BELLONA

A new state-of-the-art for battery materials production

By: Frida Røyne and Martin Sveinssønn Melvær

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Frida Røyne
Policy Advisor Metals and Minerals,
Bellona Oslo

Martin Sveinssønn Melvær
Materials and Industry Team Lead,
Bellona Oslo

About Bellona

The environmental organization Bellona is an independent non-profit foundation with the aim of solving climate and environmental problems. Since 1986, Bellona has been engaged in the most important environmental issues nationally and internationally and is renowned for its understanding of technology and solution-oriented approach. Today, approx. 70 engineers, biologists, economists, lawyers, political scientists and journalists work at our offices in Oslo, Brussels, Berlin and Vilnius, and we have representatives in several EU countries and in the US. Our websites are in Norwegian (**www.bellona.no**), English (**www.bellona.org**) and several other languages.

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Abstract

Batteries power the transition to a net-zero society, by being an enabling technology for the deployment of renewable energy and zero emission mobility. To accelerate the transition, battery manufacturing capacity has increased significantly in the last decade and is forecasted to increase manyfold in the coming years.

The development does not come without challenges. Extraction and refining of battery materials cause a range of serious environmental and social impacts. In addition, the concentration of battery value chain actors to a few countries makes the entire value chain vulnerable to policy choices of individual countries, geopolitical risks, logistical disruptions, technical failures and natural disasters.

A new state-of-the-art for battery materials production is needed to support the transition to a net-zero society. Bellona suggests the following solutions to reduce supply risks and sustainability impacts:

- **Smaller batteries:** Moderating the size of batteries reduces the pressure on material extraction. Size reduction is achieved through smaller vehicles and well developed and smart charging infrastructure.
- **Increased circular capacity:** Circular management will be an important complement to material extraction. Infrastructure needs ramping up for maximized potential.
- **New battery chemistries and substitution:** Reduced reliance on critical raw materials reduces supply risks and sustainability impacts. R&D investments and resilient planning are important strategies moving forward.
- **Responsible sourcing**: Instrumentalizing value chain responsibility with binding and standardized sustainability requirements, monitoring, and external verification reduces environmental and social risks.
- **Onshoring production to Europe:** Europe has the ability and responsibility to develop sustainable industrial practices. Incentivizing domestic capacities in the whole battery value chain reduces supply risks.

The EU and national governments will need to be driving forces for a rapid, yet structured and just battery value chain development. Industry will play a crucial part in developing responsible practices, demanding accountability from its supply chain, and innovating according to future needs and conditions.

Introduction

To move away from polluting and non-renewable energy sources like coal, gas and oil, a multitude of solutions is required. Climate targets for 2030 and 2050 require vast new installations of renewable energy for electricity and heat, massive energy efficiency improvements, and the availability of large-scale, low-cost energy storage across different timeframes.

Batteries are at the core of the transition to renewable energy. They can store and deliver renewable electricity necessary for the electrification of machinery, vehicles, and vessels, function as power banks in both on- and off-grid applications and alleviate grid congestion.

Intermediate storage of electricity in batteries becomes increasingly relevant with the uptake of non-dispatchable electricity generation from solar panels and wind turbines. Wind and sun conditions fluctuate independently of electricity demand and thus, to maximise use of the installed electricity generation capacity, surplus production must be stored for later use.

Additionally, batteries can play a role distributed around the grid to reduce excessive grid development and investments. Batteries can trickle charge from the grid and deliver high output on demand, e.g., in connection with a charging station for electric vehicles or an electric ferry. Batteries are also much more flexible than grid upgrades, as they can be redistributed depending on demand.

In other words, batteries are key to combating climate change by being an enabling technology for the deployment of renewable energy and for zero emission mobility.

In the short and medium term, the transition to battery-based mobility comes with a high demand for extraction of raw materials. In the longer term, however, the transition offers an opportunity to reduce dependency on extraction – given that battery minerals can be recycled, while fossil fuels are expended upon use in a combustion engine.

But batteries do not come without challenges. Parts of the industry behind battery raw materials are known to cause both detrimental environmental effects and human suffering in the form of deplorable working conditions and exploitation. In addition, the concentration of battery value chain actors to a few countries makes the entire value chain vulnerable to policy choices of individual countries, geopolitical risks, logistical disruptions, technical failures and natural disasters.

The solution to these challenges lies not in avoiding the use of batteries. For this, the benefits of batteries are too many. The solution instead lies in moving towards a new state-of-the-art for battery materials production. It is essential that the transition happens in a rapid, yet structured and fair manner. Bellona envisions Europe taking a leading role in a green and just transition to net zero and the development of climate technologies, including batteries[1].

This report aims to address some of the main challenges facing battery manufacturing today and to point to potential solutions moving forward.

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[1] Bellona Europa (2024)

Battery Materials Today

Batteries vary in their material composition and ratios. A lithium-ion battery, the dominating battery type on the market today, consists of an anode, cathode, separator, electrolyte, and two current collectors (positive and negative). The key minerals in the cathode are nickel, manganese, cobalt, and lithium. Graphite is a key mineral in the anode. Aluminum and copper foils are typically used as current collectors for the cathode and anode, respectively.

The battery market is booming. Globally, battery manufacturing capacity has had a more than threefold increase in the last three years[2]. Production remains concentrated in a few countries. The concentration holds true for each step of the battery value chain in Figure 1. Europe is currently only represented to a minor extent in the value chain, holding 10% or less of the supply chain for some battery materials and cells.

GLOBALLY, BATTERY MANUFACTURING CAPACITY HAS HAD A MORE THAN THREEFOLD INCREASE IN THE LAST THREE YEARS

Figure 1. The battery value chain.

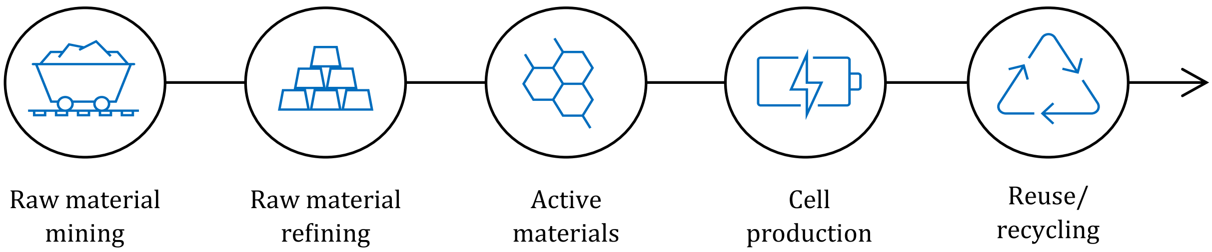


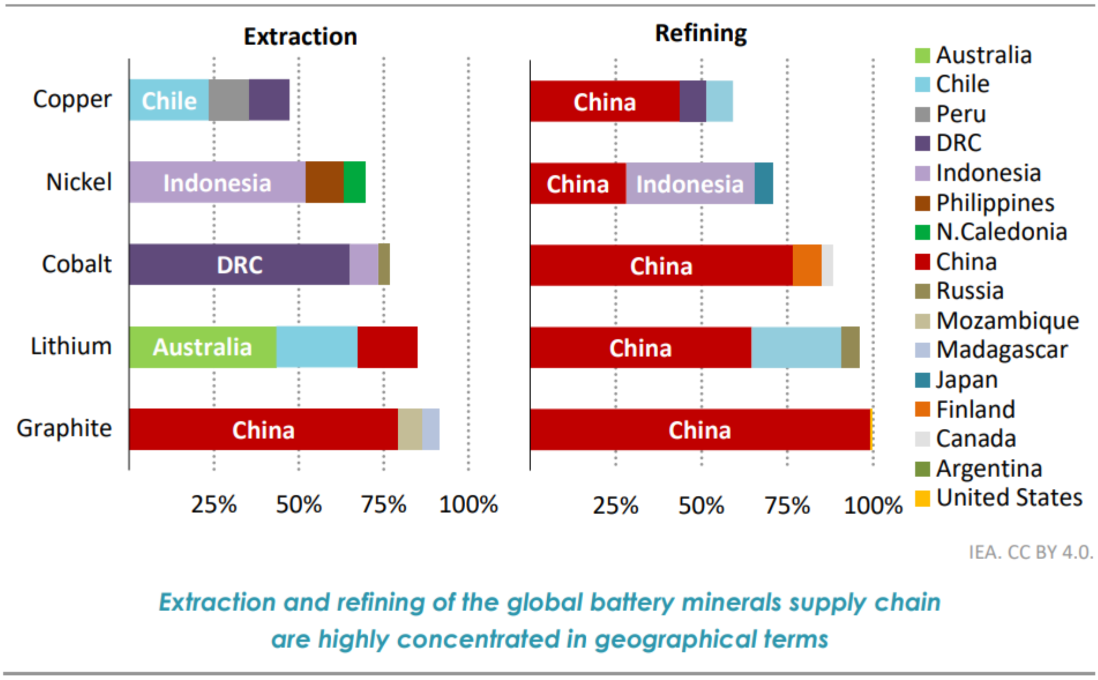
Figure 2 illustrates the dominance of a handful of countries in mineral production. For each of the minerals copper, nickel, cobalt, lithium and graphite, one country dominates global extraction. When it comes to refining, China dominates all minerals but nickel. The concentration is problematic as it makes the entire value chain vulnerable to policy choices of individual country, company decisions, technical failures and natural disasters. As shown by Figure 2, graphite is a specifically problematic material in terms of market concentration.

From a European perspective, the lack of participation in the value chain means that the battery material supply risk is particularly high. As a response to this challenge, the EU has implemented the European Critical Raw Materials Act, with the aim to ensure and secure sustainable supply, and to significantly lower the EU's dependency on imports from single country suppliers. It includes measures both to develop partnerships with third countries and to strengthen domestic supply

[2] IEA (2024a)

chains by building European capacities along the whole value chain. In 2030, the aim is that the EU domestic capacities should cover 10% of the EU's annual need for extraction, 40% for processing and 25% for recycling[3]. With only half a decade left to 2030, reaching the goals will be a massive and complex undertaking.

Figure 2. Share of the top-three countries in extraction and refining of critical minerals for batteries in 2023. Source: IEA (2024a)



Notes: N.Caledonia = New Caledonia, DRC = Democratic Republic of the Congo. Graphite extraction is for natural flake graphite. Graphite processing is for spherical graphite.

Lack of participation in the battery value chain is not only a supply risk. It is also risky since it means weak control of operations. Raw material extraction and refining often takes place in countries lacking transparency and regulatory measures, with negative environmental and social consequences. To add to the challenge, the sustainability risks are not always the same and present to the same extent for the different battery materials. The sustainability impact of the extraction of a single mineral can also vary widely depending on location and technology.

The case of lithium. Lithium is the battery mineral expected to have the largest growth in demand in the coming years. It is a key component in all lithium-ion batteries, the battery type currently dominating the battery market. Lithium comes from two main resources: from hard-rock minerals, or from brines that are pumped from aquifers of dried salt lakes.

LITHIUM PRODUCTION REQUIRES TWICE AS MUCH WATER PER TON AS COTTON

[3] European Commission (2024)

The two types of resources come with different environmental challenges. Extraction from minerals is much more energy intensive and, in many cases, has a several times higher carbon footprint than production from brines[4]. Production from brines, on the other hand, has negative impact on water. It has been estimated that the production of one ton of lithium requires 20,000 tons of water[5]. That is twice as much as for cotton, notable for its massive water consumption. The large water demand of lithium production is highly problematic in areas where water is already a scarce resource, such as in the Andean regions in South America.

The case of cobalt. Cobalt has played a crucial role in the electric vehicle revolution. At the same time, it has increasingly gained the role as the battery mineral bad guy. The cobalt concerns are multiple. Mining is often conducted in regions with lax environmental regulations, which leads to pollution and ecological degradation. The biggest concern, however, is the link to human rights abuses, including child labour, and unsafe working conditions.

ETHICAL CONCERNS HAVE MADE COBALT THE BATTERY MINERAL BAD GUY

Over 70% of cobalt production takes place in the Democratic Republic of Congo (DRC). This creates challenges for establishing responsible sourcing, especially since 15-30% of the production comes from informal artisanal and small-scale mines[6]. The DRC is also currently experiencing violent conflicts. In response to the challenges, the electric vehicle industry is actively exploring alternatives, such as increasing the content of other minerals with similar characteristics, or entirely cobalt-free designs. Cobalt demand is therefore expected to increase to a lesser extent than other battery metals. It is nevertheless expected to increase, because of overall growing electric vehicle deployment[7].

NICKEL IS THE BATTERY RAW MATERIAL WITH THE HIGHEST CARBON FOOTPRINT

The case of nickel. Nickel is to batteries what spinach is to Popeye: increased amounts lead to heightened performance. Inconveniently, nickel is also the battery raw material with the highest carbon footprint. The carbon footprint can however vary widely: Battery grade nickel from Indonesia can be up to fourteen times more carbon intensive than the same functional nickel from Canada[8]. The variety in carbon footprint depends largely on production technology, but not only. Whether the energy for mining operations comes from renewable or non-renewable sources can result in a factor three carbon footprint variance for the same technology[9].

One could thus assume that procurement strategies targeting specific technologies and energy sources would steer nickel production in a sustainable direction. This is true if we only look at the battery value chain. Batteries are however just about 10% of the source of demand for nickel production. This leads to the risk of problem shifting, where the 'clean' share of production goes to

[4] Minviro (2023a)
[5] Crawford et al. (2021)
[6] World Economic Forum (2020)
[7] IEA (2024b)
[8] Battery Materials Review (2024)
[9] Minviro (2023b)

batteries while the 'dirty' share goes to other uses, such as stainless steel[10]. The case of nickel demonstrates how battery raw material sustainability challenges must be tackled holistically.

Local conflicts. If there is one sustainability challenge all battery raw materials have in common it must be conflicts with people living where production takes place. Mining does not only require land for extraction, it also requires area for depositing large amounts of tailings. Additional roads for transportation are built, transportation that can be frequent and noisy. In countries with weak rule of law, people in the surrounding are often affected by pollution.

Even in a country like Norway, with relatively strict environmental regulation, local conflicts occur and have led to significant delays. The Nussir copper mine in Northern Norway received operation permit many years ago but has still not opened. This is partly because of plans of deposing two million tons of mine waste annually in the Repparfjord, plans that have received loud protests from environmentalists and indigenous people[11]. To secure fair and transparent processes and to reduce the potential of strong conflicts, the involvement and engagement of local communities is key. This can be a time-consuming process but saves time in comparison with conflicts that end up at a deadlock.

[10] Billy et al. (2022)
[11] National Geographics (2022, 15 February)

Solutions

The complex supply risk and sustainability challenges in the battery material value chain demonstrate that there is no quick fix. As we move towards a new state-of-the-art for battery materials, a range of solutions will have to be deployed that address both geopolitical risks as well as negative environmental and social impacts, including the potential for local conflicts.

The main objective of this report is to identify solutions for the battery value chain. However, calling out false solutions is also important, and one such is Deep-Sea Mining (DSM). Some stakeholders advocate DSM as a solution to provide minerals for the green transition and claim that such mining will have lower impacts than mining on land. Decision makers should note that science does not support such a claim. Biology and ecosystems in the deep sea are almost completely unknown, meaning that impacts from mineral exploration and extraction are impossible to predict. For this reason, leading scientists, governments and companies have called for a moratorium on deep-sea mining.

Bellona has identified five core solutions that include both demand-side and supply-side strategies. Demand for battery materials can be reduced by 1) incentivizing smaller batteries that use less materials, 2) reusing battery materials, and 3) developing new battery chemistries and solutions with reduced reliance on critical raw materials. Responsible supply can be obtained through 4) sustainability requirements and assistance in existing value chains, and 5) developing production capacity in Europe.

1 Smaller batteries

When people buy electric cars, they tend to buy them big. Of the models available in 2023, two-thirds were sport utility vehicles (SUVs) or pick-up trucks. These accounted for 50% of all electric car sales in China, 60% in Europe and 75% in the United States. In addition, new electric cars tend to be larger than their internal combustion engine vehicle counterparts.

THE GLOBAL AVERAGE BATTERY SIZE HAS INCREASED MORE THAN 60% FROM 2017 TO 2024

From a resource perspective, the size-development is problematic since it significantly increases the demand for critical minerals. In 2023, the sales-weighted average electric SUV in Europe contained a battery almost twice the size of that in the average small electric car[12]. Increase in battery size has been a year-by-year trend. The global average battery size has increased more than 60% from 2017 to 2024[13].

Bellona considers a size-development U-turn as an essential solution for several reasons: It lessens the negative environmental- and social pressure and local conflict potential that an extremely rapid

[12] IEA (2024a)
[13] IEA (2024b)

development of the mining industry risks causing. It also reduces the geopolitical risks we face when we are dependent on large and rapidly increasing material supplies.

The resource-efficiency potential is substantial. If the global average size of batteries in new electric vehicles is reduced by 28% by the end of the decade, the use of around 1.6 million tons of graphite, 700 kt of nickel, 200 kt of lithium, and 100 kt of cobalt could be avoided between today and 2030[14]. The resulting battery size is still larger than in many vehicles today[15]. The amounts are equivalent to more than half of the anticipated demand in 2030 for all clean energy technologies[14]. One measure to moderate the average size of cars has been demonstrated in France. The city of Paris has decided on tripled parking tariffs for larger private vehicles[16].

In some regions, the demand for smaller electric vehicles will increase without forcing measures. Developing economies like Thailand, India, Turkey, and Brazil are emerging markets demanding more low-cost models[17]. There is also potential to downsize batteries even in small electric vehicles. The average battery size in such vehicles sold in China in 2022 was less than half the size of similar models sold in the United States[14].

Why do customers demand large batteries? To avoid range anxiety. Large batteries are, however, not the only option. Fast charging possibilities, with more charging stations that can charge the battery fast, are needed. Another solution is smart charging. Wireless inductive charging can add range automatically during a short stop without the driver needing to get out of the vehicle. It allows trucks to recharge while they are loading or unloading. It also lets taxis charge at the taxi stand without cables and charging poles hindering their advance in the taxi line. The systems are still too expensive for typical passenger vehicles but can reach affordability with higher production volumes[18].

Shrinking vehicles and batteries is one strategy to decrease demand for battery materials. Reducing the need for vehicles is another. Transport needs can be met by shared fleets of vehicles of different sizes in connection with ride-sharing, car-sharing, ride-hailing and autonomous vehicles. Individual car ownership would be made less attractive by more compact settlements with good public transportation systems and a shift towards paid parking[19]. There is, however, an enormous amount of vehicles in private ownership globally, of which today only a small share is electric. A reducing strategy must start by targeting vehicles that run on fossil fuel. The future is shrunk, smart, and electric.

2 Increased circular capacity

Battery materials are excellent candidates for recycling. The metals are valuable and do not degrade much over time, which means that they can be used again and again. Recycling also comes with

[14] IEA (2024a)
[15] RMI (2024)
[16] La Ville de Paris (2024, 23 May)
[17] Bloomberg NEF (2024)
[18] McKinsey (2023, 03 April)
[19] IRP (2020)

several advantages. IEA (2024)[20] points to a triple benefit situation in their report “Global Critical Mineral Outlook”; recycling complements primary mineral supplies, it improves the security for regions with limited resource availability, and it enhances environmental performance and waste management. No matter how much effort we put into reducing impacts, mining of primary materials will always imply a certain level of environmental damage. Bellona therefore considers it of utmost importance to complement efforts to reduce the impacts of mining with circularity efforts that reduce the need for mining.

Recycling as a resource efficiency strategy. The importance of recycling is acknowledged by the EU through the Batteries Regulation[21], which demands specific levels of recycling efficiencies, material recovery efficiencies and minimum recycled content in new batteries. Such push mechanisms will spur recycling efforts and development. Transport & Environment (2024)[22] predicts that recycling increasingly will contribute to raw materials supply availability over the next decade, and projects 10% of feedstock demand in Europe 2030 to be covered by recycled material. The feedstock for recycling today is dominated by electronics waste and scrap from manufacturing processes. This will, however, change after 2030 when the first generation of electric vehicles reaches the end of their life[23]. It is only then that recycling will start to have global impact on the demand for raw materials.

FEEDSTOCK DEMAND FOR BATTERIES IS PROJECTED TO BE COVERED BY 10% RECYCLED MATERIAL IN 2030

As it will take several years for large battery volumes to be available for recycling, the battery recycling market is lacking incentives for innovation and scaling. Another challenge for the recycling industry is that it is highly exposed to the risk of fluctuating and declining material prices. Even though Europe and the US are making efforts, Asia stands out in both current capacity and scaling plans[24].

Having a history of progressive waste management, Europe should use that to their benefit and considerably ramp up their recycling capacities. As the variety of battery chemistries is expanding, future recycling will be complex and need high expertise and technical development. Many established processes would also benefit from innovation. Recycling of processing waste represents the largest secondary resource stream today but can be made more efficient through direct recycling, where whole structures are preserved[25].

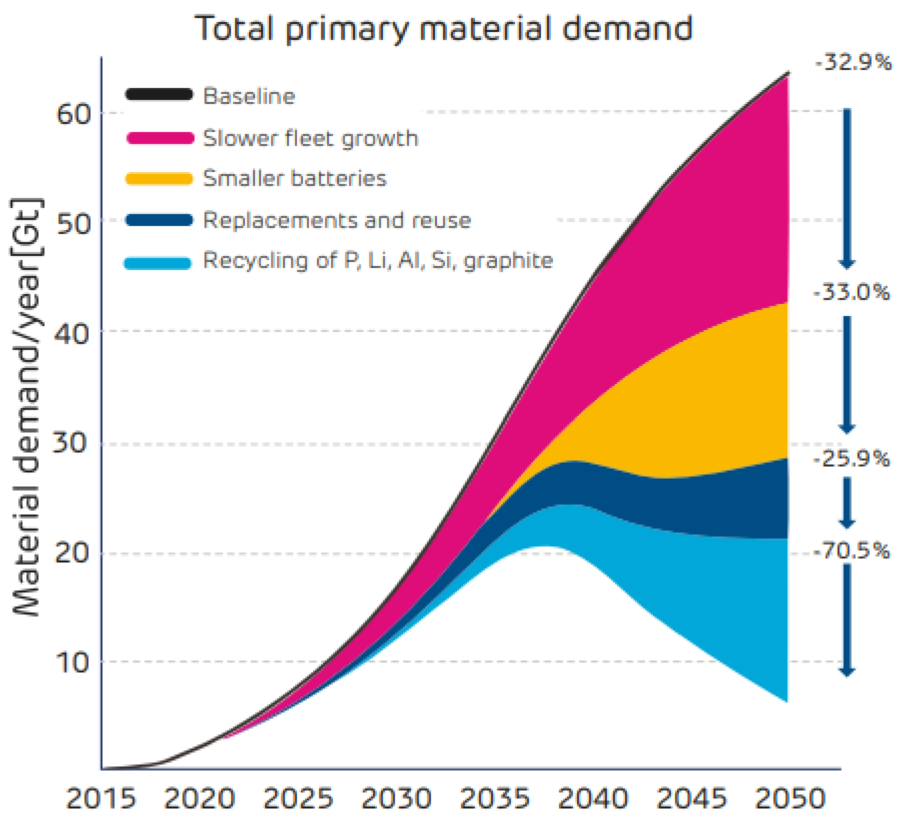
Circularity is more than recycling. Preserving the whole battery for as long as possible is the most resource efficient measure, and efforts should be directed towards maintenance and repair to enable longer use. Today, there is little information and competence on how batteries should be repaired, replacement parts are difficult to come by, and insurance companies require complete battery swaps[26]. The EU Batteries Regulation is highly focused on recycling, while other, in principle more environmentally favorable circularity measures such as remanufacturing, repair and reuse are neglected. There are challenges connected to repair such as safety risks, and not investing resources

20 IEA (2024b)
21 Regulation (EU) (2023)
22 Transport & Environment (2024)
23 IEA (2024b)
24 Battery Materials Review (2024)
25 IEA (2024a)
26 Wired (2023, 19 November)

into dealing with such challenges will be a hindrance for moving to stages in the waste hierarchy higher prioritized than recycling.

A major challenge in the coming decades will be to produce battery materials at the needed speed without compromising sustainability. Figure 3 illustrates how circularity measures in combination with shrinking strategies could play a more and more important role in decreasing the otherwise enormous demand for primary material mining.

Figure 3. The potential of different strategies for reducing primary battery material demand over time. Source: Lopez et al. (2022).



3 New chemistries and Substitution

The battery development is moving at an incredible speed. As a result of R&D and economies of scale in production, lithium-ion batteries have had a 90% cost reduction since 2010 and outclassed alternatives[27]. Speed is not the only trait of the battery market; it has also shown a tendency to take unpredictable turns. While the NMC chemistry (containing lithium, nickel, manganese and cobalt)

[27] IEA (2024a)

was the big star just a few years ago, it's cheaper but slower and bulkier cousin LFP (containing lithium, iron, and phosphate) has grown up in no-time to become the new market favorite[28].

The rise of LFP chemistry. The NMC chemistry has been in a transition towards higher nickel and lower cobalt content. Higher nickel content allows for higher energy density, while spiking cobalt prices and concerns over ethical mining practices have been incentives for cobalt reduction. Still, NMC remains challenging. Cobalt's contribution to stability makes it difficult to remove completely, and nickel has a demand for highly controlled and complex production processes. LFP offers a more stable chemistry and durability. Recent innovations have significantly improved LFP's charging capabilities, cold temperature performance, and energy density. The abundant and cost-effective mineral manganese is increasingly being considered a potential substitute for cobalt and even nickel in certain cathode chemistries (e.g. LMR-NMC, LNMO, LMFP)[29].

Innovation in battery technology beyond 2030. For electric vehicles, LFP and LMFP are set to have the largest market share from 2035. Meanwhile, low-nickel high-cobalt NMC chemistries are expected to be phased out by 2030. After 2030, other chemistries than lithium-ion will start gaining a role.

Sodium-ion batteries are anticipated to play an increasingly important role from 2030, with expected market share of almost 10% in 2040[30]. Sodium-ion batteries have the advantage of using lower cost materials and needing fewer critical minerals. As the name suggests, they contain sodium, an element found in salt, which is much more abundant than the extremely water demanding or carbon intensive mineral lithium. In addition, the technology is similar to that of lithium-ion batteries, which means that factories currently producing lithium batteries could move to sodium batteries[31]. Currently, sodium-ion batteries have up to 40% lower energy density than lithium-ion batteries. This will likely initially limit their use to vehicles used in urban areas, two- or three wheelers, and storage in the power sector[32].

There are also different ways of constructing batteries altogether. Solid state batteries (SSBs) theoretically offer a much higher energy density, and enhanced safety, than the currently used flow battery technology. SSBs could play an important role in the future but because of remaining technical challenges, it is uncertain when SSBs will make a market entrance[30].

Even though the battery market is dominated by demand for electric vehicles, stationary energy storage systems are the fastest growing source of demand. Storage batteries have different technical needs than vehicle batteries, and favor cost, capacity to charge/discharge frequently, and lifetime over energy density. Today, the chemistries for storage applications are the same as those for vehicle batteries, with an emphasis on LFP (about 80% of the storage market in 2023[33]). For longer-duration storage, such as seasonal storage, battery technologies do not offer the technical requirements. Mechanical technologies such as pumped storage hydro, or chemical such as hydrogen storage, need to be employed.

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28 Bloomberg NEF (2024)
29 Transport & Environment (2024)
30 IEA (2024b)
31 BBC (2024, 20 March)
32 IEA (2024a)
33 Transport & Environment (2024)

Sustainability implications of the technology development. The anticipated future trends in battery development imply both challenges and opportunities when it comes to sustainability. A development that relies less on nickel, cobalt and lithium lessens the negative environmental and social burdens from the mining and processing of those minerals. The question is, however, if the reduced demand will be relative or absolute. Since battery demand will increase, the reduction might only be relative to other battery materials and not absolute in terms of volume in the short to medium term.

Battery development is not only happening for the batteries themselves and their components. Mining and refining technologies are also advancing. When it comes to lithium, Europe is one of the leading continents in developing the direct lithium extraction technologies. For nickel refining, Finland is aiming to commercialize the bioheap leaching route[34]. Electrification of mining has a large potential for lowering the climate impact of energy use. At the same time, future mining prospects will generally be of lower concentrations than today, which means that more energy for each kg of extracted material will be required.

In the other end of the value chain, enhanced recycling will contribute to sustainability by lowering the dependency of mining. The recycling industry will however also be confronted with increased complexity. More and more battery chemistries will come on the market and exist simultaneously. Variations in battery design will also add complexity. Integrating battery cells into the vehicle chassis directly delivers higher energy density and lower cost but makes it more difficult to repair and recycle.

Technology lock-in or long-term vision. With a complex and somewhat unpredictable battery development it is challenging to anticipate which battery materials and value chains it makes most sense to invest in. New capacity for raw materials also takes considerably longer to build (3-5 years) than battery production facilities (1-2 years)[35], making the beginning of the value chain the highest risk factor in the equation. To avoid technology-lock in it is crucial to have a long term and resilient material strategy. All materials will have a demand in the short-term, but in the long-term, the tendency is less reliance on critical materials.

IN THE LONG-TERM, THE TENDENCY IS LESS RELIANCE ON CRITICAL MATERIALS

In the future, substituting critical with abundant raw materials will be an important strategy for several reasons. Substitution can lower cost, it can reduce the need for some of the most environmental and social negative mining activities, and it can decrease the risk of being dependent on a restricted amount of supplying countries. We already see the substitution development in batteries with the increasing use of manganese and in the coming sodium-ion chemistries. In addition, technological advancements such as innovative charging may make battery performance less dependent on specific materials.

[34] Transport & Environment (2024)
[35] Battery Materials Review (2024)

4 Responsible sourcing

Procurement requirements are a powerful way to influence suppliers, and one of the few possibilities available to influence industry operations in other countries. Since we will continue to be dependent on virgin material extraction for batteries, Bellona considers responsible sourcing of utmost importance. By setting sustainability requirements, demanding certifications, following up performance indicators, and offering transition assistance, negative environmental and social impacts, and local conflicts can be mitigated.

Battery passports. Several certification schemes and tracking tools have been developed. One very ambitious and comprehensive instrument to enhance transparency and supply chain control is the battery passport. From 2027, the EU requires that all electric vehicle and industrial batteries on the EU market have a unique battery passport. The battery passport will digitally store information about the entire lifecycle of the battery, about how the battery was produced, tested, and how it can be recycled. The passport will not only contain technical data, it will also contain information about where it was produced, recycled content, calculated carbon footprint, due diligence, certifications and hazardous substances. The passport should also contain statistics on performance and durability, which means that data must be updated when repair is conducted.

Questions remain on how exactly the battery passport should be implemented: where information should be stored and who should have access to which information. Verification and reliability are also key challenges. The value chain actor responsible for creating the battery passport will be 'the economic operator placing the battery on the market'. That can be the battery module producer, if they supply ready-made batteries. More often it will be the vehicle producers, since usually they are the ones placing battery modules in the battery casing[36]. How will the economic operator collect and verify values of greenhouse gas emissions from nickel refining in Indonesia? Or the recycled content of the constituents of cathode material produced in China? Or due diligence of cobalt production in the DRC? Tracking tools are available, but currently lack verification mechanisms and may be costly to use. It is resource intensive to map the value chain, especially since the value chain actors are often and rapidly replaced as a means for cutting costs.

Assessment-, guidance-, and certification schemes. The battery passport covers the whole battery life cycle. Other initiatives cover certain parts of it, such as mining operations. The following list describes a selection:

- OECD has developed the *Guiding Principles for Durable Extractive Contracts*. The eight principles provide guidance on how extractive projects can be developed while taking community interests and concerns into account from the beginning[37].
- IRMA is the *Initiative for Responsible Mining Assurance.* It uses internationally recognized standards to independently assess environmental and social performance at mines globally, for all mining materials[38].

[36] Rizos and Urban (2024)
[37] OECD (2020)
[38] IRMA (2024)

- TSM stands for *Towards Sustainable Mining*. It is a mining standard that mines can use to report on social and environmental performance. The standard requires external verification every three years[39].

RESPONSIBLE SOURCING IS CRUCIAL BUT NOT A SILVER BULLET THAT WILL STOP UNETHICAL PRACTICES IMMEDIATELY OR COMPLETELY

Despite efforts to improve the sustainability of mining operations, several challenges remain. IEA (2024)[40] reports that the industry is making progress on some indicators, such as worker safety, gender balance, community investment and renewable energy use. The same, however, cannot be said for emissions, water consumption and discharge, and waste generation. The Responsible Mining Foundation (2022)[41] attributes issues that have shown improvements in part to external drivers, such as legislation, requirements and reporting frameworks. Voluntary measures, by contrast, show no evidence of impact.

Responsible sourcing will be crucial going forward, but it will not stop unethical practices immediately or completely. European countries must develop and implement responsible practices, as they cannot build their own energy transition on exploiting opportunities for accelerated extraction permits and lax regulation in other parts of the world.

5 Onshoring production to Europe

An effective way of ensuring responsible value chains is to take control of them – by establishing more mineral extraction and battery manufacturing in Europe. Bellona considers this to be an essential solution for several reasons: It reduces supply dependencies for materials that are key to the green transition, forces production to operate in line with European environmental and social legislation, and not least – it brings the opportunity to pilot and commercialize new technology and improved practices. Onshoring is part of EU policy through the Critical Raw Materials Act (CRMA), establishing benchmark goals for EU extraction, processing and recycling of raw materials.

AN EFFECTIVE WAY OF ENSURING RESPONSIBLE VALUE CHAINS IS TO TAKE CONTROL OF THEM

Cutting carbon. A recent report by Transport & Environment[42] indicates that Europe has the potential to become near self-sufficient in the production of battery components by 2030, and fully self-sufficient in the production of battery cells already by 2026. By moving production to Europe, greenhouse gas emissions can be reduced by 37 % compared to production in China. For production done primarily with renewable energy, emission reductions would reach 62 %. Thus, onshoring and

[39] TSM (2024)
[40] IEA (2024b)
[41] Responsible Mining Foundation (RMF) (2022)
[42] Transport & Environment (2024)

improved practices could provide huge climate benefits while also reducing geopolitical risk associated with the battery value chain.

Safeguarding people and nature. To develop truly sustainable batteries, it will be necessary to address not only greenhouse gas emissions, but also other social and environmental impacts. Producing battery cells and materials in accordance with European legislation would lead to significant improvements with regards to working conditions and environmental practices. It would clearly prevent worst-case scenarios like child labour and disastrous pollution and present the opportunity to develop and implement solutions for some of the largest remaining sustainability challenges in the battery value chain. These are related to mineral extraction and concerns encroachment on nature as well as insufficient engagement and involvement of affected communities.

Underground mining. Open-pit mining can potentially lead to devastating environmental impacts, mainly through the destruction of vegetation at the surface level, but also by leaving permanent marks in the terrain with the potential for long-term leakage of pollutants. An alternative to open-pit mining is underground mining, which has a significantly lower impact, but can lead to parts of a mineral resource having to be left unused.

Turning waste into a resource. The metals of interest in a mineral deposit can constitute less than one percent of the volume. This results in vast amounts of mining waste being disposed of on land or in water, encroaching on nature and potentially becoming a major source of pollution. Depending on the waste composition and disposal technique, these disposal sites can leak heavy metals, hazardous chemicals and fine-grained particles, all of which can pose severe dangers to affected ecosystems. Using best available disposal techniques is imperative, but even at best, a disposal site will displace the species already living in the area. To reduce this footprint, it is key to avoid and reduce waste volumes. This means maximizing the extraction of commercial minerals in a deposit and looking into alternative uses for the remaining waste rock and tailings.

Non-toxic waste aggregates can normally be used as a replacement for virgin aggregates, or even to isolate contaminated soils, by functioning as a barrier that prevents leakage of pollutants. Aggregates can even be upcycled to construction materials that can replace carbon-intensive materials such as cement and concrete. The potential is huge, given that the cement industry alone is responsible for 8% of global carbon emissions[43].

Involving and engaging affected communities from an early stage. Mineral extraction affects large areas especially through open-pit mining and waste disposal sites, but also through the need for industrial processing and transportation. This can have severe negative effects on local communities and often leads to conflicts. Given that many mineral resources are located on indigenous land, the rights of indigenous peoples according to the ILO convention can come into play – and particularly, the right to free, prior and informed consent. In the effort to establish new mineral projects in Europe, it is imperative to design processes that inform and involve affected communities from an early stage.

[43] Leah et al. (2019)

Onshoring parts of the battery value chain to Europe will imply a significant sustainability improvement but is only the first step. By also ensuring use of renewable energy, underground and circular mining, as well as strong community involvement, the road to truly sustainable batteries may be realized.

Recommendations

1) Start shrinking material demand

Forecasted demands for battery materials are staggering and will imply tremendous risks for supply and sustainability impacts. Demand for virgin materials must be restricted with means that do not restrict the necessary transition to a net-zero society:

1.1. Focus shift from transport as a product to transport as a function

- The EU/governments must create incentives for infrastructure that reduces the need for large batteries: a much larger (fast) charging network in areas still lacking it, and innovative smart solutions such as inductive charging.
- Customers must be made aware of the absolute carbon footprint of large cars: through a standardized method covering the whole vehicle life cycle and with results that are easily available and comparable for all vehicles.
- The EU must restrict the attractiveness of producing SUVs, by introducing policies that reduce their profit margins and make them less attractive compared to smaller vehicles.
- Governments must reduce the need and attractiveness of private car ownership, especially in urban areas, by expanding public transport while restricting car infrastructure as well as making it more expensive.

1.2. Focus shift from circularity as nice-to-have to circularity as a prerequisite

- Battery value chain actors and the electric vehicle industry must comply with the EU Batteries Regulation and build knowledge, technologies and strategies supporting reuse, repair, recyclability and the use of recycled content.
- The EU/governments must fund research into innovative circularity technologies supporting the variety in battery chemistries and designs and future anticipated developments.
- The EU/governments must offer incentives for scaling up infrastructure and industry supporting battery circularity.
- The EU/governments must provide incentives to develop markets for circular materials and circular batteries. Incentives should include, but not be limited to, requirements in public procurement and legislation as well as developing standardization and validation methods that facilitate circularity.

2) Ramp up sustainability

Shrinking-strategies and increased circularity will not be enough to avoid the need for virgin battery materials. Production will for the foreseeable future be dependent on new extraction and processing and must therefore be conducted in the most responsible way possible:

2.1. Instrumentalizing value chain responsibility

- The EU must invest massively in the introduction and implementation of the Battery Passport and make it the core instrument for transforming the battery value chain.
- Value chain actors must be required to conduct sourcing with binding and standardized sustainability requirements, and KPI progress must be externally verified with regular intervals.
- Policy makers must incorporate mandatory sustainability requirements in public procurement of electric transport means and energy storage systems.

2.2. Transition assistance

- Policy support and interventions must not only focus on regulation but also on assistance in reaching sustainability goals.
- The EU/governments must provide support for rapid development and implementation of battery chemistries that are less reliant on critical raw materials and value chains with sustainability issues.
- The EU/governments must provide support for rapid development and implementation of more sustainable technology and practices for the battery value chain – from raw material extraction to battery cell production.
- European countries must act as role models and develop sustainable practices that can be adopted by developing countries.

3) Secure capacities

Europe has numerous challenges with mining practices but generally stronger regulation and monitoring of its mining industry. To secure battery raw material supply, Europe should aim to reduce its dependence on third countries and minerals:

3.1. Taking an active role in the battery value chain development

- The EU must make sustainability a key part of mutual beneficial long-term partnerships with third countries.
- The EU/governments must increase its production of raw materials and take more control of the battery market development: by incentivizing domestic capacities in the whole battery value chain including mining, refining, production of active materials, cell production and end-of-life industry and infrastructure. Where appropriate, governments could also consider taking a more direct and active role, such as in the case of state-owned Finnish Minerals Group.
- The EU should structure a collective onshoring development. The Critical Raw Materials Act must be followed up with timely and effective supplementary legislation.

3.2. Resilient planning

- The EU/governments must invest in research and development focusing on battery designs and chemistries that diversify and reduce reliability on critical raw materials.
- Governments must carefully assess the necessity of new mines and base the assessment on the criticality of the mineral itself and the role it plays in the transition to a net-zero society.
- Communities affected by new mining activity must be informed and involved from an early stage.

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1. Front page showing geopolymer cement based on mine tailings: Oioioi
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