AN INDUSTRY’S GUIDE TO CLIMATE ACTION

Indirectly emit CO₂
ACKNOWLEDGEMENTS

Grateful thanks to the Children’s Investment Fund Foundation for supporting our work on industrial climate action.

DISCLAIMER

Bellona endeavours to ensure that the information disclosed in this report is correct and free from copyrights but does not warrant or assume any legal liability or responsibility for the accuracy, completeness, interpretation or usefulness of the information which may result from the use of this report.

© 2018 by the Bellona Foundation. All rights reserved. This copy is for personal, non-commercial use only. Users may download, print or copy extracts of content from this publication for their own and non-commercial use. No part of this work may be reproduced without quoting the Bellona Foundation or the source used in this report. Commercial use of this publication requires prior consent of the Bellona Foundation.
ABOUT BELLONA

Bellona Europa is the Brussels-based branch of the Norwegian Bellona Foundation, an independent non-profit organisation working on the environmental, climate and social issues of our time. We aim to identify, promote and help implement realisable solutions for the protection of nature, the environment and health. To achieve these goals, Bellona continues to work with – and against – relevant actors and stakeholders both nationally, and internationally.

OUR ORGANISATION
Bellona was founded in 1986 in Oslo, Norway, as an environmental action group. Still headquartered in Oslo, we have since expanded with offices in Brussels, Murmansk and St. Petersburg. Our team consists of about 65 employees with diverse professional backgrounds in communication, engineering, ecology, economics, geosciences, law, physics, and political and social sciences.

SOLUTION-ORIENTED APPROACH
Our solution-oriented approach to climate issues follows the evaluation of existing options, assessment of associated challenges and promotion of identified solutions. Supported by the breadth of knowledge and skills of our experts, Bellona follows a holistic, trans-sectoral approach to assess the economics, climate impacts and technical feasibility of possible climate options.

COMMUNICATION AND COOPERATION
The challenges of climate action are complex and involve multiple influential actors and stakeholders; from national and supranational governments, to internationally operating billion-dollar companies, and the people living in respective regions and countries. To ensure collective action takes place and in the interest of society and the climate, it is crucial to retain open channels of communication. Bellona does not shy away from, and indeed seeks, the exchange with polluting industries, as well as civil society, academia and governments. We believe that the process of finding solutions to pollution from industries that are currently essential to our economy and the standard of living needs to involve them. Bellona is engaged on several platforms, where we aim to initiate discussion and fuel debate to identify the realisable climate solutions we need. We work jointly with scientific institutions on several European research projects, and follow close relationships with fellow climate NGOs across the globe.

FUNDING
Bellona’s work is largely funded by philanthropic organisations and participation in Horizon 2020 research projects.

Authors:
Dr. Jan-Justus Andreas
Ana Šerdoner
Keith Whiriskey

Contributors:
Jonas Helseth
Theo Mitchell
Olav Øye
Mark Preston Aragones

Design and layout:
Ana Šerdoner
CHAPTER 1 summary: We have a problem

Reality vs. Paris..........................................................7
The Sources of our Problem..................................................8
Electricity: Important, but not a silver bullet...................................10
Industrial Emissions in Europe..................................................12
  Cement.............................................................................12
  Steel..............................................................................14
  Chemicals........................................................................16
Too Valuable not to Decarbonise..................................................18
Enabling a Just Transition, not Just a Transition..........................20
A Web of Jobs and Supply Chains..............................................22
License to Emit..........................................................................24
Risky Business..........................................................................25
Endnotes..................................................................................28

CHAPTER 2 summary: A Diversity of Options, A Lack of Solutions

No barriers to zero-emission industry...........................................2
Reducing, Reinventing and Replacing............................................4
What does reinvention look like?..................................................8
Can we fix everything with electricity?.........................................10
  How long must we wait for a low-carbon electricity grid?.............12
  How much electricity do we plan to produce and consume?.........13
Electricity use in society and industry..........................................14
Limitations of reinventing industry with electrification..................16
Endnotes..................................................................................18

CHAPTER 3 summary: The Dawn of a New Industry

Many options, few solutions.......................................................3
CCS in Industry..........................................................................4
  How it works.......................................................................4
  Why it works for the climate................................................6
  How to do it right..................................................................8
3.1. Managing CO2: Opportunities and Traps.................................9
New opportunities......................................................................10
Not every use of CO2 is climate action.........................................12
3.2. Creating CO2 Networks......................................................15
Making Europe Climate-Proof....................................................16
It's up to Industry to break Inertia..............................................18
Moving European CO2 infrastructure down the cost curve............19
Incentivising and Financing a European CO2 Network..................21
Low carbon worlds for a low carbon world.................................22
Endnotes..................................................................................24

CHAPTER 4 summary: A Farewell to Inaction

Scandinavia..............................................................................4
  Norway..............................................................................5
  Next steps..........................................................................5
Sweden....................................................................................6
The Netherlands........................................................................8
  Next steps..........................................................................10
Germany.................................................................................12
The European CO2 Network.....................................................16
Endnotes..................................................................................17
Energy intensive industries have multiple potential options that when combined can reduce and even eliminate emissions. No single technology or action represents a silver bullet and all effective solutions are needed to reach net-zero emissions. Considerations of the industry’s location, the available resources, energy consumption and competing energy uses must all be taken into account when planning a realistic pathway for industry decarbonisation. Comprehensive climate action in the sector needs to be threefold: (1) The use and waste of products needs to be reduced. Current rates of recycling and upcycling can still be improved, bearing in mind their technical limits. (2) Replacing traditional with alternative products, such as sustainable wood for cement, is able to reduce the need for new materials. Many replacement options however suffer from issues such as scale of availability and performance. It is also important to be mindful of unintended consequences, both in the creation of new sources of CO₂ emissions and in overexploiting or over-relying on limited alternative materials. (3) This is why parallel to these measures, existing manufacturing processes also need to be reinvented through electrification and/or carbon capture and storage (CCS). Due to the limits of electrification, certain process emissions still need to be addressed. CCS thereby becomes an essential component for industry emissions, and is ready for implementation today.

EXECUTIVE SUMMARY

As the transformation of the energy system continues and new technology options are developed and brought to maturity, measures that can provide effective and deep emission reductions to industry processes are needed today. The capturing of CO₂ emissions from industrial clusters and their transport and permanent offshore storage in deep geological formations (CCS) constitutes an essential part of the solution. It complements limitations of feasibility, scale, costs and time associated with other climate tools. It is a three-step process that depends on the availability of a CO₂ transport and storage infrastructure. Yet, no single industrial site or even sector can be expected to develop the entire system themselves for reasons of cost, associated financial risk, as well as the required technical expertise. Developing a shared CO₂ transport and storage infrastructure that is open to all industries and expandable to other regions reduces costs and strengthens the regional industry base. Implementing this system is dependent on financing that can come directly from industry but also from instruments at a regional, national and European level, including the Innovation Fund and the Connecting Europe Facility (CEF). As some programs are either ending soon or still need to be made fit for purpose, time is of the essence. Overall, establishing a CO₂ network for Europe’s industry today is a no-regrets option that overcomes the notion of ‘unavoidable’ CO₂ and enables industry to deeply decarbonise, thereby protecting jobs and welfare, and ensuring governments are able to fulfil their obligations under binding international targets.

Several current developments in Europe could make a shared CO₂ network a reality in the near future. Norway has been pioneering CCS technology for decades and has the largest offshore storage reserves in Europe. The country is currently developing the world’s first shared CO₂ storage infrastructure for two domestic point sources, a cement plant and a waste-to-energy incinerator. In light of the comparably low amounts of Norway’s own industry emissions, the true potential of this infrastructure will only be attained when it is shared with other major emission sources in Europe. At the same time, the Netherlands is assessing its own CO₂ network to enable a deep decarbonisation of its industry in time to reach the country’s 2030 and 2050 targets. As the Port of Rotterdam is seeking to become the crucial CO₂ transit hub for the region, Dutch actions have the potential to kick-off similar plans in adjacent regions. This represents a major opportunity for Europe’s largest industrial region, North Rhine Westphalia in Germany, which has the chance to start its own capture projects via ship access the Dutch CO₂ network. Accomplishing the Norwegian and Dutch plans while also involving Germany would provide a strong showcase of pan-European cooperation and climate action, and would catapult Europe’s industry to the forefront of the next, green, industrial revolution.
WE HAVE A PROBLEM

SUMMARY

The 2015 Paris Agreement set the target for countries to keep global surface temperature increases to well below 2°C compared to pre-industrial times. Since then, very little has happened considering the magnitude of the task at hand, which requires the effective cessation of emissions from all human activity by mid-century.

The industrial sector has so far been largely excluded from climate discussions, and shielded from the requirements to implement effective action. Already contributing a fifth of EU emissions, the industry’s share of total emission is likely to increase further as the energy and mobility transitions continue.

This places the sector in a precarious situation. Currently, industry is able to stay out of the public spotlight, and hides behind difficult-to-abate and even “unavoidable” process emissions that do not benefit from a gradually cleaning European power generation.

Yet there can be no unavoidable emissions in a post-Paris world, nor space for pseudo climate measures that some industry sectors present to greenwash their products. Postponing real climate measures far into the future will leave industry vulnerable when the (public) climate changes. Today, the sector continues to claim it is too big, too important, too valuable, and too much in global competition to be able to do more than it currently does, which is not enough.

Immediate action in reducing industry emissions is needed to prevent worsening environmental, political and economic repercussions that will arise as the world slithers towards a well beyond 2°C climate.

This report focuses on issues not comprehensively addressed in other studies. As scenarios on the important climate measures of circularity and demand-side adjustments in energy intensive industries are being covered in a growing number of studies, they are not discussed in this report. In light of general uncertainty over developments in the future, this report focuses particularly on supply-side measures that are feasible today and on the development of a CO₂ transport and storage network for northern Europe.
REALITY VS. THE PARIS AGREEMENT

After several failed attempts at achieving agreement on collective global action to tackle the growing threat of climate change, the 2015 Paris Climate Agreement finally saw almost 200 countries commit themselves to limit the warming of the global surface temperatures to 2°Celsius compared to pre-industrial times. Hailed as the starting shot to overcome continuous climate inaction, in truth, the Paris agreement is likely the final shot to do so.

Yet the hoped-for increased action following the Paris agreement has so far failed to materialise. Global emissions continue to increase and at current rates the carbon budget to keep warming at 2°C will be exhausted by 2036 [1]. The current action and promised national contributions (NDC) accumulate to a world of 3-4°C warming rather than ‘well-below 2°C’. The difference between the two worlds is between the possible loss of tropical reefs and the loss of entire coastal cities and island states; ranging from increasing likelihood of severe weather events and permanent droughts in Europe, forests in the Arctic and large parts of China, India and the American Southwest turning into inhospitable deserts. Not to mention the deteriorating societal implications caused by famine, vast streams of climate refugees and wars over water and resources, as well as runaway global warming ever intensifying the outlined effects [2, 3, 4].

As the need for action is growing, our time to act is shrinking. To achieve the Paris goals and not slip into an ever-increasing warming of the planet, every aspect of human life needs to effectively cease emitting CO₂ as soon as possible. Already, every additional tonne of CO₂ released into the atmosphere may need to be removed in the future in order to prevent the worst climate change implications from becoming reality. Yet – as a rule of nature – it is much easier and cheaper to prevent emissions at a concentrated source point than to filter it out of the atmosphere. As such, the priority should be to stop emitting in the first place as opposed to capturing diffuse CO₂ from the atmosphere. As every sector of the economy has an obligation to deeply decarbonise, each needs to have the effective solutions available to do so.

“Despite every action taken, the billions of dollars invested in research, the nonbinding treaties, the investments in renewable energy, the only number that counts, the total quantity of global greenhouse gas emitted per year, has continued its inexorable rise” [5].
THE SOURCES OF OUR PROBLEM

CO₂ emissions come from many different sources. From the food we eat to the homes we live in, almost every aspect of our lives includes emitting greenhouse gases to the atmosphere. In Europe, 4.45 billion tonnes of CO₂ are released every year, with the average European adding 24 kg of CO₂ into the atmosphere every day [6, 7]. The pie charts below show these emissions broken down into sectors and the progress of solutions for reducing emissions in each of them.

TRANSPORT – 20%

The electrification of transport has an important role in cutting emissions, oil imports and air pollution. The deployment of electric vehicles is gaining momentum, with a record-high of new electric car registrations [8], the city of Berlin ordering their first 15 electric buses for 2019 [9], and technological developments increasing range and safety of the vehicles [10]. Rapidly improving battery technology has helped in the development of electrification solutions for heavy duty transport, with the first trucks already having 800km range per charge [11]. An increasing number of cities, including Paris, Copenhagen and Hamburg, are set to ban polluting internal combustion engines within their city limits by as soon as 2020 [12].

RESIDENTIAL – 13%

Increasing efficiency standards for buildings have enabled the deployment of a variety of technologies that have helped tackle emissions from the residential sector. Efficient construction practices, appliances and heating and cooling systems already contribute to significant reductions in the sector [13]. The increased use of technologies such as heat pumps also enables an increased use of renewable electricity in homes [14]. In the EU alone, more than half of the 210 million buildings will be in need of renewal within the coming years [15].

ENERGY SUPPLY – 30%

Decarbonisation solutions for the energy supply sector have become a synonym for climate action. Renewables have shown their potential with rapid deployment throughout Europe and globally: wind and solar PV have had annual average growth rates of 21% and 43% respectively between 2000 and 2016 [16]. In 2016, global investment in renewables totalled more than 300 billion €; with global investment in renewables and energy efficiency combined [17]. In parallel, countries have committed to phasing out coal electricity generation. The Netherlands, France, Italy, the UK, Portugal, Finland, Sweden, Norway all plan to shut down their last coal power plants by 2030 or earlier [18].

AGRICULTURE

When it comes to climate, the strategy for agriculture seems focused on solutions that lack the scale needed to achieve deep reductions. Even though the shift to sustainable agriculture seems to be underway, the major concerns relate more to other environmental factors such as biodiversity impacts, sustainable farming practices and waste management [29, 30]. While all of these will have a minor effect on the GHG emissions of the sector [31], significant reductions will require a complete change in the food system, both in consumption and production patterns.

So far, agriculture has been shielded from having to undergo such massive transformations, particularly in Europe [32]. Their essence to operate in the same way is not only supported politically, but also by large subsidies, adding up to 22.0 billion € in 2016 alone [33]. With global goals aiming at increased production [34], it is unlikely that there will be a significant change in the overall emissions of the sector.

MARINE AND AVIATION

For short range trips in marine transport, electrification is a viable option for reducing emissions [19]. The ports of Rotterdam, Gothenburg, Kiel, Lübeck, Oslo, and Bergen already provide shore power for electric and hybrid vessels [20]. Already in 2018, fully electric vessels will operate from the ports of Amsterdam, and Rotterdam [21, 22]. In 2019, Norwegian Color Line and Ulstein Verft will launch the world’s biggest hybrid vessel, able to transport 1900 passengers and 500 cars. For long distance travel, recent solutions include the use of alternative fuels without a carbon content, such as Hydrogen [23] and Ammonia [24]. Alternative carbon based fuels – potentially from seaweed [25] – will still be needed for aviation, where electrification may only be an option for short-haul flights [26].

INDUSTRY

The conversation about industrial emissions is just getting underway. While there are various options that claim to address the problem, only few have the potential to live up to the challenge. While many technological solutions are needed to address all industry emissions, the actual CO₂ reductions depend on each option’s potential scale, resource-use intensity and knock-on effects on other decarbonisation pathways.

In 2050, industry could end up being the largest emitting sector. In absolute numbers, the climate impact of European industry (857 MtCO₂) is already greater than the impact from all of Europe’s coal power plants put together (775 MtCO₂) [27]. Industries will become increasingly exposed to climate change politics as other sectors modernise. As industrial CO₂ sources grow as a percentage of total remaining emissions, scrutiny on why they emit so much and how this climate damage can be halted will only increase.
ELECTRICITY: IMPORTANT, BUT NOT A SILVER BULLET

Industry, agriculture and aviation are the climate outliers still lacking tangible decarbonisation technologies. Industries will become increasingly exposed to climate change politics as other sectors modernise, and simply cutting CO₂ emissions at the edges will not be sufficient. Forecasting into a future that lacks climate solutions for industrial production paints a worrying image both for the climate and the continued social acceptability of industry.

As more and more electricity comes from renewables, direct electrification of processes means they will take an increasing share in final energy use. People replace their diesel and petrol cars with electric ones, their heat generation will be electrified and as consumption patterns change, CO₂ emissions will drop. In this world, industrial emissions grow in proportion to total emissions, sooner or later becoming the biggest source of CO₂. It is foreseeable that without new production technologies and replacement materials, industrial sectors will be responsible for half or more of Europe’s remaining CO₂ emissions.

When climate change impacts become more pronounced and global temperatures continue to rise in the coming years – who will still stand by and accept the unreformed local polluting industry parked at their doorstep. The current defence of some industrialists - who claim their CO₂ emissions are “unavoidable” and their businesses too important - is commercially unsustainable. Will these sectors be forced to shut down or will local solutions be available to make European industry compatible with deep CO₂ reduction?

Focusing on reducing emissions in the power sector is an important and fundamental step. But it is not enough. Even though Norway is ahead of many EU countries by already generating effectively all of its electricity from low-carbon sources, it still has a similar CO₂ footprint per person as Poland – even without including Norway’s major oil and gas industry. Most of these emissions come from its economic activity, industries and the transport sector, although Norway also has the world’s largest market for electric cars.

As the country continues to struggle to meet its 40% GHG reduction targets for 2030, the Norwegian case shows the limits of clean energy and the challenging task ahead of addressing more hard-to-abate sectors.
Limestone is the major resource required when making cement. A common grey coloured rock that is formed naturally from ancient shells of sea creatures, limestone contains calcium that when processed becomes a cementitious material. As a result, cement factories are generally located close to a limestone quarry. The second major input is energy required in the limestone conversion process. In Europe this energy comes primarily from waste, natural gas or, in some cases, coal. Other inputs include clays, blast furnace slag and natural pozzolanic materials.

INDUSTRIAL EMISSIONS IN EUROPE

Sectors such as Steel, Cement and Chemicals all require a variety of different technologies to radically improve their climate performance. In order to shrink their climate impact, we need to understand where their emissions come from. The following sections describe the workings of cement, iron & steel and chemical industries that contribute the most to their greenhouse gas footprint.

CEMENT

The production and use of cement is responsible for approximately 5% of global greenhouse gas emissions, with some estimations setting the total to be closer to 8% of total emissions [39]. This is greater than the climate impact of air travel, though one could argue that building homes and dams is less frivolous than intercontinental travel [40].

CO₂ emissions from the cement industry in Europe peaked in 2007 with 173.6 Mt CO₂, approximately equivalent to the climate impact of the Netherlands [41]. Based on a cement plant with modern technology and equipment the production of a tonne of cement results in 0.65 to 0.92 tonnes of CO₂. Of this ~60% of the CO₂ comes from the calcination process, while the rest (~40%) is produced during the use of fossil fuels [41].

In Germany, clinker production, the primary component of cement, is amounted to 32 million tonnes produced in 2014 [42]. There are approximately 356 cement production installations in Europe [43].

Calcium is a key ingredient in cement manufacture. Limestone contains a chemical bond between calcium and carbon. To extract the calcium, the carbon must be separated. To achieve this limestone is crushed and heated to high temperatures (1,450°C) in a kiln. The heating process separates the limestone into calcium with the carbon converted to CO₂. This source of CO₂ is known as a process emission and would be produced even if no fossil fuel were to be used in the heating process. At the same time, the calcium is also mixed with other ingredients such as clay to produce clinker. In a final step, this clinker is ground to a powder added with different active ingredients to achieve the desired properties to produce cement.

The production and use of cement is responsible for approximately 5% of global greenhouse gas emissions, with some estimations setting the total to be closer to 8% of total emissions [39]. This is greater than the climate impact of air travel, though one could argue that building homes and dams is less frivolous than intercontinental travel [40].

Figure 5: While around 40% of the emissions from the cement industry come from the burning of fuels in the process, the majority of emissions occur due to the heating and processing of the raw materials.
IRON AND STEEL

The global iron and steel industry accounts for approximately 5% of total global CO₂ emissions. On average, 1.9 tonnes of CO₂ are emitted for every tonne of steel produced. About 2.8 Mt CO₂ per year are solely related to energy use in the iron and steel sector, about 8% of total energy related emissions [46].

Over 1.3 billion tons of steel are manufactured and used every year. Demand for steel, particularly in developing economies, has seen global CO₂ emissions from steel increase steadily [46]. The EU is the second largest producer of steel in the world after China. Its output is over 177 million tonnes of steel a year, with approximately 500 production sites throughout the EU accounting for 11% of global output. Even though about 50% of European steel is produced from scrap recycling [47], the growing demand and time lag of steel accumulation in society will keep the production from virgin materials going for a long time [48].

PROCESS

A typical European BOF steel mill produces approximately 7 million tonnes of steel per year; making them among the largest industrial complexes on the continent each requiring many millions of tonnes of inputs at a single site.

When producing new steel, the process must separate high quality iron from raw iron ore via a chemical reaction. After the inputs are prepared, coal is passed through large coking ovens at 1,100°C to drive off impurities. These impurities, in the form of a fossil gas, are used for heating and power generation at an integrated steel site. The preparation of the materials going into the blast furnace, coking and sintering, already produces CO₂ from burning fuel to generate the heat need to process the materials.

Coke, iron ore and limestone ore fed into a large blast furnace; at very high temperature of about 1,650°C, the iron is separated from the ore to produce liquid iron. Once fired up, a blast furnace typically runs continuously for six to 10 years. An unexpected shut down and cooling can irreparably damage a blast furnace. The CO₂ emissions from the blast furnace come from both the heat generation and the forming of iron in the furnace.

The liquid iron must then be upgraded to make high quality steel. At high temperatures, oxygen is blown through the liquid metal, reducing the carbon content to make steel. The BF-BOF is, along with the sintering, coking and blast furnace, one of the main sources of emissions from the steel making process.

OUTPUTS

Steel-making is closely linked to many downstream industries such as automotive, construction, electronics, and mechanical and electrical engineering. Steel is also used in renewable electricity infrastructure, such as wind generation. Even though over half of the steel is being recycled already, the high quality materials still need to be produced from virgin materials. According to some estimates, unchanged applications of steel and long lifetimes will necessitate around 50% of the steel in 2050 to still be produced from new materials [48]. Even if this demand would be drastically reduced, new production would still be needed due to the long lifetime and accumulation of steel in society [48].

Globally, steel demand is expected to exceed scrap availability, with CO₂ intensive primary steel making up the shortfall. The Indian government plans to more than double production capacity by 2030 as it pursues a massive infrastructure programme [50].

The growing demand and long lifetime an obstacle for higher recycling rates: some products can only use a limited amount of scrap due to a requirement for high quality steel. In other words, the more scrap is being used, the less control there is over the properties over the material due to the impurities in the scrap. Even if abundant scrap is available, only a limited amount of it can be used to form the higher steel quality required for several products [51].
An Industry’s Guide to Climate Action

Chapter 1: We Have a Problem

CHEMICALS

The chemical sector is one of the biggest industries in the world and is by far the largest industrial user of energy [52]. Globally, it accounts for 10% of the total energy demand [53].

In the UK, the energy demand of the chemical sector surpasses the demand of mineral production and basic metal production combined [54].

This high demand for energy, combined with an extensive use of fossil raw materials, makes the chemical sector one of the biggest emitters on the planet [53].

The German chemical industry is the fourth largest in the world [20]: with a share of 28.7% of the total industry sales in the EU, it is by far the biggest player in the European chemical industry [55].

Since the chemical industry produces a wide variety of products, the figure below focuses on the production of the most widely used carbon-based chemical – ethylene [56]. Ethylene is the building block of polymers, which make up some of the most widely used products in the world, both in industries and in private households, namely plastics. In 2016, Germany alone exported 13 million tons of plastics [57].

Figure 6: One of the most important production chains in the chemical industry, the production of polymers, uses a vast amount of oil as a raw material. Along with the energy intensive production that uses gas and crude oil, the products themselves emit CO2 when they are incinerated or decomposed.

INPUTS

A large share of the chemical industry depends on virgin fossil feedstock for both the energy consumed during the production process and raw materials. Virtually all new plastic (well above 90%) is produced from fossil fuels [58, 59], mostly natural gas and naphtha, a product of oil refining. The global production of these new materials alone is responsible for around 400 million tonnes of GHG emissions in 2012 [18]. If the current growth of production continues, plastics (not including other chemicals) will make up 15% of the global annual carbon emissions in 2050. Emissions from the incineration of plastics could reach 4.2 Gt [60].

Most of the plastics made today are produced from two industrial chemicals derived from natural gas and naphtha: ethylene and propylene (types of olefins) [58]. The production often clusters around natural gas sources, which is the most widely used fossil resource in the production of plastics.

PROCESS

Ethylene is the most widely used building block of the chemical industry, with a global consumption of 133 million tonnes a year [61]. The production of olefins, a category of chemicals that includes ethylene, is by far the most energy-demanding sub-sector in the chemical industry, both in fuel and feedstock demand [54]. The production of ethylene and other olefins, also known as the cracking process, is highly energy intensive. The inputs, which can include naphtha, ethene (natural gas) or ethanol, don’t have a significant impact on the overall environmental footprint of the product [61].

The ethylene is then combined with catalysts in specific conditions to form long chains of ethylene molecules called polymers; the raw material for all plastic products. During this process, large amounts of electric energy and heat are used to achieve the wanted reaction of the chemicals [62]. Processing the raw material to a form needed for the product (plastification) also requires a high volume of electric power for thermal energy [63].

OUTPUTS

In comparison to steel and cement, most chemical products have a significantly shorter lifespan. Products such as the ones made from plastics are usually not designed for long-term use and are incinerated or recycled; even if they are given a new form, it only takes one cycle for them to degrade substantially and to become unsuitable for further recycling [64].

In Europe, only the packaging produced from plastic generated 15.4 million tonnes waste [18]. Most of this waste ended up in the waste management chain, either in incinerators or landfills across Europe. As those materials degrade, the emissions from the initial fossil feedstock end up in the atmosphere. Per tonne of plastic burnt, about 2.7 CO2 are emitted [60].
TOO VALUABLE NOT TO DECARBONISE

As the notion of ‘pre-industrial’ temperature levels already suggests, the industry plays a central role in rising emissions and therefore climate change. Indeed, the majority of developments of the past century that allowed for the contemporary way of life are hugely CO₂ intensive. Giving up these gained comforts and lifestyles is not only an unpopular option, but would entail far-reaching economic repercussions.

The industrial sector represents the foundation of Europe’s economic growth and welfare by generating about a quarter of the EU’s GDP, and providing 50 million jobs. In other words, every fifth job in the EU is industry related [65].

In Germany, the three most polluting industries – chemicals, cement and steel – emit almost 137 MtCO₂ per year [66]. This number is equivalent to more than half of Germany’s entire coal power emissions [67]. The German chemical industry alone provides almost 450 thousand jobs and produces a turnover of over 188 billion € [68].

A European deindustrialisation due to mounting climate pressures to reach net zero would result in an immense loss of jobs, threatening livelihoods and the standard of living, as well as further macro-economic ramifications, including trade imbalances and resulting economic vulnerabilities.

About 9 thousand jobs and a turnover of about 3.8 billion € depend on the elimination of each 1 million tonnes of CO₂ that the Chemical industry currently emits [68, 7].

The case of the UK is a good example here, as the country underwent stark deindustrialisation since the 1980s [69]. As a result, the UK depends largely on imports of manufactured products, resulting in a total current account deficit of over US$ 91 billion [70]. This number already includes the UK’s surplus in services, meaning the actual trade deficit of manufactured goods is even higher. This point is particularly significant for Germany, whose economy depends on a vast industrial export sector that currently generates the world’s largest trade surplus, with an account surplus of US$ 296 billion (ibid.). However, the German export economy relies heavily (to 42%) on processed steel and metals that are worth some 506 billion € [71, 68]. Without an industry sector, European economies would increasingly rely on services, making them vulnerable to volatilities on the market and developments beyond their sphere of influence [72].

An exodus of industries due to the failure to implement timely decarbonisation solutions would therefore hit the German economy hard, and, moreover would not necessarily reduce global emissions, as there is no guarantee that the now imported products have been manufactured carbon-free. On the contrary, this exodus is likely fuelled by less stringent carbon requirements elsewhere leading to what is known as carbon leakage.

In fact, demand for products such as steel, chemicals, and cement is unlikely to disappear. Cement, for example, is a fundamental feedstock of development and infrastructure projects, as well as essential for extensive downstream use.

Across Europe, the lime and cement sectors (lime is the essential ingredient in making cement) generate over 72 thousand direct jobs, and another 365 thousand indirectly just related to cement production [73]. Over 305 thousand of these jobs relate to the production of concrete that is supplied primarily to the construction sector which itself generates about 9% of European GDP and accounts for 18 million jobs [74, 73]. In Germany, industry clusters associated directly with cement production provide 80 thousand jobs [75].

The looming shifts in economic activity if climate inaction is continued would also reduce government revenues significantly, as portions of wage, corporate and turnover tax money are set to be lost, paired with the danger of rising social welfare costs as unemployment rates increase. Together, in 2017 these three tax sources provided about half of total German tax revenues, or about 330 billion € [76].

An additional knock-on (or rather -out) effect is likely to be an European research. Innovation is fundamentally driven, and often financed, by businesses. With over US$ 200 billion in 2015, Europe boasts the largest R&D expenditures worldwide [77]. Yet even if research and development continues in Europe, it would either remain shelved in its ivory towers or monetised in industries abroad. Europe would then import the products of its own innovation.
ENABLING A JUST TRANSITION, NOT JUST A TRANSITION

Historically, the burning of fossil fuels has correlated with economic growth; the more CO₂ was emitted, the higher human living standards became. Undermining the economy and the standard of living through climate action is politically and socially unfeasible. Labour unions and governments are therefore promoting a Just Transition to achieve sustainability and climate targets while maintaining jobs and livelihoods.

In comparison, cement, chemicals and steel together account for over half a million direct jobs and are largely irreplaceable ingredients to essential products [68]. As such, unlike coal, these industries cannot be replaced as part of a Just Transition and simply ‘phased-out’.

In Germany, the transition for coal is set to continue for decades, meaning a complete coal phase-out is highly unlikely in the near future [82]. Being bad news for climate mitigation, the German example depicts the difficulty of implementing climate change measures, where they directly affect jobs and livelihoods.

The Just Transition, therefore, needs to evolve beyond its current shape and form to achieve its goal of maintaining jobs and economic growth in Germany’s industries, while reducing emissions and meeting climate goals. For Germany’s industries, retraining and turning factories into tourist sites will simply not be enough to replace the economic and societal values these industries currently generate. Similarly, implementing solutions cannot be a decade-long transition, which in light of the current inaction would result in an unjust deindustrialisation of Germany.

To harmonise and expand Europe’s just transition in coal, the EU established the ‘EU Platform for Coal Regions in Transition’ in 2017. For coal, the Just Transition involves a ‘retrain, shut-down and clean-up’ approach that includes the re-use of mines as, for example, tourist attractions. However, this is a highly expensive process that costs as much as 300 to 400,000 € per long-term job created [80].

It is important to note that this Just Transition addresses a sector with about twenty-thousand remaining direct jobs [81].

The concept is currently pushed forward almost exclusively in relation to ongoing coal power phase outs, yet Europe needs to begin a Just Transition for its industry to ensure that sustainability and climate targets can be achieved without endangering employment and welfare.

Figure 7: In comparison to the energy intensive industries in Germany, the coke and petroleum sector is relatively small. Such an intersection between high employment, welfare and high emissions calls for a just and carefully planned transition to a low carbon economy.
A WEB OF JOBS AND SUPPLY CHAINS

Energy intensive industries manufacture products for an entire web of downstream sectors. Achieving the Just Transition in energy intensive industries should be imperative, as it links a broad web of industries and supply chains that are at the core of European economies.

Materials such as steel, cement or polymers, make up various products that form a considerable part of European economies. As every product created in one of the energy intensive industries travels down the supply chain, it grows both in value and complexity.

Ultimately, it makes up the innovative and complex products Europe is exporting, such as machinery and transport equipment [83]. The downstream industries themselves state that European steel is and will remain an integral part of their supply chains [84].

Steel-making is closely linked to many downstream industries such as automotive, construction, electronics, and mechanical and electrical engineering. [85]

“The chemicals industry is one of Europe’s largest manufacturing sectors. As an ‘enabling industry’, it plays a pivotal role in providing innovative materials and technological solutions to support Europe’s industrial competitiveness.” [86]

“Cement products are essential for construction and civil engineering, while lime is irreplaceable for the steel industry, as well as construction materials, paints, plastics, and rubber.” [87]

The following graph illustrates such interconnections with the example of the steel industry in Germany; steel and metal processing, cement, chemicals and plastic production are all connected to some of the largest and most profitable industries in the country. Machinery, automotive and chemicals products are the products Germany exports the most [88].

In addition to economic output, these industries employ a vast number of people in the country, making it even more important for their entire supply chain to remain sustainable. Making their products zero carbon will be imperative to avoid unexpected closures, job losses and other volatilities in the future.

Figure 8: The German steel industry, just as other energy intensive industries, is connected to numerous supply chains that are vital parts of the economy.
A LICENSE TO EMIT

Sustained economic growth and the Paris targets are impossible to reach unless the current idleness and deliberate deception via pseudo climate measures is overcome. Industry emissions need real solutions. Greenwashing or ignoring the issue completely are not in the short, medium or long-term interest of anyone.

Threatening with their exodus, industries receive expansive climate concession from governments, as politicians also fear unions’ and workers’ worries could cost them elections. Through effective lobbying, industry emissions are given a pass in current debates that are often limited to the power, heat and increasingly transport and agricultural sector.

At the same time, when climate measures for industry are mentioned, these often oversell their actual mitigation potential.

Yet backing ineffective solutions that are sold as having a positive climate effect through accounting tricks prevent companies from using that money for effective action, squandering the limited chances that remain to keep warming below 2°C.

Implementing real, effective measures now, in a planned collective fashion, will be less costly than when the pressures of climate change increase. Costs for climate options are only set to increase the longer we wait to implement real solutions.

Today, when climate action is required, the industry continues to claim it is too big, too important, too valuable, and in too much global competition to be able to do more than it currently does – which is not enough. Rather than protect industries from the effects of climate measures without simultaneously forcing companies to develop solutions, governments need to take off the gloves and begin an honest and constructive discussion with commercial actors to develop and enable appropriate climate action.

“It is about a right balance between jobs and environment. Energy-intensive industries shall not suffer from a restructured EU Emission Trading System.”

Sigmar Gabriel [89]

“Damages from storms, flooding, and heat waves are already costing local economies billions of dollars. With the oceans rising and the climate changing,… the costs of inaction are easy to understand in dollars and cents—and impossible to ignore.”

Michael R. Bloomberg [90]
RISKY BUSINESS

In the past few decades, policies have changed drastically to respond to growing environmental, health and economic concerns. Over the course of a decade, hydrofluorocarbons were phased out to prevent damage to the ozone layer. Within the last few decades, coal production has been labelled a sunset industry as plants close down across Europe. As the effects of climate change are becoming more intense by the season, maintaining policies that allow for unaltered industrial emissions is a risky, short-term investment.

Playing jobs against the environment is unsustainable and risks both. Statements on the need to protect industries from climate policies are commonplace, and the result of the current climate policy that primarily incurs costs onto emitters, without providing effective incentives and frameworks for industries to implement change.

The consequence is increased production costs without the means to deploy effective solutions.

Decisions are always based on the consideration of risk. The risk of the consequences of action and inaction, and the risk of choosing one action over another.

Fundamentally, any decision on climate change needs to be weighed against the potential consequences of inaction. Compensatory litigation cases against companies and governments are rising as scientists are increasingly able to attribute regional effects to global emission levels. More dramatic future environmental, political and economic repercussions will arise as the world slithers towards a well beyond 2°C climate. If the current attitude of riding out the problem continues – which is not just connived, but the creation of industry lobbying and politicians – one can predict severe consequences emerging in the not-so-distant future.

Some of the more recent fraudulent attempts of climate mitigation have come from the automotive industry.
Renewable Energy Policies begin Europe’s electricity transition

Last coal powerplant closes in Belgium, phaseouts planned across Europe

Athens, Brussels, Madrid, Mexico City, Paris, Rome ban diesel cars from cities

Ireland, France, Netherlands, Norway, UK ban sale of internal combustion engine cars

Figure 9: According to the new IPCC report, the difference between 1.5°C and 2°C, let alone 4°C warming is dramatic.

Implementing effective low-carbon measures in the industry supports the fundamental interests of unions and employees. Unions represent the interest of their workers, which means their continued, long-term employment. To achieve this, they need an industry fit for the zero-emission future. Their immediate role should be to remind politicians of who they serve (i.e. the people), and push them towards climate action that ensures a sustainable, low-carbon economy.

CLIMATE

Industries are needed to achieve a zero-emission world. Their products, from wind farms, to batteries and dams, need to be low-carbon. Being a sunset away from the end of the European industrial sector is not a good option – products would continue to be needed and therefore imported, while Europe loses its capital for action. Instead, let’s pioneer green industries in Europe.

POLITICS

If politicians truly value the jobs and the benefits industries currently provide to society and the economy, a more long-term perspective is required. Particularly local governments in industry regions have to be vigilant and pro-active in finding ways to offer companies the solutions that safeguard their continued existence in a below 2°C world. Politicians and political parties need to prevent a legacy as the ones who failed to facilitate a truly Just Transition for the industry and thereby bear the responsibility for a deindustrialised Europe and a worsened climate.
Chapter 1: We Have a Problem

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Past industry policy</th>
<th>Consequent market developments</th>
<th>Evolution of assets trends</th>
<th>Public perception trends</th>
<th>Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-6°C</td>
<td>Protected by politics, actually fought against effective climate action</td>
<td>Industry bans, Loss of access to market, Shut downs</td>
<td>Complete devaluation, assets are stranded after investments were made in climate incompatible products</td>
<td>Seen as crucial contributors to climate problems, Vilified, on par with fossil fuel companies, Potentially violent action against sites and leadership</td>
<td>Excessive unpredictability of extreme climate effects and political/societal responses, Rapid, unstructured ‘Phase out’</td>
</tr>
<tr>
<td>3-4°C</td>
<td>Some action, left difficult to reduce emissions for ‘future solutions’ that never came to fruition</td>
<td>Selective product bans, Customer boycotts, Strikes following wage cuts after falling profit margins and growing uncertainty, Competition from alternative products, and companies with effective climate action</td>
<td>Product-bans leave assets stranded, Investors withdraw financing</td>
<td>Public outcry against polluters as climate effects increase, Industry as key remaining emitter receives brunt of public &amp; political pressure</td>
<td>Political knee-jerk reaction to avoid slipping into &gt;4°C, High cost for required actions, Increasing unforeseeable environmental events</td>
</tr>
<tr>
<td>2°C</td>
<td>Industries implemented effective action and approach carbon neutrality</td>
<td>Pioneers in low-carbon products have gained largest market share, Minor losses to alternative low carbon products and to production levels, due to efficiency and recycling</td>
<td>Assets appreciation through climate compatible technologies, Return on initial climate investments through market leadership</td>
<td>Decarbonised industries not in negative public focus, Public supports zero-emission goods (see ‘fair trade’, ‘organic’.)</td>
<td>Normal continued market risks, Environmental risks largely mitigated</td>
</tr>
</tbody>
</table>

Figure 10: Unless they act now, implications of the different climate change mitigation scenarios on the various stakeholders could be severe.

“The science of climate change was settled. The world was ready to act. Almost nothing stood in our way - except ourselves.”
Nathaniel Rich, NY Times [93]

Even after decades of climate change agreements and negotiations, the only thing still standing in our way is ourselves. The following chapters will explore how we can remove this barrier and create a sustainable plan of climate action, suitable for the planet, people and economies.

This chapter, first in the line of four, established and analysed the major challenges of energy intensive industries in the wake of climate change. While understanding the issue is a crucial piece of the puzzle, it is only a start. The next part of this report will therefore focus on the options the industries are facing and their potentials and limitations.
A DIVERSITY OF OPTIONS, A LACK OF SOLUTIONS

SUMMARY

While energy intensive industries (EIIs) have several options to tackle their emissions, no single technology or action represents a silver bullet and all effective solutions are needed to reach net-zero. Location, resources, energy consumption and competing energy uses must all be taken into account when planning a climate change mitigation strategy.

• **Replacing high-emitting products with sustainable materials**
  
  Replacing traditional with alternative products, such as sustainable wood for cement, is a viable option to reduce the need for new materials.

• **Reducing the use of materials**
  
  The use and waste of products needs to be reduced. Current rates of recycling and upcycling can still be improved, bearing in mind their technical limits.

• **Reinventing the manufacturing process**
  
  Existing manufacture processes also need to be reinvented to be zero carbon through electrification and/or carbon capture and storage (CCS). Due to the limitations of electrification, particularly where CCS thereby becomes an essential component for reducing industrial emissions, and is ready for implementation today.
Chapter 2: Diversity of Options, Lack of Solutions

NO BARRIERS TO ZERO EMISSION INDUSTRY

Growing global population and swelling cities along with the irrigation, transport, energy and communication infrastructure required to support them will unavoidably require an expansion to the built environment. In Europe, a huge comprehensive renovation of the building stock is just beginning. Increasing the energy efficiency of European cities will cut energy requirements and CO₂ emission but will require resource inputs, such as heat insulation materials. In addition, the increasing pace of deployment of renewable energy will require steel, cement and chemical inputs for electricity generation, transmission and storage.

In building a low carbon society it is imperative that the raw materials themselves are low carbon.

Energy intensive industries have multiple potential options that, when combined, can reduce and even eliminate emissions. No single technology or action represents a silver bullet and all effective solutions are needed to reach net-zero. Each emission reduction strategy requires actions across the value chain; moderating the resources and energy input, new clean production technologies, alternative replacement materials, improving the efficiency of product use in society and ever stricter end of life separation and recycling [1]. To make big cuts in industrial CO₂ emissions we must reduce waste, replace materials with cleaner alternatives and reinvent manufacturing processes.

There is no technological barrier to zero carbon industries, however not every option for reducing emissions in industry will be a practical solution. Considerations of the industry’s location, the available resources, energy consumption and competing energy uses must all be taken into account when planning a realisable pathway for industry decarbonisation.

“It’s a photo that I wish didn’t exist but now that it does I want everyone to see it. It serves as an allegory for the current and future state of our oceans.”

Justin Hofman, photographer

Not only do our consumption patterns harm the climate, but also damage already vulnerable ecosystems, such as the ones found in the oceans.

Photo credit: Justin Hofman National Geographic
A small estuary seahorse (Hippocampus kuda) with a cotton swab, drifting in the polluted waters near Sumbara Island, Indonesia
REINVENT

Design CO₂ separation and capture into the heart of the process (e.g., Hisaroma steel making process)

Avoid CO₂ emissions by using fuels with no carbon content

High quality sorting and recycling of materials at the end of their use can reduce the need for new production

CO₂ capture and transport to a permanent CO₂ store

REPLACE

New building practices and construction codes can avoid the overuse of products like cement and steel

Using alternative products can avoid or reduce the need for familiar materials and subsequent CO₂ emissions. However, the scale of availability and performance are critical considerations when replacing materials with alternatives.

REDUCE

Reducing the use of industrial products can cut the need for new production and overall emissions.

Changing how we manufacture the base building block materials of our society can cut CO₂ emissions from cement, steel and chemical production by as much as 90%.

REINVENTING AND REPLACING

Renewing industrial processes requires vast amounts of low cost renewable electricity and/or a shared CO₂ transport and storage network.
REDOUCING, REINVENTING AND REPLACING

Reducing use and waste of industrial products

Reducing the use of industrial products like steel can cut the need for new production and overall emission. To reduce high quality sorting and recycling of materials at the end of their use can further reduce the need for new production. Obvious first steps such as reducing the use of plastics, especially single use materials, can avoid their production and related CO₂ emissions. Manufacturers can limit waste through improving design and production. For example, reducing material use can lower the weight of products such as vehicles. This will be required to improve efficiency and in the move to battery electric drive trains. New building practices and construction codes can avoid the overuse of products like cement and steel. Moving from current rates of recycling to upcycling, where the resources are not reused to make inferior products but reused in high quality manufacturing, will require advances in both production and end of life separation. Products should be designed with material recycling considerations, avoiding material cross contamination. Consumers will need to improve separation of products and buildings that need to be replaced. For example, separation of contamination metals such as copper from steel is a requirement for improving the quality of material recycling.

Replace the product with an alternative

Industrial products are produced and consumed in massive quantities, hence their huge role in CO₂ emissions. Using alternative products can avoid or reduce the need for familiar materials and potentially CO₂ emissions. For example, construction with wood may take the place of cement in some circumstances, reducing the need for new cement production. In addition, alternative cementitious materials and reactive industrial wastes can supplement traditional cements. Scale of availability and performance are critical considerations when replacing materials with alternatives. Industrial products are produced at an industrial scale, with many substitute materials limited in supply. Replacing just 25% of globally used cement of 6.5 billion m³ with timber would require total global forest cover to increase by about 14%, 1.5 times the land size of India. While timber can act as carbon sink for as long as the building exists, in addition to the questionable sustainability of forestry at this scale the emissions from chemical treatment for fire-proofing of such timber would also need to be considered [2].

It is important to be mindful of unintended consequences, both in the creation of new sources of CO₂ emissions in new supply chains and in overexploiting or over-relying on limited alternative materials.

Reinvent the manufacturing process

Changing how we manufacture the base building block materials of our society can radically reduce our climate impact. Technologies exist to cut CO₂ emissions from cement, steel and chemical production by 90%. Reinventing the manufacturing processes of traditional industries divides into two major groups, to either avoid the use of carbon and thereby CO₂ emissions or to design CO₂ separation, capture and permanent storage into the heart of the process.

Reinventing industrial process to be zero carbon requires either very large amounts of low cost renewable electricity to replace all fossil energy, and/or a shared CO₂ transport and storage network.

Reducing, replacing and reinventing steel

Growing population, increased urbanisation, decentralised energy production and rising living standards around the world will require steel. With rapidly increased recycling and supply of alternative products demand for steel could plateau in our generation.

Today global steel production is 1,691.2 million tonnes, with Europe contributing 10% [3]. With 318,727 direct employees [4], the European steel sector is foundational to higher value added sectors in manufacturing and construction. Holding the largest trade surplus in the world, half of Germany’s exports are dependent on processed steel and metals that are worth some 506 billion € [5]. Reducing and replacing steel use can aid in cutting CO₂. In Europe, recycling of steel already makes up 40% of production [6].

Recycled steel is generally of a lower quality and may not be suitable for high value-added manufacturing. This downcycling of resources is primarily due to mixing with other metals such as copper. Continued European export of high value goods will require local high-quality steel production. The Energy Transition Commission estimates that with expansion of steel reuse, recycle and substitution that primary steel production could be stabilised at current levels.
WHAT DOES REINVENTION LOOK LIKE?

When producing steel, the process must separate high quality iron from raw iron ore via chemical reaction. Two new ways of making steel described below show the potential of industrial process reinvention to drastically cut emissions while preserving local jobs, investments and established supply chains.

**Hlsarna**, a new steel making process developed by Tata Steel in the Netherlands reduces the complexity of steel production while allowing for lower quality inputs to be used. The process avoids the need for coking and sinter plants reducing capital cost and energy use. Increased resource efficiency avoids the production of fossil waste gases that would otherwise be burnt and emitted, and reduces initial coal input by up to 20% and coking coal completely. Most importantly for climate, the new Hlsarna process results in a concentrated high purity CO₂ stream of above 95%. When combined with CO₂ capture, transport and storage, over 80% cuts in CO₂ emissions are possible [7]. If Biomass is used, which has been tested successfully in 2018, even negative emissions are possible.

**Hydrogen** can be used in the manufacturing of steel, avoiding the use of carbon. In this process hydrogen reacts with iron ore to produce pure iron. Avoiding the use of carbon is effective at deeply reducing CO₂ emissions, but the process is reliant on the availability of large volumes of low carbon hydrogen. This hydrogen can be produced via renewable electricity or from natural gas conversion fitted with CCS. Electricity use in producing enough hydrogen for a steel plant would be equivalent to an average nuclear power station. Producing clean hydrogen from fossil gas requires CO₂ transport and storage to be available [8]. Both Hlsarna and Hydrogen steel production are greenfield or brownfield developments, requiring new build or very extensive alteration to existing plants. Refitting of other emissions reduction technologies to existing plants is also possible. For example, CO₂ capture has been demonstrated at traditional steel manufacturing, with the first commercial steel mill with CCS operating in Abu Dhabi since 2016, capturing 0.8 MtCO₂ per year.

Table 1 gives an overview of the steel manufacturing methods that are able to significantly reduce process emissions in steel manufacturing. The methods are compared according to the various considerations needed for their real-world deployment.
The emission reductions of some reinvention methods mentioned in Table 1 will depend heavily on the access to vast amounts of low cost renewable electricity. While industry players are already looking into producing their steel with renewable hydrogen, they also admit that in most cases such a shift is still decades away [12]. Reducing the iron ore with hydrogen produced with CCS is an alternative that is technologically mature and available at scale. It is important to note that this process would not have such a positive climate effect without the availability of, and access to a CO₂ transport and storage infrastructure. Without it, some innovative methods would be limited to efficiency improvements without significantly reducing the emissions of the steelmaking industry.

<table>
<thead>
<tr>
<th>Steel manufacture method</th>
<th>Hlsarna + CCS</th>
<th>DRI (direct reduced iron) + ( \text{H}_2^{\text{CCS}} )</th>
<th>DRI + ( \text{H}_2^{\text{Elec}} ) Hydrogen used to manufacture steel.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ reduction</td>
<td>80% +</td>
<td>80% +</td>
<td>80% + (dependent on share of CO₂ in electricity generation)</td>
</tr>
<tr>
<td>Steel production cost</td>
<td>Conservative estimate at &lt;100% compared to conventional BF route, optimistic &lt;80%; Plus cost CCS, though cheaper with Hlsarna than BF route</td>
<td>130% -180%</td>
<td>180% [9]</td>
</tr>
<tr>
<td>Fuel</td>
<td>Low quality coals / biomass</td>
<td>Natural Gas</td>
<td>Electricity</td>
</tr>
<tr>
<td>Additional climate system benefits</td>
<td>Through addition of sustainable biomass, potential to produce carbon negative steel</td>
<td>Large scale low carbon hydrogen production advances hydrogen economy</td>
<td>Avoids use of fossil resource</td>
</tr>
<tr>
<td>Scale (in CO₂ stored or TWh used)</td>
<td>~ 10 Mt CO₂ stored per annum.</td>
<td>~ 9 Mt CO₂ stored per annum</td>
<td>40 TWh per annum, equivalent to all electricity use in greater London [9]</td>
</tr>
<tr>
<td>Technology maturity</td>
<td>Hlsarna in pilot testing. Demo planned for early 2020s</td>
<td>( \text{H}_2 ) DRI has been commercially deployed (CIRCORED) [10], Hydrogen via CCS is in operation</td>
<td>Economically viable in a few decades; first pilot with ( \text{H}_2 ) from electricity planned in the 2020s (HYBRIT) [11]</td>
</tr>
<tr>
<td>Precondition to deployment</td>
<td>Accessible CO₂ transport and storage network</td>
<td>Accessible CO₂ transport and storage network</td>
<td>Very large scale zero carbon electricity with high security of supply</td>
</tr>
<tr>
<td>Full scale deployment time horizon</td>
<td>From 2030</td>
<td>From 2030</td>
<td>From 2040s; Deployment schedule dependent on the availability of zero carbon electricity</td>
</tr>
<tr>
<td>Other considerations</td>
<td>CO₂ transport and storage not deployed. Establishing and expanding CO₂ network will take time. Not all areas will have access to CO₂ storage.</td>
<td>At current EU electricity CO₂ intensity ( \text{H}_2^{\text{Elec}} ) would increase emissions</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 Comparing the cost, requirements and benefits of two new low carbon steel manufacture processes. Scale of steel production an average steel manufacture facility (7.5 million tonnes of steel per annum)
CAN WE FIX EVERYTHING WITH ELECTRICITY?

Electricity is one part of our daily energy usage. In terms of final energy consumption, of the energy that used in homes, businesses, transport and industry, electricity only accounts for around one fifth, or 20% of the total. That means that other energy uses such direct use of oil in transport, gas and solid fuel for heating make up the majority of final energy use.

OIL

Oil is the single largest component of final energy consumption. With the majority of this used in private road transport, road freight and aviation. In 2015, a year of low oil prices, total spending on crude oil imports in the EU was 187 billion € [16]. Electrification of transport has a significant advantage in cutting both oil dependencies and emissions. Electric vehicles outstrip the efficiency of their oil driven counterparts by 3 to 1, meaning that for ever unit of electricity used by battery electric cars, 3 units of liquid transport fuel will be avoided.

GAS

We use as much natural gas as a share of our total energy use as we use electricity. Gas is used in seasonal heating of homes and year-round in industrial processes. Direct use of electricity for heating will not reduce overall final energy consumption. However, the use of electricity to power high efficiency heat-pumps can displace some gas use and in turn reduce total energy demand.

ELECTRICITY

Currently, electricity within the EU grids supplying the homes, offices and industries of the 28 member states is still produced predominantly by burning of fossil fuels. Increasing efforts to integrate renewable energy sources into the grid have been very successful, with 30% of the electricity consumed in Europe coming from renewable sources [17].

Electricity, although ubiquitous and growing cleaner, is today only a moderate part of our energy use landscape [13].

Norway is a country where electricity is almost entirely generated by zero-carbon renewable hydropower (96%) [14]. Using electricity in Norway emits almost no CO$_2$.

However, as with the rest of Europe the primary energy consumption of the country is still largely reliant on oil and natural gas [15]. As a result, even with clean electricity Norway remains a CO$_2$ intensive country with emissions per person equivalent to Germany.

It is crucial for reducing total emissions to increase the overall low carbon electricity production, its share in final energy consumption, while simultaneously reducing that consumption in heating, transport and industry through efficiency improvements.
How long must we wait for a low-carbon electricity grid?

The German Energiewende has led the way globally on the rapid expansion of renewable electricity generation. As a result, the CO₂ intensity of German electricity has dropped by 23% from 1990 levels. According to the official plans of the German government, the share of renewables in electricity will be at least 80% in 2050.

In its 80% emission reduction scenario, the Federation of German Industries (BDI) estimates that the added capacity of both wind and PV needs to amount to 240GW by 2050 to achieve 90% share of RES by 2050 in Germany to electrify primarily the transport sector and residential heat, while process heat in industry would remain completely fossil based [20].

To also electrify industry heat processes, and achieve a 95% emission reduction, an additional 100TWh of renewable electricity would have to be generated by 2050.

On the journey to a fully or predominantly low carbon renewable electricity grid, adaptations to the electricity market and an expansion of the electricity transition network, the electricity grid, will be essential.

The electricity supply systems will need to evolve to increase flexibility in both electricity production, consumption and storage to make the most of variable renewable supply [21]. This greater flexibility is commonly known as a “smart grid” and will see dynamic pricing of electricity, new markets for energy storage and benefits for consumers that can adapt electricity consumption in line with renewable electricity production.

Renewable electricity is produced where the renewable resource is present (windy and sunny areas), thus electricity networks will be just as important to deliver this electricity to the cities and industry where it can directly be put to use and also reduce CO₂ emissions.

A larger more integrated European electricity system, where electricity is easily imported and exported between member states will increase the resilience of renewable electricity grids [22]. The German grid infrastructure plan foresees up to 4,000 additional kilometres of transmission lines by 2030 [23].

### Table 2: Quantitative targets for integrating renewable energy into the German economy.

<table>
<thead>
<tr>
<th>Renewable electricity</th>
<th>2014</th>
<th>2020</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Share in electricity consumption</td>
<td>27.4%</td>
<td>35%</td>
<td>80%</td>
</tr>
<tr>
<td>Share in final energy consumption</td>
<td>13.5%</td>
<td>18%</td>
<td>60%</td>
</tr>
</tbody>
</table>

By 2050, Germany is planning to increase the renewable share in its final energy consumption to 60%.

### Table 3: Quantitative targets for energy efficiency improvements in Germany. [25]

<table>
<thead>
<tr>
<th>Energy efficiency</th>
<th>2014</th>
<th>2020</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity consumption</td>
<td>-4.6%</td>
<td>-10%</td>
<td>-25%</td>
</tr>
<tr>
<td>Primary energy consumption</td>
<td>-8.7%</td>
<td>-20%</td>
<td>-50%</td>
</tr>
</tbody>
</table>

Along with the increase in renewable generation capacities, Germany plans to keep the demand steady by using the electricity in more efficient applications.
How much electricity do we plan to produce and consume?

We have seen that European electricity generation is not yet low carbon but is greening over time. As currently planned, the transition to green our existing electricity production will likely take a generation, reaching a predominantly renewable grid by 2050.

The current German Energiewende plan, an important part of which is the switch to renewable electricity, does not foresee a sharp increase in electricity demand by 2050. In fact, the main principles of the transition to renewable electricity assume that the generated electricity will be used more efficiently through improvements in machinery and products, which will cause a drop in overall electricity demand [24].

The range of projected added capacity varies from one analysis to another, but no projections assume electricity generation several magnitudes greater than the current total electricity production. Even though there are variations depending on the scenarios and the efficiency gains, electricity use is planned to rise only by approximately 4% from 2015 to 2050 [24]. The German Federal Ministry for Economic Affairs and Energy even emphasises the need for a reduction in energy demand in all sectors [24]. No European government currently plans a renewable electricity system several times larger than the current one.

Overall, general planning has been about stabilising or even reducing overall electricity demand rather than increasing it.

In the future we will have low carbon electricity, but supply will not be unlimited and current actions indicate supply will be roughly equivalent to current electricity generation.

According to the new IRENA REmap scenario, the EU could almost fully (94%) decarbonise its electricity production by 2050.

Achieving an entirely renewable electricity grid by 2050 is possible and should be one of the main climate targets for EU member states.
ELECTRICITY USE IN SOCIETY AND INDUSTRY

Direct and indirect electrification of process and raw materials is an option increasingly touted as the sole tool for the decarbonisation of industry sector [26]. Crucial for this approach is the availability of vast amounts of low carbon renewable electricity. Below, we look at the scale of current electricity production and use, and examples of the future electricity requirements that would need to be met if we rely on electrification. Germany, as Europe’s largest economy is used as a case study.

TRANSPORT

Today transport is only a small user of electricity. The vast majority of trucks and cars burn fossil fuels, with only a small but growing fleet of battery electric cars currently on our roads. Today, most of the electricity in transport is used to drive trains, trams and metros. The Deutsche Bahn (DB) is the single largest consumer of electricity in Germany; approximately 1.1 billion kWh per year, equivalent to the electricity consumption of over 3.1 million households. [29]

HOUSEHOLDS AND SERVICES

From everyday life we see the use of electricity in our home and commercial settings. Electrification of lighting, heating, air conditioning, refrigeration, communications and entertainment. All aspects of our daily lives from our homes to our offices and commercial settings. Electrification of lighting, heating, air conditioning, refrigeration, communications and entertainment. All aspects of our daily lives from our homes to our offices and commercial settings.

For the cement industry, heat processes currently fuelled by fossil fuels could be electrified in the future. The would avoid combustion and reduce emissions by as much as 40% if we assume the electricity is zero carbon.

However, the emission reduction potential is limited, as about 60% of process emissions unrelated to heat would remain. Converting all current cement production in Europe would lead to a comparatively moderate increase in electricity demand, equivalent to the electricity consumption of Poland.

A proposed hydrogen steel factory in Austria is said to require half the country’s total current electricity. The project is planned to be operational in 2045, a generation away as low carbon electricity on the scale required will not be available until then at the earliest. Manufacturing all primary steel in Europe via the renewable hydrogen route would be a significant addition for electricity planners to manage, with the steel sector requiring as much electricity as all of Germany uses today.

For the cement industry, heat processes currently fuelled by fossil fuels could be electrified in the future. The would avoid combustion and reduce emissions by as much as 40% if we assume the electricity is zero carbon.

However, the emission reduction potential is limited, as about 60% of process emissions unrelated to heat would remain. Converting all current cement production in Europe would lead to a comparatively moderate increase in electricity demand, equivalent to the electricity consumption of Poland.

ELECTRIC TRANSPORT

The European chemicals sector is a major user of electricity today (190TWh), the closest comparison being the electricity consumption of all of Spain [36]. The chemical industry is highly dependent on fossil fuels as the core feedstock to make products such as plastics. Replacing these fossil raw materials with materials manufactured with electricity is theoretically possible but will again require vast amounts of electricity. The process requires the manufacture of hydrogen via electrolysis. This process requires low carbon electricity to be climatically effective [34]. CO₂ can be reacted with this hydrogen to build the basic building blocks of organic chemistry. The CO₂ must be sustainable sourced, since using CO₂ of fossil origin undermines much of the potential climate gains. Collectively this process is sometimes referred to as Carbon Capture and Utilisation or CCU [37].

Cefic, the European Chemical Industry Council and DECHEMA, the German society for Chemical Engineering, estimate that converting the European chemicals sector to be based on electricity would require 4,900 TWh, almost 10 times the electricity demand of Germany, and more than all the electricity used in Europe today [38]. The inefficiencies of the electrification process would increase overall energy use in the sector 3 ½ times, from 5,059 PJ today to 17,640 PJ in 2050 [36]. Whether the electrification of the chemicals sector reduces or increases emissions will be highly dependent on the CO₂ intensity of the electricity used and the source of the CO₂ used as a carbon feedstock.

For the cement industry, heat processes currently fuelled by fossil fuels could be electrified in the future. The would avoid combustion and reduce emissions by as much as 40% if we assume the electricity is zero carbon.

However, the emission reduction potential is limited, as about 60% of process emissions unrelated to heat would remain. Converting all current cement production in Europe would lead to a comparatively moderate increase in electricity demand, equivalent to the electricity consumption of Poland.

A proposed hydrogen steel factory in Austria is said to require half the country’s total current electricity. The project is planned to be operational in 2045, a generation away as low carbon electricity on the scale required will not be available until then at the earliest. Manufacturing all primary steel in Europe via the renewable hydrogen route would be a significant addition for electricity planners to manage, with the steel sector requiring as much electricity as all of Germany uses today.

For the cement industry, heat processes currently fuelled by fossil fuels could be electrified in the future. The would avoid combustion and reduce emissions by as much as 40% if we assume the electricity is zero carbon.

However, the emission reduction potential is limited, as about 60% of process emissions unrelated to heat would remain. Converting all current cement production in Europe would lead to a comparatively moderate increase in electricity demand, equivalent to the electricity consumption of Poland.

ELECTRIC TRANSPORT

The European chemicals sector is a major user of electricity today (190TWh), the closest comparison being the electricity consumption of all of Spain [36]. The chemical industry is highly dependent on fossil fuels as the core feedstock to make products such as plastics. Replacing these fossil raw materials with materials manufactured with electricity is theoretically possible but will again require vast amounts of electricity. The process requires the manufacture of hydrogen via electrolysis. This process requires low carbon electricity to be climatically effective [34]. CO₂ can be reacted with this hydrogen to build the basic building blocks of organic chemistry. The CO₂ must be sustainable sourced, since using CO₂ of fossil origin undermines much of the potential climate gains. Collectively this process is sometimes referred to as Carbon Capture and Utilisation or CCU [37].

Cefic, the European Chemical Industry Council and DECHEMA, the German society for Chemical Engineering, estimate that converting the European chemicals sector to be based on electricity would require 4,900 TWh, almost 10 times the electricity demand of Germany, and more than all the electricity used in Europe today [38]. The inefficiencies of the electrification process would increase overall energy use in the sector 3 ½ times, from 5,059 PJ today to 17,640 PJ in 2050 [36]. Whether the electrification of the chemicals sector reduces or increases emissions will be highly dependent on the CO₂ intensity of the electricity used and the source of the CO₂ used as a carbon feedstock.

For the cement industry, heat processes currently fuelled by fossil fuels could be electrified in the future. The would avoid combustion and reduce emissions by as much as 40% if we assume the electricity is zero carbon.

However, the emission reduction potential is limited, as about 60% of process emissions unrelated to heat would remain. Converting all current cement production in Europe would lead to a comparatively moderate increase in electricity demand, equivalent to the electricity consumption of Poland.

A proposed hydrogen steel factory in Austria is said to require half the country’s total current electricity. The project is planned to be operational in 2045, a generation away as low carbon electricity on the scale required will not be available until then at the earliest. Manufacturing all primary steel in Europe via the renewable hydrogen route would be a significant addition for electricity planners to manage, with the steel sector requiring as much electricity as all of Germany uses today.

For the cement industry, heat processes currently fuelled by fossil fuels could be electrified in the future. The would avoid combustion and reduce emissions by as much as 40% if we assume the electricity is zero carbon.

However, the emission reduction potential is limited, as about 60% of process emissions unrelated to heat would remain. Converting all current cement production in Europe would lead to a comparatively moderate increase in electricity demand, equivalent to the electricity consumption of Poland.

A proposed hydrogen steel factory in Austria is said to require half the country’s total current electricity. The project is planned to be operational in 2045, a generation away as low carbon electricity on the scale required will not be available until then at the earliest. Manufacturing all primary steel in Europe via the renewable hydrogen route would be a significant addition for electricity planners to manage, with the steel sector requiring as much electricity as all of Germany uses today.

For the cement industry, heat processes currently fuelled by fossil fuels could be electrified in the future. The would avoid combustion and reduce emissions by as much as 40% if we assume the electricity is zero carbon.

However, the emission reduction potential is limited, as about 60% of process emissions unrelated to heat would remain. Converting all current cement production in Europe would lead to a comparatively moderate increase in electricity demand, equivalent to the electricity consumption of Poland.
LIMITATIONS OF REINVENTING INDUSTRY WITH ELECTRIFICATION

While electrification certainly has an important role to play in reducing industrial emissions, our analysis shows that solely relying on it is a great risk to take. If all of these industries choose electrification as their main mitigation effort, they would need more than 5,500 TWh of entirely renewable, low-cost electricity. In comparison to 974 TWh of renewable electricity produced in Europe in 2017 [39], this estimate seems to be beyond all reality.

Currently, the most efficient emission reductions with electricity come from using it directly in sectors such as transport and heating. Devices capable of using the most of the renewable electricity provided have a much greater climate impact than complex production processes incurring immense losses of electricity along the way. Prioritising uses in vehicles with electric motors for transport and efficient heat pumps in heating allows for bigger reductions in emissions in comparison to the full-carbon alternatives. Apart from having efficient electrification solutions readily available, these two sectors are a priority for electrification because of the significant potential fossil fuel displacement [40].

In a nutshell, prioritising efficient uses of the valuable renewable resources we have will enable us to reach climate targets on time.

In addition to efficiency, timing indirect uses of renewable electricity together with a clean electricity grid is crucial for their climate footprint.

According to the German Federal Ministry for the Environment (BMU), producing synthetic fuels with current German grid electricity would result in a carbon footprint 3.5 times larger than that of fossil diesel [41]. This number does not yet include the additional footprint dependent on the carbon source that differs significantly between carbon from industry sources and biogenic ones or the air.

To prevent this unfavourable effect, industries would need to follow the renewable power to wherever it may be available. That would imply either a relocation of European industries to places with stranded renewable electricity, or the import of massive amounts of renewables to Europe [42], neither of which are realistic decarbonisation options. Betting on such a strategy would risk unpredictable consequences, compromising Europe’s energy security and industry base.

Using electricity to decarbonise energy-intensive industries also falls short of addressing one of the key challenges of industrial decarbonisation: process emissions. The latter mostly occur due to the basic raw materials needed for manufactured products and not the fossil fuels being burned in the process. Consequently, electricity has a physical limit to decarbonising Europe’s manufacturing industries.

The limitations of electrification clearly show that there is a need for a mixed strategy for the reinvention of the way we produce the building blocks of our society.

“False hopes are worse than no hope at all: They undermine the prospect of developing real solutions.”

Nathaniel Rich
Losing Earth, NY Times
We need an additional

5500* TWh

Renewable electricity
produced in the EU
amounted to

974 TWh

in 2017.

*The cumulative amount of electricity needed for the decarbonisation of cement, steel and chemicals, as given in Figure 6 and based on reports done by the respective industries.

This chapter, second in the line of four, examined the options energy intensive industries have to reduce their climate footprint. The analysis shows that the recipe for reducing emissions depends heavily on the resources available, energy consumption and knock-on effects on other decarbonisation strategies. While establishing the limits of some options is necessary, it alone does not lead to a constructive conversation. The next part of this report will focus on starting industrial decarbonisation now, not in 2050. Chapter three will discuss scalable solutions which can lead to significant emission reductions and can be deployed in the near term future.
THE DAWN OF A NEW INDUSTRY

SUMMARY

As the transformation of the energy system continues and new technology options are developed and brought to maturity, measures that can provide effective and deep emission reductions to industry processes are needed today.

- The capturing of CO₂ emissions from industrial clusters and their transport and permanent offshore storage in deep geological formations (CCS) constitutes an essential part of the solution.
- It complements limitations of feasibility, scale, costs and time associated with other climate tools.

It is a three-step process that depends on the availability of a CO₂ transport and storage infrastructure. Yet, no single industrial site or even sector can be expected to develop the entire system themselves due to high cost, associated financial risk and the required technical expertise. Developing a shared CO₂ transport and storage infrastructure that is open to all industries and expandable to other regions reduces costs and strengthens the regional industry base. The implementation of this system is dependent on financing that can come directly from industry but also from instruments at a regional, national and European level, including the Innovation Fund and the Connecting Europe Facility (CEF). As some programs are either ending soon or still need to be made fit for purpose, time is of the essence.

Overall, establishing a CO₂ network for Europe’s industry today is a no-regrets option that overcomes the notion of ‘unavoidable’ CO₂ and enables industry to deeply decarbonise. By doing so, it protects jobs and welfare and ensures governments are able to fulfil their obligations under binding international targets.
Chapter 3: The Dawn of a New Industry

While options for the decarbonisation of the industry are many, solutions are few. Electrification, recycling and upcycling, as well as the use of alternative materials in production processes and as final products all help reduce industry emissions.

While each of these measures is needed, each is limited through issues of scale, cost, effective CO\textsubscript{2} reductions and temporal availability, and even after implementing all of them, emissions will remain in many industry processes.

As demand for products is increasing with global population levels and rising living standards, industry emissions are set to become the primary source of CO\textsubscript{2} within the next decades.

Limiting today’s industrial climate action to the above mentioned tools will not be enough to reach net zero-emissions by mid-century and thereby avoid the most dramatic effects of climate change.

What is needed is an option that is ready to be implemented and that can provide effective emission reductions as the transformation of the energy system continues and new technology options are developed and brought to maturity.

To ensure that carbon neutrality in Europe’s industry is achieved by mid-century, the capturing of CO\textsubscript{2} emissions from industry clusters and their transport and permanent storage (read: in perpetuity) in deep geological formations (CCS) constitutes an essential part of the solution.

CCS complements limitations of feasibility, scale, costs and time associated with other climate action tools.

"The receiver containing the gas became itself much heated - very sensibly more so than the other - and on being removed, it was many times as long in cooling. An atmosphere of that gas would give to our earth a high temperature; /.../ if the air mixed with it a larger proportion than at present, an increased temperature /.../ must have necessarily resulted."

The discovery of the greenhouse gas effect by Eunice Newton Foote, an American scientist, inventor and women’s rights campaigner (American Journal of Science and Arts 1856)

382

**On the Heat in the Sun’s Rays.**

**Art. XXXI.**—*Circumstances affecting the Heat of the Sun’s Rays;* by Eunice Foote.

(Read before the American Association, August 23d, 1856.)
An Industry’s Guide to Climate Action Chapter 3: The Dawn of a New Industry

Ensures that an industry where emissions cannot be reduced
from cement production is pure enough to be easily captured,
Innovative production processes have been developed in the
HIsarna Steelmaking
not) to capture and store their remaining CO₂
process and provides a high purity CO₂ waste stream. CO₂ can be captured more easily and therefore cheaper [2].
In the steel industry, the HIsarna ironmaking process removes the
LEILAC Cement
other parts of the world in creating such optimised processes.
European energy intensive industries have already leapfrogged
The cement industry has developed a production process that
improves the efficiency and effectiveness of capturing CO₂
emissions from industrial sources. New innovative industrial processes build CO₂ separation and capture into the heart of industrial manufacturing, cutting costs and increasing efficiency.

HOW IT WORKS

**HIsarna Steelmaking**
Innovative production processes have been developed in the steel industry. The HIsarna ironmaking process removes the need for climate intensive coke and sintering in steel making. This makes HIsarna both a more energy efficient production process and provides a high purity CO₂ waste stream. CO₂ can be captured more easily and therefore cheaper [2].

**LEILAC Cement**
European energy intensive industries have already leapfrogged other parts of the world in creating such optimised processes. The cement industry has developed a production process that results in a high purity CO₂ stream when the main raw material in cement making, limestone, is being processed [1]. The LEILAC project (short for Low Emissions Intensity Lime & Cement) enables the separation of gases in such a way that the CO₂ coming from cement production is pure enough to be easily captured, transported and stored. This efficient way of cement making ensures that an industry where emissions cannot be reduced through direct electrification alone has the option (and no excuse not) to capture and store their remaining CO₂ at a low cost.

**Capturing CO₂**
Established capture technologies for industry sites include pre-, post-, and the oxyfuel combustion. Generally, in industries where the CO₂ is more concentrated it is easier and cheaper to isolate and store it. European pilot projects and new ways of manufacturing continue to improve the efficiency and effectiveness of capturing CO₂ emissions from industrial sources. New innovative industrial processes build CO₂ separation and capture into the heart of industrial manufacturing, cutting costs and increasing efficiency.

**Producing valuable goods for a sustainable society**

**Transporting CO₂**
CO₂ is liquefied and transported via truck, train, barge, ship and/or pipeline.
Most people are familiar with CO₂ as an ingredient in fizzy drinks. CO₂ is already being transported across Europe by companies such as the German Linde AG. There are flexible transport options from capture sites to transport hubs, including trucks, barges or ships [3]. Since most of Europe’s emitters are clustered in industrial hubs close to major transport waterways, ships and river barges are an efficient and flexible way of transporting CO₂ from the emissions source to offshore storage sites [4]. These transport choices may also be applied in the first phase of deploying CCS to ensure a lower cost and commercial risk of kick-off CCS projects [5]. For instance, linking up industrial sites along the river Meuse and Rhine to the Port of Rotterdam’s CO₂ infrastructure via barges could still allow the transport of millions of tons of CO₂ per year. Depending on the size of the river, barges have a tonnage of up to 3,000 t and can operate in convoys. For the Rhine this means 45 convoys, consisting of six barges and operating year-round can deliver 35 MtCO₂ per year from Düsseldorf to Rotterdam [6]. From a CO₂ hub, pipelines are the most scalable option to link up with storage sites. Just as gas transporting ships, existing offshore natural gas pipelines can be re-used to transport CO₂ and potentially onshore pipelines if conditions are met [7]. In other words, stranded natural gas infrastructure that becomes obsolete as renewables take over power generation can help reduce CO₂ in other sectors.

**Storing CO₂**
Deep underground CO₂ storage takes place in porous and permeable rock layers at a depth of several thousand metres. The CO₂ eventually binds with the surrounding salty water molecules and remains stored between impermeable layers of rock for thousands of years.

The storage sites are located beneath a non-permeable barrier-rock that prevents the CO₂ from expanding upwards rather than sideways. The potential for CO₂ storage is greatest in offshore saline aquifers and depleted oil and gas fields. CO₂ is injected in the pores and gaps of the rock. Effectively, this represents a return of carbon into formations from where carbon-intensive fossil fuels had been extracted before. Since 1996, an annual one million tonnes of CO₂ have been stored in the Sleipner field under the North sea in Norway [8]. Since 2008, another 4 million tonnes of have been stored at Norway’s Snøhvit CCS project [9].

Recent assessments of Sleipner, the longest running industrial-scale storage project have shown that the CO₂ has stayed trapped in the storage reservoir, meaning no CO₂ has leaked nor has its injection fractured the cap rock [10, 11].

**Figure 1: An illustration of a CCS capture on an industrial point source, transport and off-shore storage chain.**

---

**Figure 2: CCS IN INDUSTRY HOW IT WORKS**

**Extraction of raw materials**

**Capturing and compressing CO₂**

**Groundwater**

**500m**

**1000m**

**1500m**

**2000m**

**CAPTURE**

**TRANSPORT**

**Storing CO₂**

**Deep saline aquifer or depleted gas/oil fields**

**Impermeable seal rock**

**Sea bed**

**BELLONA**

**BELLONA**

---

4

5
WHY IT WORKS FOR THE CLIMATE

During the last major Ice Age, the global surface temperature was only between 2 to 4°C degrees cooler than during the 19th century [12]. Yet, all of northern and central Europe was covered under a kilometre-thick ice sheet. The last time the world was 3°C warmer, during the Pliocene three million years ago, beech trees grew in Antarctica and the sea levels were 25 metres higher [13].

Humans have been releasing CO₂ from the geological sphere much faster than the natural process of the carbon and geological cycles can return it. Simultaneous large-scale deforestation has caused the natural ability of capturing CO₂ to decline. The atmospheric CO₂ concentration has consequently increased from 280 parts per million (ppm) around the year 1800 to about 408ppm in 2018 [18]. This increase has already resulted in a global surface temperature increase of over 1.1°C.

The world as an ecosystem is able to rebalance itself over the course of millions of years. In the meantime, as global surface temperatures rise, the planet will be increasingly inhospitable for a variety of living organisms — including humans.

CCS buys humanity time and industry a functional climate transition.

CCS can bridge the boundary between the atmosphere and the geosphere, and thereby help achieve a more rapid return of CO₂ from resources that are still consumed in many industries and whose products are crucial to implement other climate technologies, such as an enormous expansion of wind power [19].

Arriving at a carbon free world is possible in the future. Considering the short timeframe we have left to prevent irreversible global warming, CCS helps stabilise a warming atmosphere by stopping industry emissions to be dumped into the air.

While the precise consequences of such a warming are unknown, one can imagine children born today will live through a world of drastically changing coastlines, flooded cities, and growing deserts, a world where natural ecosystems that support human civilisation are pushed beyond their ability to adapt [14].

CO₂ is the key greenhouse gas (GHG) that contributes to the warming of the planet. GHGs prevent some of the heat originating from the sun to be reemitted back into space. The higher the amount of GHGs in the atmosphere, the more heat is trapped, increasing the global surface temperature and thereby altering the world’s climate [15].

CO₂ occurs naturally and is part of the carbon cycle in which plants absorb it from the air to grow. The carbon cycle is part of a larger cycle that includes the geological sphere, where previously captured atmospheric CO₂ is stored underground [16].

Over millions of years organic matter (i.e. dead plants) form into limestone, coal, oil and gas. These fossil fuels are important energy sources for our current industrialised society, yet their extraction and burning releases eons of trapped carbon back into the atmosphere [17].

The world as an ecosystem is able to rebalance itself over the course of millions of years. In the meantime, as global surface temperatures rise, the planet will be increasingly inhospitable for a variety of living organisms — including humans.

CCS buys humanity time and industry a functional climate transition.

CCS can bridge the boundary between the atmosphere and the geosphere, and thereby help achieve a more rapid return of CO₂ from resources that are still consumed in many industries and whose products are crucial to implement other climate technologies, such as an enormous expansion of wind power [19].

Arriving at a carbon free world is possible in the future. Considering the short timeframe we have left to prevent irreversible global warming, CCS helps stabilise a warming atmosphere by stopping industry emissions to be dumped into the air.

While the precise consequences of such a warming are unknown, one can imagine children born today will live through a world of drastically changing coastlines, flooded cities, and growing deserts, a world where natural ecosystems that support human civilisation are pushed beyond their ability to adapt [14].

CO₂ is the key greenhouse gas (GHG) that contributes to the warming of the planet. GHGs prevent some of the heat originating from the sun to be reemitted back into space. The higher the amount of GHGs in the atmosphere, the more heat is trapped, increasing the global surface temperature and thereby altering the world’s climate [15].

CO₂ occurs naturally and is part of the carbon cycle in which plants absorb it from the air to grow. The carbon cycle is part of a larger cycle that includes the geological sphere, where previously captured atmospheric CO₂ is stored underground [16].

Over millions of years organic matter (i.e. dead plants) form into limestone, coal, oil and gas. These fossil fuels are important energy sources for our current industrialised society, yet their extraction and burning releases eons of trapped carbon back into the atmosphere [17].
HOW TO DO IT RIGHT

Carbon capture and storage, as any other climate technology, needs to deliver its environmental goals. As with any implementation of new processes, there needs to be a set of sustainability criteria ensuring that CCS is done right to reach its full climate change mitigation potential.

Planning changes to avoid closures
Careful planning is needed to minimise effects on industrial processes: interruption during construction and production, corrosion, wear and tear costs etc. Some short-term disturbances are inevitable for the industries if they seek to avoid a more permanent discontinuation of operations in the future.

Complementing efficiency improvements
Where possible, pairing CCS with more efficient manufacturing processes such as LEILAC and Hlsarna can minimise energy demand and costs. The goal of CCS is to complement efficiency improvements in energy intensive industries, not deter them.

Lowering energy penalties
Processes such as Hlsarna and LEILAC are capable of both increasing manufacturing efficiency and producing a very pure stream of CO₂. By implementing such innovative manufacturing processes, European industries can capture the CO₂ without having the conventional added energy usage burden that comes with capturing CO₂ from mixed gas streams. Additionally, when compared to options such as most carbon capture and utilization (CCU) technologies, CCS will always have a significantly lower energy requirement.

Ensuring safety
In order to meet concerns on the safety of the storage, all of the storage sites must be properly assessed, selected and monitored both during the injection and after it. Prioritising Europe’s vast offshore storage capacity will keep CO₂ storage activities distant from population centres.

Keeping the CO₂ out of the atmosphere
Since keeping the CO₂ away from the atmosphere permanently will be crucial to realise the climate mitigation potential of the technology, other options that use CO₂ to release it back into the atmosphere should not be regarded as climate mitigation solutions.

Working together to bring CCS down the cost curve
Just like for any other climate action strategy, in order to work CCS must be a joint effort. Coordination and collective regional action can overcome risks and generate a business case for each link of the value chain.

Finally, CCS cannot become a one-stop shop for all industrial emissions.
On the contrary, it is complementary to technologies such as recycling, alternative resource use, electrification and efficiency increases.
All of these climate action technologies need to be developed in parallel, rather than inhibiting each other’s development.
3.1
MANAGING CO$_2$:
OPPORTUNITIES AND TRAPS
Although natural gas is around half as climate damaging as coal, it is still not close to being a climate friendly energy source. Globally, one fifth of all CO₂ emissions from fossil fuels are from natural gas. In the Netherlands burning gas releases more CO₂ than either coal or oil [20]. CO₂ transport and storage networks can reduce the climate impact of natural gas and support a more rapid transition to a zero-carbon hydrogen energy system.

Hydrogen is well placed to replace CO₂ intensive natural gas, aiding decarbonisation of heating, industry and long-range transport. Manufacturing hydrogen from electricity is dependent on the availability of low carbon and low-cost electricity. The speed of the scaling up of hydrogen production will be dictated by the speed of the renewable electricity that can be directed to the manufacture of hydrogen. Yet in Europe, only few areas have the share of renewables required to produce hydrogen at scale.

### The origin of H₂ matters

In Germany, renewables make up 31.2% of total electricity production. In 2016, 3.7 TWh of renewable generation was curtailed [21]. Using this curtailed electricity to produce hydrogen would displace only 0.33% of German natural gas demand [22]. It is important to note that producing hydrogen through electrolysis with Germany’s electricity mix that still includes gas and coal power plants, would significantly increase emissions [23].

Improving the grid through greater interconnection and smart grids further reduces curtailment in the future, leading to a more efficient direct use of electricity where needed.

Globally, the bulk of hydrogen (96%) is produced from fossil sources, the majority from natural gas, which is not low carbon as the CO₂ produced in the process is rarely captured and stored [24, 25]. Producing hydrogen in combination with CCS allows for large scale low carbon hydrogen to be produced year-round independent of local renewable generation [26]. Hydrogen produced in this way can supplement and accelerate development of hydrogen from renewable electricity sources. Both hydrogen sources can aid co-developing hydrogen transport infrastructure, supplying the same hydrogen market and growing the share of hydrogen as a clean energy source, while reducing the use of carbon intensive fuels.

Low carbon hydrogen is already produced in combination with CO₂ storage at the Valero Port Arthur Refinery, Texas, USA where 1 MtCO₂ is captured and prevented from entering the atmosphere every year [27].
In addition to halting CO₂ emissions from energy, transport and industry, limiting warming to below 2°C with a high degree of success will require CO₂ to be removed from the atmosphere [14].

The reliance of IPCC models on carbon negative technologies clearly shows just how steep the reductions in our emissions need to be to actually solve the climate crisis. CO₂ removal can be done in a variety of ways, such as the planting of forests, changing of agricultural practices and through the permanent geological storage of CO₂ [28]. For any carbon negative technique to be effective, the CO₂ must be permanently locked away from the atmosphere.

Accesses to CO₂ transport and storage allows for CO₂ to captured and stored directly from the air or from a biogenic source; both routes remove CO₂ from the atmosphere if the biomass sourcing is sustainable. Capturing CO₂ directly from the air is energy intensive and also requires low carbon electricity to be climate effective [29]. The cost of separating CO₂ from air is also anticipated to remain far higher than capturing emissions directly from concentrated industrial sources [30].

The combination of biomass and CO₂ storage can produce carbon negative products, such as heat, electricity and industrial products. It is important that any biomass used for energy or heat, with or without CCS, needs to be sustainably sourced. If this sustainability is ensured, the use of biomass alone can allow for some CO₂ emissions mitigation, but the use of biomass with CO₂ storage can enhance the mitigation, delivering carbon dioxide removal [31]. Some regions already use biomass at scale to heat and power cities.

In Sweden and Finland 32 and 40 million tonnes of CO₂ from biomass are emitted to the atmosphere every year [32].

The use of sustainable biomass with subsequent emission of CO₂ to the atmosphere should be seen as a climactically wasteful practice, underutilising the climate potential of a scarce and valuable renewable resource. Indeed, a major concern is that increased use of biomass in industry and energy can also result in negative biodiversity and climate impacts. However, using biomass in the industry sector where CCS is needed already, reduces costs and valorises negative emissions through a net negative industry product. For energy generation, renewable energy sources should be the preferred option due to greater efficiency and issues of sustainability.
NOT EVERY USE OF CO₂ IS CLIMATE ACTION

Although frequently discussed simultaneously, due to its similarity to CCS in name and abbreviation, Carbon Capture and Utilisation (CCU) refers to the use of CO₂ in various processes and products, whose climate impact varies significantly depending on the final product and the origin of CO₂.

CCU thereby rarely achieves the same climate benefit as storage of CO₂ [33]. The two reasons for this are 1: Nearly always and immediately (months) all the CO₂ ends up in the atmosphere leading to increased warming, and 2: the electricity requirements are massive, particularly when it comes to fuels and chemicals.

These limitations mean that realistic deployment is distant and will directly compete with much more efficient (climactically and in practice) direct electrification of transport, heating and industrial processes.

Due to its inefficient process, the associated high demand for renewable electricity and consequent costs, as well as its limited utility in actually decarbonising industry processes, CCU will not play a major role in facilitating a net-zero emission future by mid-century. Without appropriate sustainability criteria and life-cycle analyses of CCU products in place, CCU can in fact lead to a prolonged dependence on fossil fuels in Europe’s electricity generation. It may thereby undermine the development and deployment of technologies that use electricity directly, e.g. electric mobility that would be much more effective at avoiding fossil extraction.

Using CO₂ might be a strategy for replacing fossil feedstocks, but in most cases, it is not a climate change mitigation tool. CCU’s attractiveness derives mostly from substituting fossil fuels as carbon sources and energy carriers. Most CCU products re-emit the CO₂ into the atmosphere [34]. This point in time differs from a mere hours after production, to days, or years. This is a significant make or break factor in climate change mitigation, the point of which is to keep the CO₂ away from the atmosphere [35].

CCU products with the longest storage ability — such as mineralisation — offer a relatively small market in comparison to our huge annual emission of CO₂. For other CCU processes that readily re-emit CO₂, no carbon from industrial (or other fossil sources) can be used to reach the carbon neutrality needed to deliver the Paris Climate Agreement. Here, only biogenic sources and direct air capture should provide the CO₂. In addition, a carbon neutral CCU process depends on 100% carbon free electricity.

CCU as a CO₂ sink: Mineralisation

Ex-situ mineralisation is the mining of reactive minerals to be combined with CO₂ at its source. The reactive minerals, such as olivine, are the primary resource input. Under ideal circumstances CO₂ may react with wollastonite, a naturally occurring mineral. For every 1 tonne of CO₂ absorbed some 7 tonnes of wollastonite must be mined and processed. For large-scale CO₂ mineralisation of, for example, 2 million tonnes, about 14 million tonnes of minerals are needed to react, resulting in over 16 million tonnes of reactant that will need to be disposed of [36]. The real-world testing of this is at a very small scale in lab sized reactors and has a low technology readiness. The largest potential reactors are on the scale of 100 thousand tonnes of CO₂ per year. This involves a pressure reactor drilled to about 1 km depth into the earth. Here CO₂ and olivine are mixed at a high head pressure from the km of material to be fed in from the top [37, 38].
**Most CCU requires electricity, and lots of it**

The process of turning the waste product CO₂ into a valuable feedstock requires the use of large quantities of electricity. Depending on the grid mix, CCU can therefore have a negative climate effect. Overburdening the electricity production prematurely to fuel large-scale CCU can also prolong fossil fuel dependence in the power sector.

For CO₂ to Fuels / CO₂ to chemicals, abundant zero carbon electricity is the major resource requirement. Under favourable assumptions, the use of 1 tonne of CO₂ in the formation of methanol (used as fuel or chemical feedstock) requires some 6.5 MWh of zero carbon electricity. Using 2 MtCO₂ would need 13,000 GWh of zero carbon electricity (11% of all Dutch electricity generation).

Using grid mix electricity would therefore multiply emissions. All of this used CO₂ will end up in the atmosphere when the fuel is used, and next to all will be emitted with current disposal of plastic. Manufacturing a synthetic diesel fuel that car companies such as Audi promote would double the electricity requirement [39].

**CCU is neither capable of boosting the energy transition, nor of decarbonising industry.**

CCU is also promoted as an essential energy carrier in support of the renewable energy transition.

The power to gas (PtG) process is based on hydrogen from electrolysis and the adding of CO₂ to create synthetic gas. By using only ‘excess’ renewable electricity, PtG is said to act as an energy storage. However, ‘excess’ renewable electricity is only a phenomenon of the current underdeveloped European power grid and, to reiterate, hydrogen produced with curtailed electricity would only displace 0.33% of German natural gas demand, an already negligible amount, which would only shrink further with the additional inefficiencies of CO₂ synthesis [22]. Indeed, due to the highly inefficient process, PtG is extremely costly with severe energy losses compared to the direct use of electricity [40]. To reduce costs, electrolysis and methanisation need to run at full-load hours, further undermining any idea of only using ‘excess’ renewable electricity [40].

The alternative path for using PtG for energy storage is through importing large quantities from faraway places with stranded renewable electricity to reduce costs and allow for full-load hours. Yet, the production of synthetic gas and fuels in regions, such as the Middle East and Northern Africa (MENA) or Australia defeats PtG’s potential to use CO₂ from Europe’s industries [41, 40, 42]. Furthermore, to create electricity storage, synthetic gas would have to be actually stored, i.e. prevented from entering the grid where it simply competes against renewable electricity and is immediately used rather than saved for times when no wind and sun is generating power. Establishing major underground storage sites for a highly combustible gas close to demand centres bears its own risks [43].

**Figure 6: By far the biggest resource used in the manufacture of products using CO₂, especially hydrocarbons, is electricity.**
3.2 Creating CO$_2$ networks
MAKING EUROPE CLIMATE PROOF

The creation of a common European CO$_2$ network is effective for climate protection, strengthens the regional industry base, and promotes trade and growth. As climate requirements of zero emissions become more pronounced, industries and regions with access to a CCS system gain a competitive edge in a low-carbon market and over regions lacking the respective infrastructure. A European CO$_2$ transport and storage network generates climate proof industry regions that can withstand growing political and financial pressures associated with the rising climate concerns of the 21$^{st}$ century.

"They have to deliver it to the gate, we do the rest"

Allard Castelein, CEO of the Port of Rotterdam Authority [45]

Industry sites linked to a CO$_2$ transport and storage infrastructure benefit from increased range of decarbonisation options that help secure their assets against growing political uncertainties and financial risks. Regions in which these industries are located are more able to retain existing jobs and their economic basis. Such climate proof regions are likely to become attractive for companies seeking to invest and expand their production sites; the creation of a CO$_2$ network helps to ensure continued employment, income and growth. For industrial countries, such as Germany, CCS represents a crucial component to protect the climate as well as almost half a million direct jobs in the German cement, chemical and steel industry, plus jobs and income in dependent industries downstream.

Furthermore, countries without a major industrial base, but with significant storage potential, such as Norway, will benefit economically. A recent study suggested that establishing a European CCS industry in Norway could generate up to 40,000 related jobs in 2030, and up to 90,000 by 2050 [46]. By helping to achieve the climate target and maintaining jobs and livelihoods, CCS systems ensure a ‘Just Transition of Europe’s industry.

Photo credit: Port of Rotterdam
Chapter 3: The Dawn of a New Industry

**CO₂ networks are a public good**

In the early 19th century, London planned to expand its sewage system, yet faced widespread public opposition. Particularly wealthier people, living uphill, did not see why a general sewage system was needed and hence did not want to pay to improve the property of private individuals ‘downhill’. In fact, sewage was not seen as a public good, and so the government initially considered it improper to use public money. It took several cholera epidemics, thousands of deaths, and the ‘Great Stink’ of 1858 for London to finally modernise and upgrade its sewage system, at last stopping the unchecked dumping of human waste into the river Thames.

Just as it is no longer acceptable to toss sewage onto the street, an accessible CO₂ transport and storage system will prevent us from dumping climate damaging CO₂ into our shared atmosphere.

CCS is a three-step process that depends on the availability of an adequate CO₂ transport and storage infrastructure. Similar to waste management, this infrastructure needs to ensure that CO₂ is picked up and safely taken care of. No single industrial site or even sector can reasonably be expected to develop the entire system themselves for reasons of cost, associated financial risk, as well as the required technical expertise.

A shared CO₂ network provides a public service by taking care of harmful emissions associated with goods widely used by society; from concrete that is the foundation to our infrastructure, houses and wind farms, to steel and metals that are the backbone of society’s tools, technology, and modes of transportation, as well as chemicals, such as paint, plastics and pharmaceuticals.

“The principle] was of diverting the cause of the mischief to a locality where it can do no mischief.”

Sir Joseph Bazalgette, Civil Engineer who upgraded London’s sewage network and brought an end to the cholera outbreaks [44]
IT’S UP TO INDUSTRY TO BREAK INERTIA

If industries and regions want to establish a CO₂ network that provides them with the means to deeply decarbonise, secure their assets, and retain jobs and economic activity, the current inertia of industry and politics needs to be overcome.

Despite being one of the largest emitters of CO₂, industries have been largely shielded from real climate action. Effective lobbying and concerns over global competition and potential job losses have prevailed over the provision of clear targets and incentives for effective measures that would hold industries accountable to their role in anthropogenic climate change and provide them with the means to deeply decarbonise.

The current inaction by politicians to enforce, and companies to demand support for the decarbonisation of industry undermines the Paris agreement and threatens the future of the climate and Europe’s economy alike.

Concerned with the perceived and real costs and limitations of decarbonising industry, emissions from employment, energy and CO₂ intensive industrial processes are too often described as ‘unavoidable’. This notion has resulted in a sense of exceptionalism for the industry that sees itself exempt from implementing climate measures. Yet, there are no unavoidable CO₂ emissions in a post-Paris, zero-emission economy.

Nevertheless, few governments and civil organisations actually have a strategy for the industry’s deep decarbonisation. At the same time, companies aware of the looming climate pressures and associated commercial risks do not receive the necessary regulatory and financial support to begin avoiding or capturing their CO₂, let alone any access to CO₂ storage.

The deep decarbonisation of Europe’s industry needs clear long-term goals and respective support mechanisms that reduce risks of investments in climate measures, including capture technologies and the CO₂ infrastructure. Industries deciding to reduce their emissions should be rewarded rather than face a competitive disadvantage. Similar to the renewable energy transition, CCS technology requires public-private partnerships in which the government establishes a supportive financial framework, assumes some of the investment risks, and provides a market for the final good until its commerciality is established; in this case, a zero-emission final industrial product. In doing so, Europe’s industry stands to gain a competitive edge in a zero-carbon future, as it already has in renewable energy generation.

Others are already moving ahead

Norway
Norway is moving forward on two capture projects, a cement plant and a waste to energy incinerator, linked up via ship and pipeline to a storage site several kilometres off the coast of Norway. This project is set to be the corner stone of the country’s long-term plan to decarbonise its economy and expand its storage infrastructure with the possibility and aim to link up with other countries [54].

Sweden
Norway’s neighbour Sweden seeks to be carbon neutral by 2045. Sweden’s climate roadmap from 2018 therefore calls for a concrete CCS strategy for the Swedish cement production [55], as well as the steel sector to reach its targets [56]. Joining the Norwegian effort would be beneficial for both nations, and the world’s climate.

The UK
The UK’s Clean Growth Strategy requires CCS at scale by 2030, which has already led to the planning of six large-scale projects [57]. Existing pipeline and well infrastructures are currently assessed for re-use [58].

The USA
Across the Atlantic, the USA increased already existing tax incentives for companies to store CO₂ rather than release it to the air from US$ 10 to US$ 50/tCO₂ in 2018 [59].

The Netherlands
The Netherlands plans to store several million tonnes of CO₂ per year by 2030. The Port of Rotterdam — host of multiple energy intensive industries in the country - has already begun preparing to do its part in reaching the targets, focusing on the development of strategic infrastructure to serve the port. This includes a backbone CO₂ pipeline to provide access to offshore CO₂ storage, and extra capacity to expand and scale over time. Rotterdam effectively seeks to become the CO₂ transport and storage hub of the region.
MOVING EUROPEAN CO$_2$ INFRASTRUCTURE DOWN THE COST CURVE

A CO$_2$ network is to be developed across national borders and various industry branches due to the differing geographic locations of industry clusters and CO$_2$ storage sites. The creation of an industrial CO$_2$ infrastructure therefore requires collective European action.

The implementation of CCS does not have to and should not be a national, solo effort. As there is ample offshore storage available across Northern Europe, countries may choose to develop their own full CCS chain or begin a CO$_2$ network by sharing with countries with more mature CO$_2$ storage development. As the infrastructure is established, expanding becomes easier, growing to provide decarbonisation for more sectors in more areas. Through cooperation, total offshore storage potential in the North Sea and Norwegian Sea of about 202 billion tonnes of CO$_2$ would not be a limiting factor of CCS in halting warming to 2°C and below.

Costs for CO$_2$ networks are reduced the more industry sites capture their process emissions and share the transport and storage infrastructure. For CCS, this means focusing on regional industry clusters and creating CO$_2$ transit hubs. Through cooperation, risks are lowered for each party involved and shared benefits are increased.

The pooling and sharing of resources is the most cost effective and efficient way to ensure European industries can deeply decarbonise. Once a CO$_2$ network is established, smaller CO$_2$ point sources can gain access to the CCS system more easily. These ‘smaller’ point sources, such as waste incinerators, still make significant contributions to climate change. A typical waste-to-energy incinerator, for example, still produces over 37% of CO$_2$/MWh compared to a typical coal power plant [50].

### CO$_2$ Capture Costs [53]

<table>
<thead>
<tr>
<th>Sector</th>
<th>Process</th>
<th>Cost per tCO$_2$ abated in €/ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron and steel</td>
<td>Blast Furnace</td>
<td>53 (30-79)</td>
</tr>
<tr>
<td></td>
<td>Hot Blast Stove, power/steam plant</td>
<td>71 (71-85)</td>
</tr>
<tr>
<td></td>
<td>Cokes oven</td>
<td>83 (83-92)</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Aluminium smelter</td>
<td>15</td>
</tr>
<tr>
<td>Chemicals</td>
<td>Ethylene oxide</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Hydrogen (ammonia/methanol)</td>
<td>34 (18-43)</td>
</tr>
<tr>
<td></td>
<td>Ethylene/propylene</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>Process heaters/cogeneration (CHP)</td>
<td>101</td>
</tr>
<tr>
<td>Gas treatment</td>
<td>Gas treatment</td>
<td>12</td>
</tr>
<tr>
<td>Pulp and Paper</td>
<td>Power process</td>
<td>67 (34-69)</td>
</tr>
<tr>
<td>Cement</td>
<td>Pre-calcination</td>
<td>37 (21-50)</td>
</tr>
<tr>
<td></td>
<td>Complete installation</td>
<td>61 (35-111)</td>
</tr>
</tbody>
</table>

Table 1: CO$_2$ capture costs for various energy intensive industries

Implementing CCS in Europe’s industry would raise the price of the final good, such as a car built with carbon neutral steel or a house built with zero-emission cement by a mere 1 percent without reducing the quality of the product [51, 52]. Zero-emission certificates similar to existing Fair Trade and Organic (Bio) seals can help raise awareness and supply a growing market of an environmentally and climate-aware populace, while helping to prevent a runaway climate change before it is too late.
Coordination and implementation

The decoupling of the capturing from the transport and storage of CO₂ creates counter-party risks. Industries are unwilling to begin capturing their emissions at scale without certainty that this CO₂ will be picked up, transported and stored. Simultaneously, CO₂ infrastructure operators require assurances that CO₂ will indeed be delivered, and their services remunerated. Varying timeframes need to be aligned; for example, efforts for the identification and development of new storage facilities need to take place on average 5-10 years prior to CO₂ capture.

Creating a CO₂ network requires a coordinating body that manages the interests of the involved actors by planning, timing and investing in infrastructure, coordinating development, and assuming responsibility and commercial risk. These Market Maker institutions can become the delivery framework for a European CO₂ infrastructure, and the allocators of market risks and liabilities between the public and private sectors. They can act under a regional, national and supranational statute to plan and execute the delivery of CO₂ network development.

The implementation of a CO₂ network follows a consecutive two-stage business model:

1. The first pre-commercial phase is about the creation of a CO₂ market and the transport and storage infrastructure. Development costs have to be covered. Through tenders/auctions and contracts for difference, costs for CO₂ storage and remuneration levels can be identified. In most cases, state authorities would establish market maker institutions to manage and implement the necessary tasks, develop a market for CCS and carbon neutral goods, and assume risks. In the medium- to long-term, these institutions can be partially privatised or even dissolved.

2. The second phase rests on private entities in a liberalised market framework in which public financial and regulatory support is largely obsolete. Individual companies make decisions on business models, risk allocation and the potential extensions to the CO₂ network. The state withdraws to a mere moderating role to prevent monopolies from arising and to establish mechanisms that render CCS a tenable business option. Robust CO₂ pricing, a premium on low-carbon products or storage incentives can achieve this, as seen in the US.
INCENTIVISING AND FINANCING A EUROPEAN CO₂ NETWORK

While low-hanging fruit climate measures, such as efficiency improvements, have taken place over the past decades and resulted in industrial emission reductions, such measures were implemented primarily because they made immediate commercial sense. Any widespread future climate action needs to do the same.

Costs for CCS depend on the CO₂ purity of the emission waste stream, capture technologies and distance between source point and storage site. Breakthrough technologies in both steel and cement could generate price levels of about US$ 20/tCO₂, similar to the chemical industry that on average benefits from purer CO₂ waste streams. Full chain costs are likely to range around 50 €/tCO₂ depending on the above factors [53, 60].

However, it is not expedient to wait for a higher price for allowances in the European Emissions Trading System (ETS) to make capturing CO₂ less expensive than emitting it into the air. Even if the necessary price levels are reached and, against current experiences, remain stable for a foreseeable time, the industry will already need a solution at hand, not begin investing in improved technology options and planning an infrastructure that will take several years to be developed.

The ETS alone is neither able to deliver the necessary climate action on time, nor cost effectively. Relying solely on the ETS to drive effective climate action puts an excessive financial burden on Europe’s industry. It would postpone the decision on CCS until the 2030s, which means there will not be a CO₂ infrastructure ready until 2040. In the meantime, a rising ETS price solely incurs higher production costs that may result in the exodus of Europe’s industrial base.

In addition to clear political frameworks, financial incentives need to be identified, used and created.

CCS is technologically mature, yet not commercial. Technical studies on potential storage sites, their subsequent development and continued monitoring, as well as the identification of transport routes paired with the provision of transport solutions need to be financed. The creation of a CO₂ infrastructure relies on financial support from public and private sources.
Industry contributions are important sources of funding and some companies are already investing in the development of capture technologies. Additional financial instruments exist on a regional, national and European level, such as revenues of the European Emissions Unit Allowance trade of the ETS. As a European cross-regional project, a CO₂ transport network is eligible for financial support as a Projects of Common Interest (PCI) under the Connecting Europe Facility (CEF). A potentially created Just Transition Fund should also extend to support job saving climate action in industry sectors.

At an EU level, some funding mechanisms, in accordance with their criteria, could be used to support the development of CO₂ storage, the deployment of strategic CO₂ infrastructure for industrial clusters and hubs, and partially covering of the cost for capturing CO₂ through a market maker institution. Pioneering CCS projects that lay the foundation for a European CO₂ network need to be able to access the available funding mechanisms; however, many are either ending soon or still need to be made fit for purpose before their immediate launch. If this rapidly closing timeframe is missed another decade may be lost until new opportunities arise.

LOW CARBON GOODS FOR A LOW CARBON WORLD

As a CCS market is established, commercial deployment will follow. The creation of a market for zero-emission goods is not an insurmountable obstacle. Transferring the additional cost of an environmentally superior and climate neutral good onto the consumer is done frequently, as with renewable electricity and organic food products.

Green Public Procurement can help the creation of a market for low carbon goods, as governments at all levels give weight to environmental and emission considerations when evaluating offers for public-funded infrastructure, buildings and transport systems [61]. Government incentives can also soften price increases through, for example, reduced VAT rates on low-carbon goods. A useful tool in this regard would be the extension of the Ecolabel that has so far focused on energy performance, to also indicate the emission intensity of a product.

A zero-emission certificate for industry products down the value-chain, similar to existing Fair Trade or Forest Stewardship Council (FSC) seals, can help raise public awareness and supply a growing market of an environmentally and climate-aware populace.

In the long-term, bans for uncertified products can phase out polluting goods on Europe’s market.

Figure 7: CO₂ storage potential, in bill.tons (Acatech, CCU und CCS- Bausteine fuer den Klimaschutz in der Industrie, 2018)
Establishing a European CCS network benefits the industry, unions, governments and the environment by mitigating the worst effects of climate change.

**Avoiding stagnation in emission reductions**

CCS provides a feasible path for industry to deeply decarbonise its processes. It thereby protects already made investments and existing assets, from which value is currently realised, and where growing value and products need to be generated in the future.

**Keeping jobs**

With CCS as a corner stone of a just transition for industries, labour unions ensure that jobs in heavy industry and dependent sectors remain in Europe even under increasingly strict climate obligations. It safeguards the welfare of Europe’s workers.

**Meeting targets**

Governments at a local and national level are able to fulfil their obligations under binding international targets and towards their constituents by protecting their health, their jobs, and the environment and climate.

**Dealing with ‘unavoidable’ emissions**

By supporting a shared CO₂ network, the civil society ensures that no industry emissions are considered ‘unavoidable’ and forces industry to deeply decarbonise. With no excuses left, industry decarbonisation will not be delayed further.

**Enabling significant reductions**

Emission levels continue to grow globally with only sluggish reductions even in the energy sector, despite already having solutions readily available. Establishing CCS for industries allows for deep emissions reductions over the coming decade in a sector that has pushed climate measures into the distant future, using their integral process emissions and dependence on a fully decarbonised electricity supply as a pretext for inaction. A shared CO₂ infrastructure thereby changes the conversation on what is possible. Whether or not other effective decarbonisation options emerge in the future, Europe will not regret having actually begun reducing emissions through CCS today. Preventing runaway climate change and building the foundation for its transition towards a low carbon economy, CO₂ networks open up new opportunities for other climate measures and drive innovation in industry decarbonisation. While the exact amount of ‘residual’ CO₂ needed to be stored can and should be subject to debate, what is clear, however, is that these emissions will be too significant to be ignored.

This chapter, third in the line of four, discussed how managing industrial emissions with carbon capture and storage can help achieve climate goals. Without the discussion on significant reductions in process emissions, climate action in industry comes to a standstill. By discussing CCS as a vital part of the climate change mitigation strategy, this report aims to steer the conversation away from concepts such as ‘unavoidable emissions’ and point to options that are in line with the worlds climate targets. Accordingly, the next part of this report will estimate the potential for a regional implementation of CO₂ capture, transport and storage networks.
4

don’t panic, we can fix it.
A Farewell to Inaction

SUMMARY

Several current developments in Europe could make a shared CO₂ network a reality in the near future. Norway has been a pioneer of the CCS technology for decades and has the largest offshore storage reserves in Europe. The country is currently developing the world’s first shared CO₂ storage infrastructure for two domestic point sources, a cement plant and a waste-to-energy incinerator.

In light of the comparably low amounts of Norway’s own industrial emissions, the true potential of this infrastructure will only be attained when it is shared with other major emission sources in Europe.

At the same time, the Netherlands is assessing its own CO₂ network to enable a deep decarbonisation of its industry in time to reach the country’s 2030 and 2050 targets. As the Port of Rotterdam is seeking to become the crucial CO₂ transit hub for the region, Dutch actions have the potential to kick-off similar plans in adjacent regions. This represents a major opportunity for Europe’s largest industrial region, North Rhine-Westphalia in Germany, which has the chance to start its own capture projects and access the Dutch CO₂ network via the major waterways in the region.

Accomplishing the Norwegian and Dutch plans while involving Germany would provide a strong showcase of pan-European cooperation and climate action, and would catapult Europe’s industry to the forefront of the next, green, industrial revolution.
In the longer term, the availability of CO₂ networks allows for the deployment of more diverse CO₂ capture techniques and even entirely new ways of making products that rely on CO₂ transport and storage. The first required step is now being considered in Norway, a shared CO₂ network with two diverse industrial capture projects showcasing where CCS can dramatically reduce emissions and allow neighbours such as Sweden and Denmark to join and reach their own climate goals.

Norway

Norway has been a pioneer in CCS technology for decades, and has proven that through the appropriate sustainability requirements and measures, the storage of CO₂ underground in saline aquifers and gas deposits is safe and successful in abating CO₂. The offshore storage potential of 113 billion tonnes, advanced geological understanding and an existing infrastructure can be used to place Norway as leading CO₂ storage service provider to Europe and technology exporter globally.

Norway’s government has stated an ambition to moving the so-called full-scale CCS project forward, albeit with reservations and postponement of decisions. The project seeks to establish a shared CO₂ transport and storage infrastructure, connected to currently two pilot projects: a cement plant in Brevik, and a waste-to-energy incinerator in Oslo. Government ministers have stated that international interest will impact on the political support for the project [1].

The Norwegian process industry will need about 9.2 MtCO₂ stored annually by 2050 [2].

Developing the world’s first shared CO₂ storage infrastructure

Norway’s planned CO₂ storage site will be designed to receive CO₂ from multiple sources. Until now, each of the world’s existing CO₂ storage sites are connected to one single source of CO₂. The Norwegian model will allow industrial emitters to focus on the capture of CO₂, while they can leave the transport and storage to others.

This is likely to become a game changer for countries with little or no available CO₂ storage at home.

CCS enjoys a wide consensus among Norway’s main trade unions, the trade associations for land-based industry, the oil and gas association, politicians, and environmental NGOs. The support of this ‘CCS coalition’ for state investment in CCS is particularly visible in high-stakes political processes [3]. One example is politics in the run-up and aftermath of the adoption of Norway’s state budget for 2018. In a rare show of unity, the organisations made coordinated advocacy for full-scale CO₂ capture, transport and storage. At public hearings, CCS was among their top priorities for the 2018 state budget.

Building on the expertise available to move towards a net-zero economy

Equinor (formerly Statoil), Shell and Total have teamed up to jointly develop a storage site. The offshore oil and gas producers and supply industry can use their skills and knowledge in compressors, pipelines, storage tanks, platforms, wells, subsea applications, and monitoring equipment that will be needed for all parts of the CO₂ value chain [3]. Moreover, in a European economy facing increasingly stringent climate targets, the Norwegian gas producers have a self-interest in decarbonising natural gas. As fossil gas is phased out, Norway’s role in Europe will be forced to change from a high-carbon gas peddler to a low-carbon hydrogen supplier.

Next steps

Creating a market for low carbon products

Low carbon products and services such as cement, steel or district heating are likely to have higher up-front costs, at least in the medium term, pending drastic increases in the price of CO₂ quotas under the EU’s Emissions Trading System. More stringent criteria in public procurement tenders can help create a market for climate friendly products. To name one example: Norway’s public sector alone buys goods, services and construction work for about 500 billion NOK (52 billion €) annually [4]. Governments have market power to initiate a shift from high to low carbon products.

Making CO₂ infrastructure available to Europe

As the Norwegian CCS project is underway, its full potential will only be reached and the returns on investment will only be highest when it is connected to European industries that require CCS to decarbonise. Developed with an eye to expansion, Norway’s CO₂ transport and storage network is the foundation to enable CCS in countries such as Sweden and Germany. The Norwegian government should act quickly to invite governments and companies to join efforts for a carbon neutral European economy.
Sweden

Sweden seeks to become carbon neutral by 2045 [5]. Several Swedish officials and politicians have identified cooperation with Norway on a CO\textsubscript{2} transport and storage infrastructure to be beneficial to both countries, and sensible commercially. After having published a series of roadmaps for emissions reduction in a broad range of industry sectors [6], Sweden’s national climate coordinator has pointed to CCS as one of five key political measures that need to be addressed [7]. The Swedish government recently commissioned a study on negative emissions. CCS will be part of the study, which will be done by January 2020 at the latest [8]. These developments indicate that Sweden is serious about developing a zero emission society and economy.

There is already a handful of potential CO\textsubscript{2} capture projects. In the Gothenburg area, the refinery Preem has initiated a study of options for CO\textsubscript{2} capture [9]. Stockholm’s district heating system, which runs largely on local waste biomass, has also signalled interest in CCS. In addition, the cement industry has pointed to CCS as an essential technology for reducing CO\textsubscript{2} emissions [10].

Growing interest in pursuing CCS cooperation with Norway. But for such discussions to move from non-committal talk to action, Norway’s offer of CO\textsubscript{2} infrastructure needs to provide more commercial predictability and clarity for Swedish CO\textsubscript{2} emitters.

What is needed are cost estimates, development timelines and contractual modalities. This will expedite a real conversation about terms and modalities for Swedish companies to join an effective decarbonisation route.

Using EU funding to aid the Swedish national climate strategy

Strategic investments are required for a climate neutral Sweden to be achievable by 2045. To access EU funds Sweden requires achievable national industrial decarbonisation projects.

The upcoming Innovation Fund and the Connecting Europe Facility (CEF) have the potential to support Swedish CO\textsubscript{2} capture, transport and storage development. The Innovation Fund could support CO\textsubscript{2} capture from cement, district heating or other industries. CEF funding can support CO\textsubscript{2} transport infrastructure such as pipelines and shipping terminals, a good fit for developing transport links to North Sea and Norwegian CO\textsubscript{2} storage sites.

Timing is essential. Project development needs to take into account the funding schemes’ timelines and vice versa. To be in competition for these funds Swedish projects must rapidly mature, complete feasibility planning and develop a framework for national support. More mature projects with lower engineering and political risk are better placed to receive EU funding.

“Norway and Sweden are neighbours. It is therefore especially efficient and important to work together on such large-scale projects”

Elisabeth Undén, Gothenburg Environmental Party [11]
Dutch CO2 Infrastructure benefits the entire economy and allows breakthrough technologies to be brought to market, accelerating the transition towards a 21st century zero-emission economy.

In 2015, a Dutch court made a decision in a landmark ruling that the government of the Netherlands has a constitutional duty to protect its citizens from the impacts of climate change, and therefore ordered more ambitious action to cut carbon emissions.

The Netherlands have hence set a minimum 49% emission reduction target for 2030 compared to 1990 levels and a 95% target for 2050 [12]. In the 2017 Coalition Agreement, the Netherlands acknowledged the need for CCS at large scale in its industry to fulfil this obligation. According to the draft of the Dutch Climate Agreement from July 2018, industry is to reduce emissions by over 1 MtCO2 by 2030 – the largest proportional reduction required by any sector – potentially half of which through CCS. To achieve this goal, investments in innovation and infrastructure of up to 20 billion € are needed [13].

The Value

The ambitious climate agreement and the acknowledgement of the need for CCS allows the Netherlands to live up to its reputation as a forward thinking climate leader and aficionado for cutting-edge technology solutions. Even if CCS is replaced in some sectors through a closed cycle circular economy in the future, this is likely to take multiple decades to realise, although suggested by the draft agreement to be the “short term” goal [13]. Until then, the Dutch government will have protected its citizens and the climate from millions of tonnes of harmful CO2 emissions by deploying CCS.

Through the creation of a CO2 network, the Netherlands is providing industries not just with the tools to deeply decarbonise but also with the obligation to do so. As the myth of ‘unavoidable emissions’ is overcome, this obligation is spread even beyond its borders. Dutch industries benefit from the means to effectively reduce emissions, lowering climate risks and protecting jobs. New jobs are created as part of the CO2 network operation and from potentially growing and relocating industry sites.

For highly industrialised and emitting regions such as Rotterdam, CCS is a major requirement to protect its future existence. Rotterdam is host to many energy intensive industries and a nucleus of emissions with a share of about 20% of total Dutch CO2. Efforts already focus on the development of strategic CO2 infrastructure to serve the port. A backbone CO2 pipeline will provide the Port access to offshore CO2 storage and extra capacity to expand over time. Through its geographic location, the Port is likely to become a key CO2 hub for Central-Western Europe.

The Netherlands Transport and Storage Cost Calculations by 2030 [14]

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Medium</th>
<th>New built</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 abated (Mt)</td>
<td>476</td>
<td>654</td>
<td>654</td>
<td>964</td>
</tr>
<tr>
<td>Mothballing*</td>
<td>133</td>
<td>216</td>
<td>120</td>
<td>474</td>
</tr>
<tr>
<td>Injection</td>
<td>1 499</td>
<td>7 240</td>
<td>4 154</td>
<td>3 382</td>
</tr>
<tr>
<td>Offshore Transport</td>
<td>740</td>
<td>764</td>
<td>764</td>
<td>1 404</td>
</tr>
<tr>
<td>Onshore Transport</td>
<td>366</td>
<td>366</td>
<td>366</td>
<td>376</td>
</tr>
<tr>
<td>Onshore compression</td>
<td>1 490</td>
<td>2 072</td>
<td>2 072</td>
<td>3 072</td>
</tr>
<tr>
<td>Total Cost in million €</td>
<td>4 229</td>
<td>6 158</td>
<td>7 477</td>
<td>8 707</td>
</tr>
<tr>
<td>€/tCO2</td>
<td>8,9</td>
<td>9,4</td>
<td>9,0</td>
<td>11</td>
</tr>
</tbody>
</table>

*Costs during transition period of natural gas infrastructure before re-used for CO2 transport.
Making full use of the market maker

The Dutch government needs to capitalise on the vast expertise of its state-owned companies. The Port of Rotterdam Authority manages the world’s third busiest and Europe’s largest port, which seeks to serve as the transhipment hub of CO₂ captured from industry plants. Gasunie, which operates the country’s 12,000 km of gas pipelines, is well-placed to run the transportation network of CO₂ by, for example, reusing offshore natural gas pipelines to the storage facilities, where EBN, with its decades of experience in the subsurface exploration, extraction and storage of gas and oil on behalf of the Dutch state, can now ensure the safe storage of CO₂. Jointly, they embody the Dutch Market Maker, coordinating and operating a shared CO₂ infrastructure for CCS in the Netherlands.

With the transport and storage system up and running, industry sites are finally provided with the means to deeply decarbonise and need to begin capturing their CO₂ independently. Employing the already planned tender mechanism to find the most cost-efficient investments ensures CCS projects are economic and drives industry investments into innovation [13].

Complementing other climate action measures

Any financial support at the national level needs to be specifically designed and dedicated to CCS and should not compete with other climate measures, such as renewables. Dividing the implementation and operation of the different stages along the CCS value chain allows for the use of targeted finance instruments for capture and infrastructural aspects.

Expanding to European industry clusters

The goal of the Dutch CO₂ infrastructure needs to be its expansion to neighbouring European industry clusters. Rotterdam’s proximity to Antwerp and river links via the Rhine and Meuse to North Rhine Westphalia, Chemelot and Liege are the basis for a first stage of expansion. Not only does a parallel international focus next to the national one towards expanding the infrastructure to Europe boost the business case of the Dutch CCS project, it also opens the door for financial support from the European level. Under the Innovation Fund and Connecting Europe Facility (CEF), Infrastructural Projects of Common Interest (PCI) are eligible to financial support. CO₂ hubs servicing transboundary emissions sources, pipelines, and CO₂ transit infrastructure can all benefit from European support. For the Netherlands to increase its chances of gaining access to European moneys, current projects need to be planned and implemented with an eye on European partners.

With most applications, the capturing of CO₂ is the most expensive part of CCS per unit of CO₂ abated, many industries are already investing in improving capture technologies to increase efficiency and drive down costs. Although additional R&D funding can help fine-tune existing and new capture technologies, the crucial investments that are needed to set-off large-scale CCS in the Netherlands are the creation and operation of the CO₂ transport and storage infrastructure.

While, for most applications, the capturing of CO₂ is the most expensive part of CCS per unit of CO₂ abated, many industries are already investing in improving capture technologies to increase efficiency and drive down costs. Although additional R&D funding can help fine-tune existing and new capture technologies, the crucial investments that are needed to set-off large-scale CCS in the Netherlands are the creation and operation of the CO₂ transport and storage infrastructure.

The Eastern Scheldt storm surge barrier, the longest dam in the Delta Works, is based on massive concrete pillars, each weighing 18,000 tons (Deltawerken.com 2018).
GERMANY

Germany seeks to reduce emissions by 55% in 2030 and by 80-95% in 2050 compared to 1990. Although immediate targets are even more ambitious than those of the Netherlands, ambition alone is not enough. A debate on industry decarbonisation or even CCS has largely been side-lined in Germany, with some new impetus emerging from studies by the German Industry Association (BDI) and Acatech in 2018 [16, 17]. Without meeting the challenge represented through its set targets and providing the means to achieve them, Germany will miss its 2030 and 2050 targets and breach its commitments under the Paris Agreement.

This failure will come after the German government has already given up on reaching its 2020 targets. To put the current gap between ambition and action into relation: the estimated overshoot of Germany’s 2020 emission target is more than double the amount the Netherlands needs to abate over the next decade to reach its 2030 target [28, 29, 30]. Germany’s industry is its economic backbone as well as a major source of CO2 emissions; nowhere more so than in North Rhine Westphalia (NRW). Both Germany’s economic wealth and its ability to achieve the Paris climate targets depend on providing NRW and other Länder with an effective and Just Transition for its industries.

To bring domestic emissions in line with the requirements under Paris, and therefore reach the upper end of the 95% target, industry needs to reduce current emission levels of about 180 MtCO2 to 14 MtCO2 by 2050 [18]. A recent BDI study showed that this target is impossible to reach without CCS – or significant deindustrialisation. They also found that settling for a lower reduction level to avoid the implementation of CCS will also be more expensive per t/CO2 abated than with CCS [16].

To make CCS available as a tool to deeply decarbonise the industry, Germany needs to develop a clear policy framework and targets to increase the incentive for industries to act and invest.

Germany’s industry has to stop using global competitiveness and notions of ‘unavoidable’ CO2 emissions as excuses from real climate action. Any such notion is incompatible with the Paris Agreement. Instead, industry actors need to approach local and central governments and ask for support. In 2018, the Federal Ministry for the Environment (BMU) announced to fund 50% of the development costs for technologies aimed at reducing industry emissions [19]. Additional funding measures are required, as well as a general policy strategy which ensures that employing measures to deeply reduce emissions is rewarded, while inaction is punished. Policy tools, such as eco labelling, carbon contracts for difference, advance disposal fees, and tax instruments (e.g. reduced VAT rates) can play an important role in preparation of a market for low carbon goods and a zero-emission economy [20].

Developing pioneering CCS projects

One or more CCS projects at industrial scale can showcase the technology at sites in need of CCS to reduce emissions to zero. Through flexible transport options of truck, barge or ship, initial capital expenditures can be minimised with a long-term view to easily expand the CO2 transport network to neighbouring industry sites, including waste incinerators currently contributing about 11 MtCO2 per year [21].
Joining forces with neighbouring countries to create shared offshore CO₂ storage

As in the Netherlands, onshore storage of CO₂ is not an option for Germany. Yet, through its access to the North Sea, Germany can store its industry CO₂ in shared facilities with Norway and the Netherlands. Germany’s industry clusters are mostly located close to the country’s many major transport waterways that allow for a flexible transport of captured CO₂ to Hubs on the shores of the North Sea.

Ensuring financial support by developing a defined plan

Such a plan should be presented jointly by government and industry.

Details of the plan need to cover the respective project site(s), involved actors, and overall timeframe, as well as the target amount of CO₂ to be sequestered.

With respective transport requirements and clear development stages set, overall project costs should be clearly identified. Infrastructural costs, such as transnational shipping terminals for CO₂ storage, may be eligible for financial support as Projects of Common Interest (PCI) under the Connecting Europe Facility (CEF). EU funds and corporation with neighbouring states would allow Germany to put the essential infrastructure in place to make Germany’s economy compatible with a low-carbon world.

Making the problem is twice as expensive as solving it.

Investments made for Nord Stream 2 to import an additional 55 billion m³ of gas to Europe each year, the equivalent of 106 MtCO₂/year solely through its use in power generation, ignoring further GHG emissions from flaring and leakage [23, 24, 25].

Investments needed for entire network to transport 60 MtCO₂/year from the German industry via pipeline or ship for offshore storage [22].
The biggest point sources in the region are located next to major waterways in Germany. The CO₂ from those sources can be transported via ship through the Mitteland channel and stored in the North sea.

North Rhine Westphalia is the most polluting region in all of Europe. With emissions higher than most EU member states combined and thousands of jobs relying on its industrial hotspots, the region is bound to come up with a comprehensive plan for lowering its emissions in the coming years.

Some of the CO₂ can also be transported through the Netherlands, to another industrial hub close by, Rotterdam. By tapping into the developing projects in the neighbourhood, North Rhine Westphalia could share infrastructure and, consequently, costs of climate change mitigation.
Protecting jobs with transnational CO\textsubscript{2} transport infrastructure

In addition to the industries that are able to fully decarbonise and thrive in future low-carbon products markets, economic benefits from the creation of a CO\textsubscript{2} network can also support structurally disadvantaged regions. For example, Bremerhaven is well located to become an important CO\textsubscript{2} hub by linking up to industry sites via barges through the Weser and the connected Mittellandkanal. Also the port of Emden has the potential to become an important trans-shipment place for captured CO\textsubscript{2}, particularly since the nearby offshore Norpipe, connected to Norway’s Sleipner field, and the two Europipes that deliver Norwegian natural gas to Germany can likely be re-used to deliver German industry CO\textsubscript{2} to Norwegian storage sites in the future.

Pioneering Project Example

HeidelbergCement (HC) is already at the forefront of developing new capture technologies for the cement industry at its Norcem plant in Norway, and Lixhe plant in Belgium. Such breakthrough inventions will see industry CCS costs drop in the future. Several sites in Germany would lend themselves to become domestic showcases, providing an example of how to implement industry CCS in Germany.

Three exemplary cement plants, one in Lower Saxony and two in NRW, jointly produce about 1.6 million tonnes of CO\textsubscript{2} per year, of which approximately 900,000 tonnes are process emissions [26]. Unable to be abated without CCS, it would require over 4,046 km\textsuperscript{2} of new forest to offset these emissions, an area four times the size of Berlin [27]. While afforestation is an important climate tool, its limits should make alternative measures a priority where possible.

Eliminating these cement emissions via the CCS route can be achieved through a mere 2-3 barges per cement plant and is the equivalent of taking 200,000 passenger cars off the road.

Located at the Mittellandkanal, two to three barges can transport the annual process emissions of 300,000 tCO\textsubscript{2} of the Hannover cement plant via the Weser to Bremerhaven. As the other two cement plants in NRW do not have direct access to any transport water ways, the CO\textsubscript{2} would first have to transported via truck to the port of Hamm. From there, another 6 barges could ship their 600,000 tonnes of CO\textsubscript{2} for storage through the Port of Rotterdam (via the Rhine) or the Port of Emden (via the Dortmund-Ems Kanal).

By providing the transport network for pioneering projects, the government showcases that CCS is an effective solution, and provides industry with the means to decarbonise.
This chapter, last in the line of four, analysed specific national cases for a CO$_2$ transport and storage network. The favourable geographical position of the examined set of countries, along with their mammoth emissions, makes them perfect candidates for the development of such a network. Without it, they will remain the biggest emitting regions on the continent.