, decommissioning phase)
LTO	Long-Term Outage (WNISR reactor status category), or Long-Term Operation
LTS	Long-Term Shutdown (reactor status category, International Nuclear Energy Agency)
LWR	Light Water Reactor
MENA	Middle East and North Africa
METI	Ministry of Economy, Trade and Industry (Japan)
MHLW	Ministry of Health, Labour and Welfare (Japan)
MOEA	Ministry of Economic Affairs (Taiwan)
MOTIE	Ministry of Trade, Industry and Energy (South Korea)
MoU	Memorandum of Understanding
MOX	Uranium-plutonium Mixed-OXide
MP	Member of Parliament
NDA	Nuclear Decommissioning Authority (United Kingdom)
NDC	Nationally Determined Contribution
NDK	<i>Nükleer Düzenleme Kurumu</i> – Nuclear Regulatory Authority (Türkiye)
NEA	Nuclear Energy Agency (of the Organisation for Economic Co-operation and Development)
NECP	National Energy and Climate Plan
NRA	Nuclear Regulation Authority (Japan)
NSSC	Nuclear Safety and Security Commission (South Korea)
NT\$	New Taiwan Dollar (Currency)
OECD	Organisation for Economic Co-operation and Development
OL3	Olkiluoto-3 (Reactor, Finland)
ONR	Office for Nuclear Regulation (United Kingdom)
OPG	Ontario Power Generation (Company, Canada)
OSGE	ORLEN Synthos Green Energy (Company, Poland)
PEJ	<i>Polskie Elektryczne Jądrowe</i> – State-owned Polish company (former PGE EJ1)
PGE	<i>Polska Grupa Energetyczna</i> – Polish Energy Group (Company, Poland)
PLEX	Plant Life Extension
PPA	Power Purchase Agreement
PRIS	Power Reactor Information System (of the International Atomic Energy Agency)
PTC	Production Tax Credit
PV	Photovoltaics
PWR	Pressurized Water Reactor (Reactor type)
R&D	Research and Development
RBMK	<i>Reaktor Bolshoy Moshchnosti Kanalny</i> (Soviet reactor design)
REMIT	European Regulation on Wholesale Energy Market Integrity and Transparency
RITM	Russian reactor design (Generation III+)
RPV	Reactor Pressure Vessel
RTE	<i>Réseau de Transport d'Électricité</i> – Transmission System Operator (France)

RUB	Russian Ruble (Currency)
RWE	<i>Rheinisch-Westfälisches Elektrizitätswerk</i> – Rhine-Westphalia Power Utility (Germany)
SB	Senate Bill (United States)
SDA	Standard Design Approval
SEK	Swedish Krona (Currency)
SLR	Subsequent License Renewal (operating license extension beyond 60 years, U.S. Nuclear Regulatory Commission)
SMART	System-integrated Modular Advanced Reactor (Reactor design, South Korea)
SMR	Small Modular Reactor
Sogin	<i>Società Gestione Impianti Nucleari SpA</i> – state-owned Decommissioning Company (Italy)
SWIFT	Society for Worldwide Interbank Financial Telecommunications
TEİAŞ	<i>Türkiye Elektrik İletim A.Ş.</i> – Turkish Electricity Transmission Corporation
TEPCO	Tokyo Electric Power Company (Japan)
TMI	Three Mile Island (Nuclear Power Plant and nuclear accident at the plant, 1979, United States)
TVA	Tennessee Valley Authority
TVEL	(Rosatom subsidiary, Russia)
U.K.	United Kingdom
U.S.	United States of America
U.S. NRC	United States. Nuclear Regulatory Commission
UAE	United Arab Emirates
UAH	Ukraine Hryvnia (Currency)
UNDP	United Nations Development Programme
US\$	U.S. dollar (Currency)
VALCOE	Value-Adjusted Levelized Cost of Energy
VD	<i>Visite Décennale</i> – Decennial Safety Review (France)
VFD	Variable Frequency Drives
VVER	<i>Vodo-Vodianoï Energueticheski Reaktor</i> (Russian Pressurized Water Reactor design)
WIP	<i>Fachgebiet Wirtschafts- und Infrastrukturpolitik</i> – Workgroup for Economic and Infrastructure Policy (of the Technische Universität Berlin, Germany)
WNA	World Nuclear Association
WNISR	World Nuclear Industry Status Report
WNN	<i>World Nuclear News</i> (publication of the World Nuclear Association)
ZAR	South African rand (Currency)

ANNEX 7 – ABOUT THE AUTHORS

Maahin Ahmed is a copyeditor based in Calgary, Canada. This is her second year working on the WNISR. Her editing work focuses on academic and technical writing, and her academic background is in international relations with a focus on historical memory and oral histories. Previously, she has been a copyeditor apprentice with the [1947 Partition Archive](#) and contributed to two reports published by the International Union for Conservation of Nature's (IUCN) Commission on Ecosystem Management.

Phred Dvorak is an independent journalist based in the Washington, D.C. area. She previously worked as a reporter and editor for the *Wall Street Journal*, mostly in Asia. She got a crash course in all things nuclear when she was assigned to cover the disasters at the Fukushima Daiichi nuclear power plant as they unfolded. More recently, she has been writing about energy and climate change, in the U.S. and globally. She is fluent in Japanese.

Emilio Godoy is an investigative journalist based in Mexico. He is focusing on energy and the environment since 2007. Mexican and international media outlets have published his articles on the effects of the climate catastrophe and energy transition, original reporting that has been awarded journalistic prizes and investigative fellowships. In 2022, he received the prestigious Prince Albert II of Monaco Foundation Award for coverage of climate change, biodiversity, and water, presented by the United Nations Correspondents Association (UNCA).

Dmitry Gorchakov, born in 1983 in Yekaterinburg, Russia. In 2006, he graduated from the Faculty of Physics and Technology at Ural State University (Russia), specializing in Nuclear Reactors and Power Plants, and later completed postgraduate studies at the Ural Branch of the Russian Academy of Sciences in the field of Environmental Protection. He conducted research in radioecology at the Russian Academy of Sciences, developed technologies for radioactive waste management and environmental monitoring in private companies, and worked as an independent consultant and analyst in the field of nuclear energy. He has published frequently in Russian media, has given lectures on nuclear energy, and has written for both scientific and popular publications. As a journalist and expert, he has visited dozens of nuclear facilities in Russia and other countries. After condemning Russia's invasion of Ukraine, he left the country in 2022, relocated to Lithuania, and joined the Norwegian Environmental NGO Bellona Foundation as a nuclear adviser. As part of the nuclear team, he has since co-authored several reports and dozens of publications on nuclear risks related to Russia's war in Ukraine and the global nuclear industry's dependence on Russian technologies and supplies.

Özgür Gürbüz is a columnist, researcher and independent consultant working in Türkiye and abroad. Gürbüz has been writing on environmental, economic, and energy issues since 1994 and is known for his work in various civil society organizations. He is co-founder of the [Ekosfer Association](#), which specializes in climate change and energy. He has published a book

on climate change entitled “Energy and Cows” and has contributed to several other books and articles on journalism, energy, and the environment.

Julie Hazemann, based in Paris, France, is the Director of EnerWebWatch, an international documentation monitoring service, specializing in energy and climate issues, launched in 2004. As an information engineer and researcher, she has maintained, since 1992, a world nuclear reactor database and undertakes data-modelling and data-visualization work for the *World Nuclear Industry Status Report (WNISR)*. Active in information and documentation project-management, she has a strong tropism for information structuration, dataviz and development of electronic information products. She also undertakes specialized translation and research activities for specific projects. She is a member of *négaWatt* (France) and develops EnerWebWatch in the framework of the *Coopaname Coop*.

Bernd Hrdy, Dipl. Ing. Mag., is a junior scientist at the *Institute for Safety and Risk Sciences (ISR)* of the *University of Natural Resources and Life Sciences (BOKU)*. His fields of research are dispersion modeling, nuclear safety, and renewables. After finishing his studies in philosophy and physics, he worked in Central Asia for seven years. First, as project coordinator with focus on renewable energy sources and democracy building / media in Almaty (Kazakhstan) for international NGOs, then at the American University in Central Asia in Bishkek (Kyrgyzstan) as scientist and lecturer. After returning to Austria, he studied Civil Engineering and Water Management at BOKU with focus on energy and water resources. Since 2021, he works at the ISR in the field of nuclear safety and risk analysis. He is currently doing a PhD on the risk analysis and dispersion modeling of nuclear substances in the atmosphere.

Paul Jobin is Associate Research Fellow at the *Institute of Sociology, Academia Sinica*, Taiwan, and adjunct Associate Professor at the International College of Innovation, National Chengchi University. He has conducted extensive research on industrial risks and environmental justice issues in Taiwan and Japan, and more recently on geopolitical risks in the context of Taiwan and East Asia. Among his recent publications is the book *Environmental Movements and Politics of the Asian Anthropocene*, co-edited with Ming-sho Ho and Hsin-huang Michael Hsiao (2021).

Timothy Judson is an independent consultant who provides industrial and policy analysis, with over 25 years of experience in the United States. He has published several reports on the nuclear energy industry and energy and climate policy, including “Nuclear Power and Climate Change: An Assessment for the Future” and “Too Big to Bail Out: The Cost of a National Nuclear Energy Subsidy.” Since 2014, he has served as the Executive Director of Nuclear Information and Resource Service, a non-profit environmental organization based in the United States. He lives in Syracuse, New York.

Yuki Kobayashi is a senior research fellow in the Security Studies Program of the *Sasakawa Peace Foundation*. His research focuses on nuclear energy and nuclear non-proliferation. He received a master’s degree in international relations from Sciences Po Strasbourg in 2013, and a master’s degree in public policy from Sciences Po Rennes, France, in 2014. He enrolled in the doctoral course at Mines ParisTech in 2015, earning his Ph.D. in 2019 with his thesis on “The

Relationship between Politics and Science in the Crisis Response to the Accident at Fukushima Daiichi Nuclear Power Plant.”

Letizia Magaldi is a Member of the Board of Magaldi Power S.p.A. and Executive Vice President of Magaldi Green Energy. In 2000, she graduated in Law from the University of Salerno, subsequently obtaining a Master’s degree in SME Management from SDA Bocconi in Milan. In 2011, she earned her second Master’s degree in Brand Management and Communication from the Istituto Europeo di Design in Milan. In June 2024 she has been elected President of the **Kyoto Club**. Since 2023, she has been member of the Scientific Committee of Cespi, member of the Executive Committee of Aspen Institute Italy and member of the Promoters Committee of the Symbola Foundation. Since October 2020, she is Member of the Doctoral College in Engineering and Energy and Industrial Sciences, 36th cycle, La Sapienza University of Rome. From 2022 to 2024, she was Member of the Council of the Long Duration Energy Storage Council founded by McKinsey. Since 2018, she is Vice President of the Donnaregina Foundation, Contemporary Art Museum Madre in Naples. Since 2021 she holds the position of President of the Mexican Chamber of Commerce in Italy. In 2023, she was awarded the “Iconic Women Creating a Better World for All” prize by the Women Economic Forum (WEF) and in 2025 the SEIF Prize.

Arnaud Martin, web designer and full-stack developer, initiated the development of the CMS **SPIP** in 2000, and launched the social network **Seenthis.net** in 2009. His work can be seen on **23FORWARD**.

Friedhelm Meinaß, born in 1948, is a **visual artist and painter** based in the Frankfurt area, Germany. His **characteristic pieces** including his cover art for Nina Hagen, are on display in the German History Museum in Berlin, and his work is internationally acclaimed. Amongst others, Meinaß has cooperated with Leonard Bernstein, The Byrds, Johnny Cash, Vladimir Horowitz and Billy Joel. He is collaborating with young and talented Luis Redwanz, who congenially implements his ideas. Meinaß held a professorship at the University of Design in Darmstadt in the early 1970s.

Nikolaus Müllner, Dr., is Head of the **Institute for Safety and Risk Sciences (ISR)** of the **University of Natural Resources and Life Sciences (BOKU)**. He is chairman of the **International Nuclear Risk Assessment Group (INRAG)**. His fields of research include nuclear safety, licensing of nuclear installations, deterministic and probabilistic safety analysis, severe accidents and modelling of thermal hydraulic systems. After completing his studies in physics at the University of Vienna, he worked for ten years at the Pisa University of Technology, Nuclear Research Group San Piero a Grado. N. Müllner has been Austria’s representative in the Nuclear Safety Standards Committee of the International Atomic Energy Agency (IAEA) from 2013 to 2020 and is an adviser to the Austrian Ministry for Sustainability and Tourism, Nuclear Coordination. He is the author of numerous publications in journals, conference proceedings, and co-author of books and publications of the IAEA and the OECD’s Nuclear Energy Agency (NEA).

M.V. Ramana is the Simons Chair in Disarmament, Global and Human Security and Professor at the [School of Public Policy and Global Affairs](#), University of British Columbia, Vancouver, Canada. He received his Ph.D. in theoretical physics from Boston University. Ramana is the author of “The Power of Promise: Examining Nuclear Energy in India” (*Penguin Books*, 2012), “Nuclear is not the Solution: The Folly of Atomic Power in the Age of Climate Change” (*Verso Books*, 2024), and co-editor of “Prisoners of the Nuclear Dream” (*Orient Longman*, 2003). He is a member of the [International Panel on Fissile Materials \(IPFM\)](#), the [International Nuclear Risk Assessment Group \(INRAG\)](#) and the [Canadian Pugwash Group](#). He is the recipient of a Guggenheim Fellowship and a Leo Szilard Award from the American Physical Society.

Ruggero Schleicher-Tappeser, born in 1952, grown up in northern Italy, after his baccalaureate at the Scuola Europea in Varese, studied physics in Bern/Switzerland. After his thesis on the atmospheric dispersion of exhaust gases from a nearby nuclear power plant, he worked as a science journalist and consultant on energy policy in Switzerland. For many years, he was on the board of the Swiss energy foundation. In 1985, he moved to Bonn/Germany and worked in a research project on regional innovation policies. He was the founding director for fifteen years of the EURES-Institute for Regional Studies in Europe in Freiburg, working on sustainable development, transport, and other infrastructure policies for all levels of government, including the EU Commission, across many countries in Europe. After a diplomatic intermezzo as Secretary General of the Alpine Convention, he settled in Berlin as a [consultant and writer in energy policies](#). He advised the German Government in the foundation process of the International Renewable Energy Agency (IRENA), built an EU network for 100% Renewables for the Böll Foundation, and coordinated a large photovoltaic manufacturing project on behalf of the Fraunhofer Society in Germany, the CEA in France, and Meyer-Burger in Switzerland. He co-founded and led a start-up developing silicon carbide technologies for 3D-printing and battery anodes.

Mykle Schneider is an independent international analyst on energy and nuclear policy based in Paris. He is the Coordinator and Publisher of the [World Nuclear Industry Status Reports \(WNISR\)](#). He is a founding board member of the [International Energy Advisory Council \(IEAC\)](#) and served as the Coordinator of the [Seoul International Energy Advisory Council \(SIEAC\)](#). He is a member of the [International Panel on Fissile Materials \(IPFM\)](#), based at Princeton University, the [International Nuclear Security Forum \(INSF\)](#), both in the U.S, and the [International Nuclear Risk Assessment Group \(INRAG\)](#), Austria. He provided information and consulting services, amongst others, to the Austrian Ministry for Climate Action, Environment, Energy, the Belgian Energy Minister, the French and German Environment Ministries, the U.S. Agency for International Development, the International Atomic Energy Agency (IAEA), the European Commission, and the French Institute for Radiation Protection and Nuclear Safety (IRSN). Schneider has given evidence and held briefings at national Parliaments in 16 countries and at the European Parliament. He has given lectures at over 20 universities and engineering schools around the globe.

Nina Schneider is a freelance proofreader and translator with [Coopaname](#), Paris, France. Her involvement with the World Nuclear Industry Status Report dates back to 2014 and has been evolving ever since, adding fact checking, background research, and various production tasks to her responsibilities.

Agnès Stienne is a freelance artist, cartographer and graphic designer. She worked for over ten years as a cartographer for the French newspaper *Le Monde Diplomatique*. For several years now, she has been leading a research project focusing on agricultural practices, “land grabbing” and other fundamental issues related to agriculture and food. This work takes the form of “geo-poetic” narratives published on the cartographic experimentation website *Visioncarto.net*. Among these, she produced a series of paintings based on satellite images from Google Earth as a continuation of “Géographie du palmier à huile” exhibited in Le Mans (France) in 2020 and 2021. In 2023, she published “*Bouts de bois - Des objets aux forêts*”, a free and sensitive essay with Éditions La Découverte, Zones collection.

Sebastian Stier is a European patent attorney who has been working for the Munich-based law firm Betten&Resch since 2012. He represents clients before the European Patent Office (EPO) in patent prosecution, opposition, and appeal proceedings. His clients include large international tech firms mainly from the telecom, computer, and electronics industries. He has a diploma in physics from the University of Heidelberg (1985) and obtained a PhD in artificial intelligence from the University of Hamburg (1990). At corporate research of Siemens AG in Munich, he worked as a research engineer and held various positions in technology and innovation management. In the Mobile Phones Division, he was responsible for the integration of a newly acquired mobile phone company in Aalborg/Denmark. In 2005, he joined a patent law firm and qualified as European patent attorney in 2009.

Tatsujiro Suzuki is President of the Japanese non-profit organization “Peace Depot” since April 2025, and a Visiting Professor at the *Research Center for Nuclear Weapons Abolition at Nagasaki University (RECNA)*, Japan. Before joining RECNA, he was a Vice Chairman of Japan Atomic Energy Commission (JAEC) of the Cabinet Office from January 2010 to March 2014. Until then, he was Associate Vice President of the *Central Research Institute of Electric Power Industry (CRIEPI)* in Japan (1996–2009) and Visiting Professor at the Graduate School of Public Policy, University of Tokyo (2005–2009), an Associate Director of MIT’s International Program on Enhanced Nuclear Power Safety from 1988–1993 and a Research Associate at MIT’s Center for International Studies (1993–1995). He is a member of the Advisory Board of Parliament’s Special Committee on Nuclear Energy since June 2017. He is also a Council Member of *Pugwash Conferences on Science and World Affairs* (2007–2009 and from 2014~), Co-Chair of the *International Panel on Fissile Materials (IPFM)* and a Board member of *Asia Pacific Leadership Network for Nuclear Non-Proliferation and Disarmament (APLN)*. Dr. Suzuki has a PhD in nuclear engineering from Tokyo University (1988).

Yun-Chung Ting is a Postdoctoral Research Associate at the *Institute of Sociology, Academia Sinica*, Taiwan. He received his Ph.D. in Sociology from Washington State University. His research interests span environmental sociology, political sociology, development studies, and the social studies of science and technology. His recent work focuses on comparative studies of energy transition, nuclear energy governance, environmental movements, and the development of community renewable-energy initiatives such as energy cooperatives in Taiwan.

Alexander James Wimmers is a research associate in the AT-OM research group at the [Workgroup for Economic and Infrastructure Policy \(WIP\)](#) at the Berlin University of Technology (TU Berlin), and guest researcher at the German Institute for Economic Research (DIW Berlin), Germany. Before joining WIP, he worked as a consultant for renewable energy markets at a renowned energy consulting firm in Berlin. He holds an MSc in Business Administration and Engineering (Wirtschaftsingenieurwesen) from RWTH Aachen University and a PhD in economics from TU Berlin. His current research focuses on the political economy of nuclear power, from new build, operation, decommissioning to nuclear waste management.

Hartmut Winkler is a Professor in the Department of Physics of the [University of Johannesburg](#) in South Africa. After completing his PhD in Astronomy at the University of Cape Town, he joined the Soweto Campus of the former Vista University, where he started engaging on air quality research, which led to an interest in solar irradiance studies, solar energy potential and later energy studies in the broader sense. After a stint in the University administration as Dean of Science, he returned to scientific work after joining the new University of Johannesburg. In recent years, he has been one of South Africa's most visible television and radio commentators on the country's electricity crisis. His [contributions](#) include numerous media articles on various nuclear energy issues in South Africa.