Urban Insight
By Sweco

Trend report:

The race towards a green and resilient industrial sector

SWECO

A more circular economy can cut CO_2 emissions from heavy industry by 56% by 2050. New business models and collaboration is key.

Technological advancements, innovative business models and collaborations together with new net-zero technologies are growing at a rapid pace.

The latest addition to the European Green Deal was the Net-Zero Industry Act, which aims to scale up the manufacturing of clean technologies in the EU and make sure that the Union is well equipped for the clean-energy transition.

Demand for steel is expected to increase by 30%, cement and ammonia, which, among other things, is used to produce hydrogen gas, by 40% and aluminium by as much as 80% over the next three decades

The race towards a green and resilient industrial sector

Content

Introduction

If climate was the big issue and both a big risk and major challenge a few years ago, then the green transition is sustainability as an opportunity and in action right now.

The industrial sector is at the heart of this transition. It contributes to about 5% of global CO_2 emissions and a third of CO_2 emissions from global energy use, which adds up to between 25% and 30% of total global CO_2 emissions.[1]

During the last decade, the industrial sector has gone from slow movers to a green transition, which today can best be described as a race towards net zero. No-one wants to be left behind, neither companies nor countries.

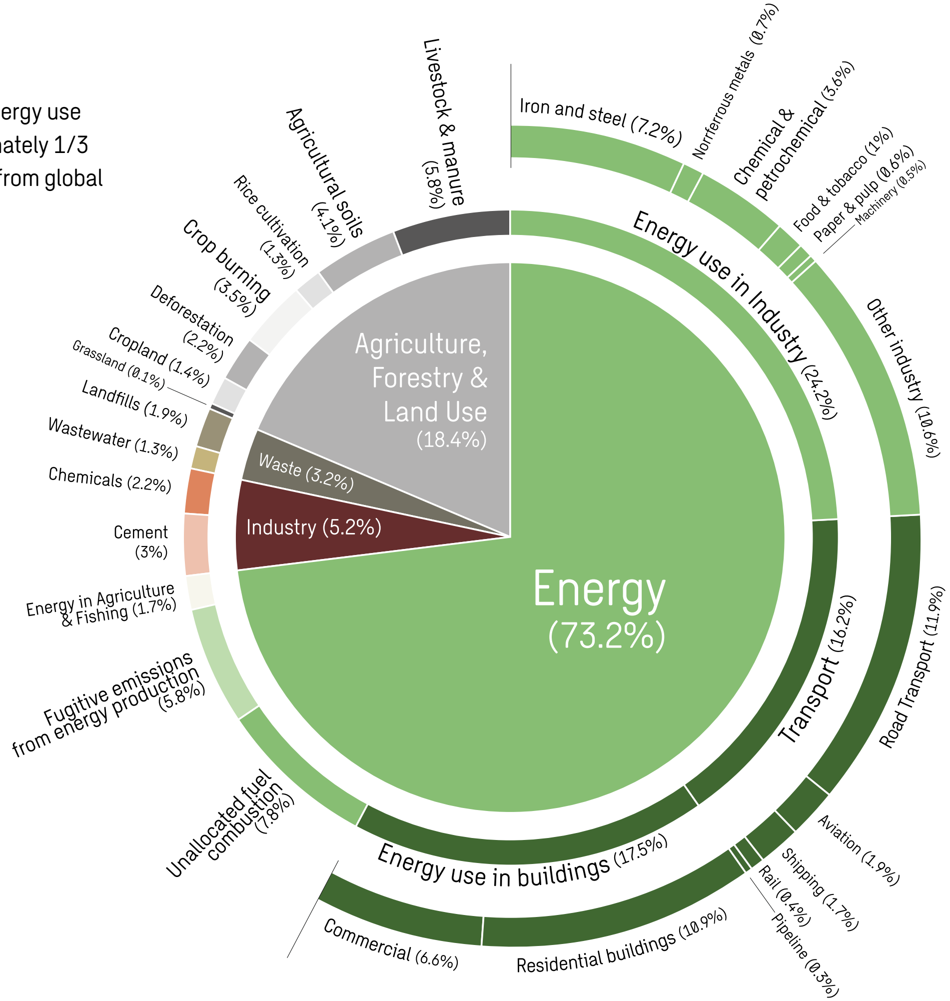
There are a number of reasons why this is happening right now. “Industry players are starting to notice the rising price of CO_2 emissions. A lot of actors and countries have made the commitment to reach net zero, introducing new regulations and carbon dioxide duties, together with increasing demand in the value chain, increasing competition and, last but not least, the arrival of money, both state and private”, says Björn Nykvist, researcher at the Stockholm Environment Institute, SEI.

The focus has shifted from concentrating on solving industrial CO_2 emissions with the help of carbon capture and storage (CCS) to a wide range of innovations.

However, for the industrial sector to become sustainable, it not only needs to reach net zero but become more resilient as well.

Global greenhouse gas emissions by sector

CO_2 emissions from energy use in industry is approximately 1/3 of the total emissions from global energy use.[2]



Source: Hannah Ritchie (2020) - “Sector by sector: where do global greenhouse gas emissions come from?” Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/ghg-emissions-by-sector' [Online Resource]

What is a green and resilient industrial sector?
Resilience plays a crucial role in tackling climate change and attaining a net-zero future. Resilient industries can navigate uncertainties, economic downturns, technological shifts and other challenges, while continuing to evolve, innovate and contribute to the economy. The need to pay significant attention to resilience and sustainability, in addition to profitability, is part of the work carried out by the European Commission and is referred to as Industry 5.0.[3] Industry 5.0 specifically recognises the "power of industry to achieve societal goals beyond jobs and growth, to become a resilient provider of prosperity, by making production respect the boundaries of our planet and placing the well-being of the industrial worker at the centre of the production process".

In the short term, the green industrial transition means increased risk-taking because companies are testing new technologies that have not been run on an industrial scale anywhere in the world. But in the long term, the change is something that enables the industrial sector to survive.

Björn Nykvist, researcher at SEI

This report from Urban Insight, Sweco's cross-border knowledge initiative, emphasises the need for industries to become both greener and more resilient, highlights the challenges and opportunities, but also potential risks and unintended consequences associated with this transformation that must be addressed to ensure a resilient and equitable shift.

Industrial processes - the overall picture

Emissions from fuel combustion and processes in industry today contribute to more than 30% of global greenhouse gas emissions.[4] Population and economic growth will continue to drive demand for industrial products. Demand for steel is expected to increase by 30%, cement and ammonia, which, among other things, is used to produce hydrogen gas, by 40% and aluminium by as much as 80% over the next three decades.

In particular, these so-called hard-to-abate industries, such as steel, cement, chemicals and aluminium, which together account for around 75% of all industrial emissions, must change radically, and several of them are now in the lead of the transition.

The Energy Transition Commission's Mission Possible report outlines how it is technically and - with the right support - economically possible for hard-to-abate industrial sectors to reach net-zero emissions by 2050 at a cost to the economy of less than 0.5% of global GDP and with minor impact on consumer living standards. [5] However, it will require significant investment. The EU Commission calculates the cost of the continued energy and industrial transition as EUR 1200 billion per year.

"The hard-to-abate sector must reduce its carbon dioxide emissions by 90 per cent to reach net zero throughout the economy. Is it possible and, if it is, how can it be achieved?" asks Aaron Maltais, researcher at SEI.

Europe´s green transition

DRIVERS:

- Geopolitics
- Regulatory & political priorities
- Consumer demand & expectations
- Investor sentiment
- Technical development

OPPORTUNITIES:

Energy transition

EUR 300b RePowerEU investment package

Transport transition

2x Europe´s high-speed rail traffic infrastructure to be doubled by 2030

Industrial transition

EUR 40b Deployable capital from the EU Innovation Fund over the next decade

Urban transition

EUR 580b Of EU´s budget will be allocated to climate-relevant actions during the period from 2021 to 2027

The driving forces towards a net-zero industrial sector

A continuing wave of regulations

The pressure from new targets and legislation relating to the green transition has gradually increased during the last decade. What started with the UN Sustainable Development Goals 2015 has been followed by a series of overall goals and new regulations.

The European Commission introduced the European Green Deal 2019, its flagship plan that aims to make Europe climate neutral by 2050, with an intermediate goal of reducing net greenhouse gas emissions by at least 55% by 2030, relative to 1990 levels. This intermediate goal is called Fit for 55. The European Climate Law wrote these climate-neutrality targets into binding EU legislation. Another intermediate goal, to reach 90% net reduction of greenhouse gas emissions by 2040, was recently proposed by the EU Commission.

In order to meet the EU's climate and energy targets for 2030 and reach the objectives set out in the European Green Deal, it is vital that investments are directed towards sustainable projects and activities. The EU Taxonomy classifications system, which entered into force

> We need a regulatory environment that allows us to scale up the clean-energy transition quickly. The Net-Zero Industry Act will do just that.

Ursula von der Leyen, President of the European Commission

in 2020, aims to achieve this. The Sustainability Reporting Directive (CSRD) came into force for large and listed companies from 1 January 2024. This directive expands the scope of sustainability reporting, affecting approximately 50,000 companies across Europe, with the aim of standardising non-financial data reporting.

The USA is not being left behind. The Inflation Reduction Act came into law in August 2022, marking the most significant action Congress has taken on clean energy and climate change in the nation's history. The latest addition to the European Green Deal was the Net-Zero Industry Act, which aims to scale up the manufacturing of clean technologies in the EU and make sure that the Union is well equipped for the clean-energy transition.[6]

"We need a regulatory environment that allows us to scale up the clean-energy transition quickly. The Net-Zero Industry Act will do just that. It will create the best conditions for those sectors that are crucial for us to reach net-zero by 2050. Technologies like wind turbines, heat pumps, solar panels, renewable hydrogen, as well as CO_2 storage. Demand is growing in Europe and globally, and we are acting now to make sure that we can meet more of this demand with European supply", said Ursula von der Leyen, President of the European Commission, in connection with the presentation of the Industry Act in March 2023.

An increasing number of heavy industrial companies are setting goals and strategies for net zero. For example, the Global Cement and Concrete Association (GCCA), which represents over 40 leading cement companies, has announced the production of net-zero concrete by 2050.

Market forces: competition is intensifying due to increased demand for green products

The green transition is also increasingly customer- and demand-driven. Today, the automotive industry is in dire need of batteries and green steel if they want to be able to market their cars as 'green'. They have placed large pre-orders many years in advance with steel companies. Some steel consumers tolerate the so-called 'green premium' better than others.

Transport, for example, accounts for around 20% of global steel consumption. However, steel is a relatively small part of the total cost of a vehicle, making it easier for companies to absorb the premium or pass it on to customers. According to BloombergNEF, a 25% increase in the price of steel would raise vehicle production costs by 1%.

Increased customer demand also means that competition is intensifying between Europe, the USA and China and between companies in the same sectors. The USA's Inflation Reduction Act has caused an intense debate since it became clear that it includes green subsidies that put European industries at a disadvantage and these subsidies are, seemingly, more accessible than the European incentives, with more certainty and clarity about what you get and how.

20% is the share of global steel consumption that the transport sector is responsible for.

25% increase in the price of steel would raise vehicle production costs by **1%**, according to BloombergNEF.

The capital is flowing in - but is it enough?

Investments in the industrial transformation towards sustainability and net-zero emissions are significant and growing, as industries worldwide recognise the need to address climate change. These investments cover a broad range of areas, including renewable energy, energy efficiency, electrification, technological advancements and circular economy practices. The transition of industrial-heavy economies will require large amounts of transformative capital and access to low-emission technologies, along with associated infrastructure such as green energy, hydrogen and carbon sequestration.

According to the European Commission, Europe will require investments of more than EUR 700 billion a year to meet its energy-transition goals and combat climate change.[7]

"Overall, additional investments of about EUR 620 billion annually will be needed to meet the objectives of the Green Deal and of our REPowerEU plan, with an additional EUR 92 billion needed to address the objectives of the Net-Zero Industry Act over the 2023-2030 period," the Commission stated in its 2023 Strategic Foresight Report.

EUR **700 billion**

is required annually for Europe to meet its energy-transition goals and combat climate change, according to the European Commission.

EUR **620 billion**

annually will be needed to meet the objectives of the Green Deal and REPowerEU plan.

EUR **92 billion**

will be needed to address the objectives of the Net-Zero Industry Act.

Innovative technical solutions and business models - paving the way

Technological advancements, innovative business models and collaborations, together with new net-zero technologies, are growing at a rapid pace. Electrification, circularity, industrial symbiosis, renewable-energy solutions, batteries, hydrogen, carbon capture, usage and storage, energy storage, power-to-x, electro-fuels, smart manufacturing through the use of sensors, connected machinery, AI and data analysis... There is certainly nothing wrong with the innovative power of the energy and industrial sectors. Let's have a look at how some of the heavy industry sectors are already well on their way to contributing to the green transition but also what new risks and challenges this can bring.

The steel industry takes the lead

Steel is found in practically everything - buildings, bridges, cars, planes, ships, washing machines... However, this manufacturing process is one of the world's dirtiest, contributing to about 8% of total global carbon dioxide emissions, more than any other heavy industry. These emissions have also increased over the past decade in line with continued increased demand for steel, according to the International Energy Agency, IEA. A demand that is also expected to increase by a further 30% by 2050.[8]

Today, there are roughly 1,000 steel mills in the world with approximately 1,400 traditional blast furnaces.[9] In these blast furnaces, crude iron is produced by reducing iron ore with the help of coal in the form of coke. This is where the majority of steel companies' climate emissions occur. The challenge in the transition of the steel sector is, therefore, significant because coal is such an integral part of the entire production process.

There are at least three technical solutions that will allow the steel industry to reposition primary steelmaking to work towards net-zero emissions: direct reduction with hydrogen gas, which is the one chosen, for example, by SSAB/Hybrit, as well as Arcelor Mittal and Salzgitter, carbon dioxide capture and an electrochemical process similar to that in aluminium production. More may well be added, and different parts of the industry will certainly choose different paths. It is clear, however, that all of the European steel companies are undergoing a green transition but are at various stages of the process

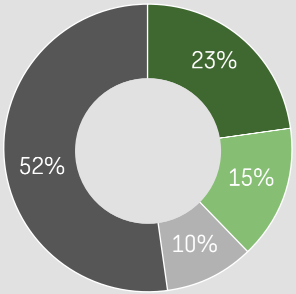
From a European perspective, it is crucial to take immediate action to address the challenges posed by climate change and accelerate the transition to a sustainable and low-carbon economy. This requires efficient and streamlined permit processes that facilitate the development and deployment of innovative and environmentally friendly technologies.

Martina Söderström, Division Manager Environment & Planning at Sweco Sweden.

Global green steel projects

Project scale	No. of projects
R&D Partnership	21
Pilot	13
Demo	9
Full scale	46

(In percentage)



Full scale green steel projects online and under construction in Europe

Country	No of projects
Austria	2
Belgium	2
Finland	2
France	4
Germany	3
Italy	1
The Netherlands	2
Norway	1
Romania	1
Russia	1
Spain	5
Sweden	3
United Kingdom	1

Source: The Leadership Group for Industry Transition.
Vogl, V; Sanchez, F; Torres Morales, E; Gerres, T; Lettow, F; Bhaskar, A; Swalec, C; Mete, G; Åhman, M; Lehne, J; Schenk, S; Witecka, W; Olsson, O; Rootzén, J. 2023, Green Steel Tracker, Version 04/2023, Stockholm, Dataset, www.industrytransition.org/green-steel-tracker/

8%

of total global carbon dioxide emissions derive from the steel industry.

30%

is the estimated increase in steel demand up till 2050.

61%

of all fossil-free steel projects in the world are located in Europe.

Startups are tapping into the green transition

The need to completely reset a heavily invested process industry that has largely functioned in the same way for centuries also opens up the option of starting from scratch.

A number of startups have, therefore, appeared in the steel sector in recent years. They have a number of advantages over established players because they have been able to build an Industry 5.0 from scratch.

Smart manufacturing is transforming new greenfield factories even more through the use of sensors, connected machinery, AI and data analysis tools that enable predictive maintenance, optimised production and real-time monitoring.

“Heavy industry is changing radically. It is a reset on a completely different level, almost like industrialisation all over again. Many old companies are at risk when new players come in, it can change the entire market. The new players also have a completely different structure and a completely different leadership” says Fredrik Axby from Sweco.

The Norwegian company Blastr Green Steel has plans for an iron pellet plant in Great Britain, which will supply the company’s planned green steel mill in Finland with raw material. However, Blastr has not yet resolved the entire financing for the project, which it hopes to be able to test start by 2028 at the latest.

A French startup, Gravithy, also has plans to build hydrogen-based plants for fossil-free steel in Finland and near Marseille in France; however, funding remains to be resolved. Among the European newcomers is also Spain’s Hydnum Steel, which plans to have its first steel plant ready by 2026 and hopes to produce 2.6 million tonnes of green steel annually from 2030.

A Swedish company is among those that have progressed the furthest in their plans to establish a brand-new steel mill. They have secured financing of SEK 75 billion and expect to be in full production before the previously planned start date of 2030.

Countries can repatriate the processes that create value, such as green steel production, thanks to automation. In the past, Sweden exported a lot of unprocessed ore because it was so expensive to produce steel in Sweden because it is a labour-intensive process. Being able to base the entire process within the country’s borders has many advantages, not least from a resilience point of view

Fredrik Axby, Acting Division Manager for Energy & Industry at Sweco Sweden

New solutions require new energy sources

Because of the new solutions used, several of the steel companies are dependent on hydrogen for their green steel processes. Production of hydrogen, in turn, requires large amounts of energy, which must be fossil-free in order for the hydrogen produced to be green hydrogen and, ultimately, to create green, fossil-free steel. In the short term, this is the main challenge for the steel companies' transition. They require large-scale hydrogen production and, in order to achieve this, they need access to a sufficient amount of fossil-free electricity.

"There is an increased need for electricity all over Europe, but in northern Sweden the increase is exceptional, with usage potentially doubling. The main explanation is that we are moving the processing of steel back to Sweden and introducing new processes," says Fredrik Axby.

The green industrial transition will also place new demands on the energy supply in Germany. Thyssenkrupp is going to build a green steel mill in Duisburg based on a process of direct reduction using hydrogen, which is expected to be ready by 2029 at the earliest. This steel mill will require electricity production equivalent to 500 wind turbines to produce the hydrogen gas needed.

The steel industry proactively tackled potential risks of falling behind on the climate transition by embracing change early. However, concerns remain regarding sufficient and affordable electricity and the optimal choice among various technologies, although the global scale of the industry suggests that a diversity of technologies can coexist worldwide.

Björn Nykvist, researcher at SEI

"We have focused so much on the steel industry because they acted early, and they did so because they saw what was happening and understood that acting now involved a lower long-term risk than not acting. But there are also risks associated with this transition, for example, will there be enough green electricity at the right price? Also, the fact that there are different possible technologies, which one will be the best? That said, the steel sector is large, so there is probably room for the use of different technologies in different parts of the world," says Björn Nykvist, researcher at SEI.

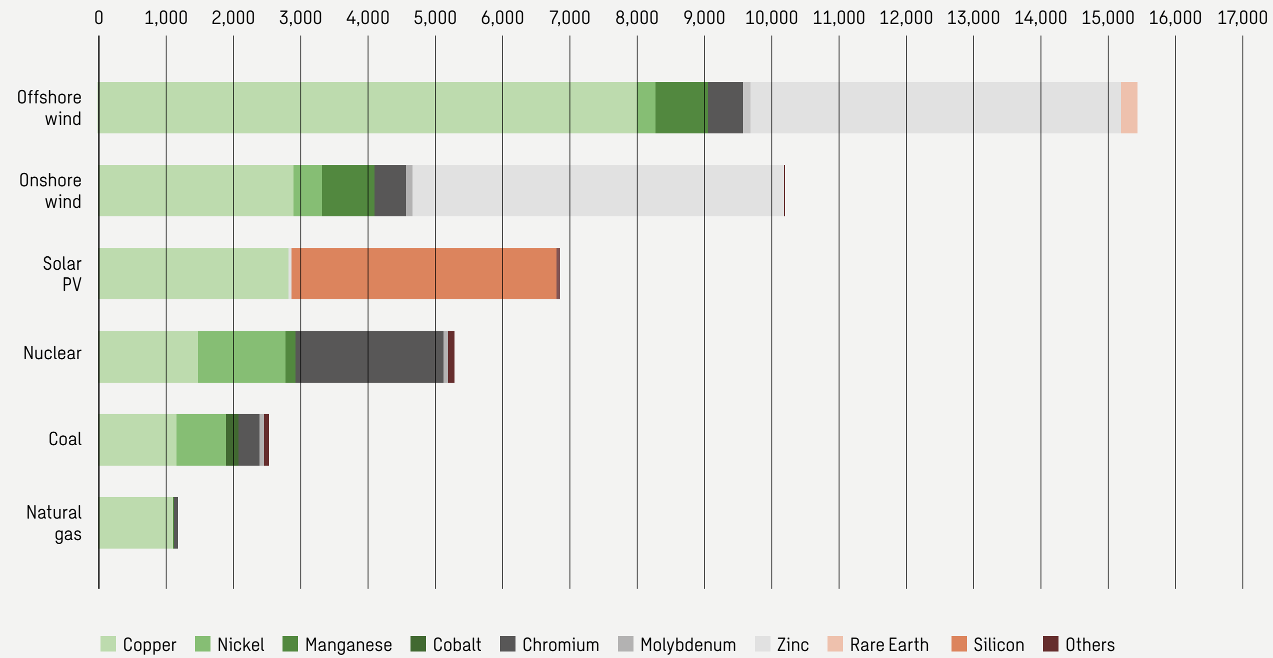
The availability of cheap, fossil-free electricity in sufficiently large quantities might thus assist the transition and possibly also lead to a geographical repositioning of heavy, energy-intensive industry. The Middle East and North Africa could become world leaders in green steel and the newly emerging trade of green iron, according to a report by the Institute for Energy Economics and Financial Analysis, IEEFA.[10]

Using its abundant solar-energy resources to produce green hydrogen for direct reduced iron, DRI-based steelmaking, together with the MENA region's rich supply of high-grade iron ore means that the region is perfectly positioned to supply India as the key growth market for steel, as well as demand for green steel in Europe, stated in the report from IEEFA.[10]

Increasing demand for new raw materials

Access to raw materials can change the industrial game plan. As the world gears up for net zero, demand for raw materials is set to soar. Meeting existing demand already requires double the current amount of these raw materials. In order to reach net zero by 2050, governments and industry will need six times more raw materials. For instance, producing an electric car requires six times more raw materials than a conventional vehicle and an onshore wind plant demands nine times more minerals than a gas-fired power plant.[13]

Minerals used in clean energy technologies compared to other power generation sources

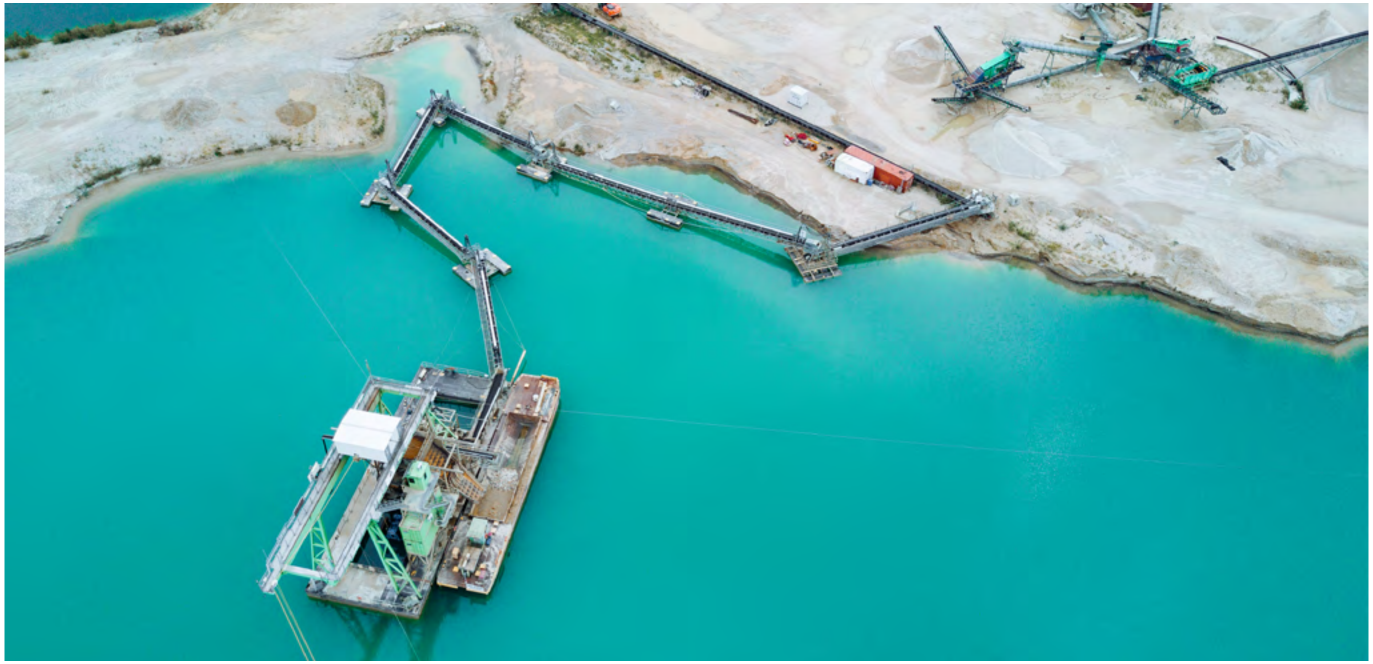


Source: IEA; The Role of Critical Minerals in Clean Energy Transitions, https://www.iea.org/data-and-statistics/charts/minerals-used-in-clean-energy-technologies-compared-to-other-power-generation-sources, IEA. Licence: CC BY 4.0

The graph above shows the increased demand for raw materials required to meet the clean energy goals of different climate mitigation strategies compared to 2020.

The energy transition presents unique challenges for metals and mining companies, which will need to innovate and rebuild their growth agenda.

However, if the raw materials required for the green transition aren't sourced responsibly, there could be many negative impacts, from environmental pollution and biodiversity losses to carbon emissions from plant and soil disruption.



New conflicts might emerge

There will be complicated trade-offs between, for example, the protection of rainforests in biodiversity hotspots and the mining of the materials underneath them for low-carbon technologies.[14] Some countries are also exploring the viability of deep-sea and seabed mining and will have to consider how this could negatively impact the fishing industry and other sources of income. Furthermore, the impacts of climate change, especially flooding and water stress, are becoming more severe and could themselves pose a threat to sources of critical mineral supply.

Additionally, more than half of the energy transition mineral projects worldwide are located on or near the lands of indigenous people or in economically deprived areas.[13] Over 80% of lithium projects and more than half of nickel, copper and zinc projects are located in the territories of indigenous peoples.[14]

To reduce dependence on China, the EU wants to greatly increase the mining of rare earth metals. This has led to conflicts, for example, in Sweden with the only indigenous people in the EU.

Booming commodity demand could lead to aggravating socio-environmental issues and inequality.

Over 80%

of lithium projects and more than half of nickel, copper and zinc projects are located in the territories of indigenous peoples.

The cement industry is emerging as the next leading sector

The total volume of cement production worldwide amounted to an estimated 4.1 billion tonnes in 2022.[15] Back in 1995, the total global production of cement amounted to just 1.39 billion tonnes, an indication of the extent that the construction industry has grown since then.

Reducing CO_2 emissions while producing enough cement to meet demand will be challenging.

"Cement is the binding agent that gives concrete its strength and concrete is the manufactured material that we use the most on the entire planet. We are talking about huge amounts, and the demand will just keep on increasing," says Aaron Maltais, researcher at SEI.

Cement CO_2 emissions remain stubbornly high according to data from the International Energy Agency, IEA.[16] So, what is the role of cement in clean-energy transitions?

Key strategies to cut carbon emissions in cement production include improving energy efficiency, switching to lower-carbon fuels, promoting material efficiency (to reduce the clinker-to-cement ratio and total demand) and advancing innovative near-zero emission production routes. The latter two contribute the most to direct emission reductions in the net-zero scenario. Aligning with that scenario will require the development and deployment of technology that is not currently available.

Many entrepreneurs are scratching their heads trying to come up with new solutions. Mixing concrete with, for example, by-products from iron and coal production to reduce the proportion of cement is one option. Another possible solution is to inject carbon dioxide into the concrete. The concrete is then mineralised, which makes it harder which, in turn, leads to less material being used. An additional benefit is that the concrete acts as a kind of carbon sink. A carbon sink is

anything that absorbs more carbon from the atmosphere than it releases. Canadian Carboncure is a leader in this field.

Recycling is also crucial for reducing CO_2 emissions. Cemvision is a Swedish startup founded in 2020. Cemvision's first product line consists of two cement binders produced using residual industrial products instead of virgin limestone. Last year, the company started a pilot scale production of 'the world's first 100 per cent circular, fossil-free, decarbonised cement clinker'.

Another trend is to produce concrete that contains alternative binders, such as slag from steelmaking.

Many Swedish concrete manufacturers already offer a climate-improved concrete with up to 40 per cent lower climate impact than standard concrete according to Karin Comstedt Webb, Vice President at Heidelberg Materials, Sweden. But today, the reduction of CO_2 emissions from cement still relies heavily on CCS due to chemical reactions when heating limestone to produce clinker.

Heidelberg Materials recently launched the world's first carbon captured net-zero cement produced in Brevik in Norway. According to the current schedule, the first net zero cement is expected to be delivered in 2025. The goal is to establish a CCS plant more than four times as large in Slite by 2030. The carbon dioxide will be separated "at the chimneys", compressed into a liquid and shipped to Norway, where it will be permanently stored at the bottom of the North Sea.

"If you were to start producing green cement in Sweden, I believe that many construction companies would find it difficult not to buy it given sustainability efforts and goals", says Aaron Maltais.

"But green public procurement is also important for the cement sector. Given that the government has decided that we are aiming for net zero, it is reasonable to expect that the state will start buying green cement to create the first markets", adds Björn Nykvist, researcher at SEI.

Pioneering Industrial-Scale CCS in Cement Production

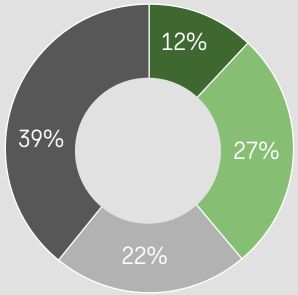
Sweco is assisting Heidelberg Materials' Brevik cement plant in Porsgrunn, Norway to reach net-zero by 2030 with a carbon capture facility scheduled to start operation during 2024. The carbon capture in Brevik is a part of the CCS project "Langskip" and the transport and storage part of the project will be conducted by Northern Lights with storage sites in the North Sea.

Read more at Swecogroup.com

Green cement projects

Project scale	No. of projects
Feasibility study	6
Demonstration	14
Pilot	11
Full scale	20

(In percentage)



Full scale green cement projects under construction in Europe.

Country	No of projects
Austria	1
Belgium	2
Bulgaria	1
Croatia	1
Denmark	1
France	2
Germany	5
Greece	1
Norway	1
Poland	1
Spain	1
Sweden	1
United Kingdom	1

Source: The Leadership Group for Industry Transition.
Lorea, C; Sanchez, F; Torres-Morales, E. 2023. Green Cement Technology Tracker, Version 07/2023, Stockholm, Dataset, https://www.industrytransition.org/green-cement-technology-tracker

Many Swedish concrete manufacturers already offer a climate-improved concrete with up to

40%

lower climate impact than standard concrete, according to Karin Comstedt Webb, Vice President at Heidelberg Materials, Sweden.

95%

of the full-scale projects in green cement worldwide are currently in Europe.

The total volume of cement production worldwide amounted to an estimated

4.1

billions tonnes in 2022.

CCS/CCU - a necessary complementary solution

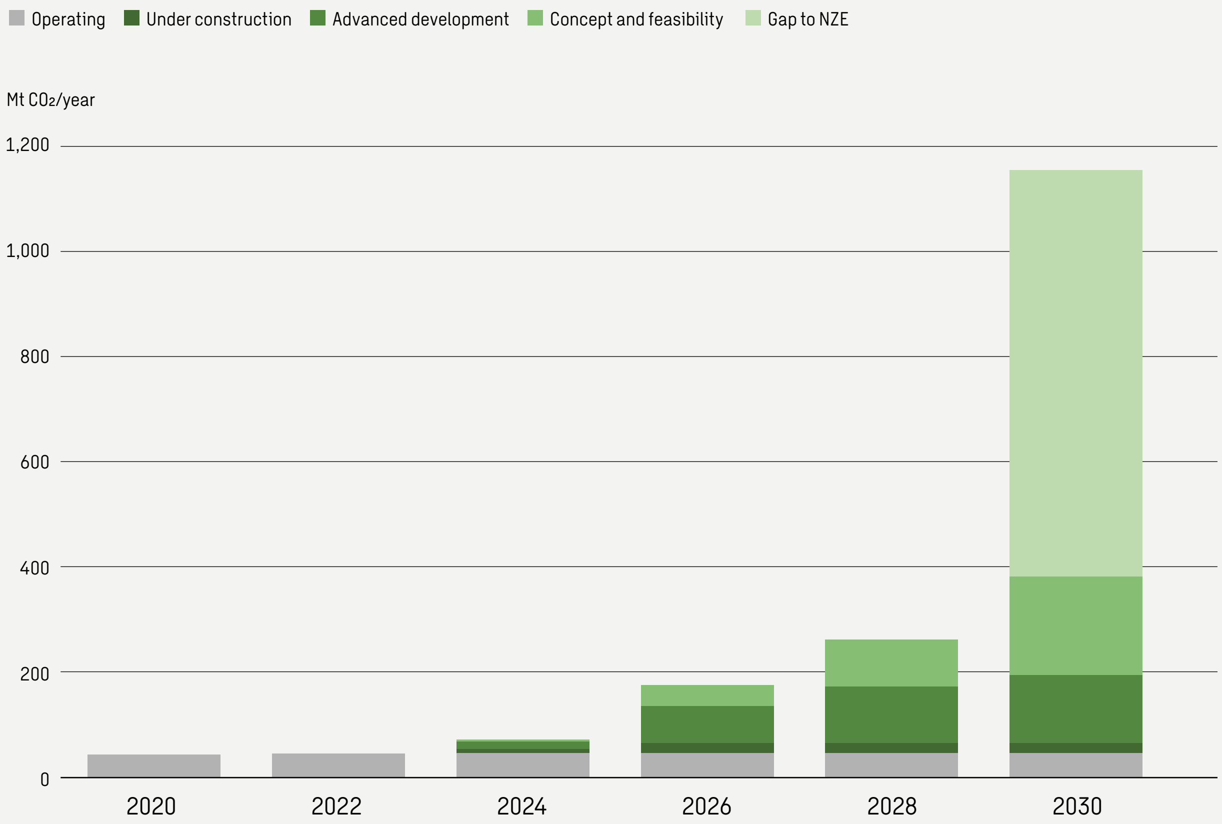
CO_2 has been captured, transported and stored in Europe since 1996 when the Sleipner project started in Norway. Apart from heavy industries, carbon capture and storage (CCS) can be supplied to gas-fired power plants, which provides flexibility to an electricity grid with a higher share of intermittent renewables.

CCS is an important part of the EU's climate policy. Recently, a legally binding target was set to reach an annual injection capacity of at least 50 million tonnes of CO_2 by 2030. Today, as the map below indicates, ongoing and planned CCS projects will amount to 35 million tonnes of CO_2 per year by 2030. In March 2023, Denmark became the first country in the world to develop a cross-border CO_2 storage site, shipping CO_2 from Belgium and injecting it into a depleted oil field under the Danish North Sea. If the technology can be used in the future for biogenic carbon dioxide from large-scale combustion, it can also enable negative carbon dioxide emissions. The carbon dioxide that is separated can be used as a raw material in the manufacturing industry; the term CCU is used, where the U stands for utilisation.

CCS is still an emerging technology. It is noted by some that carbon capture and storage (CCS) has been promoted as a means to mitigate CO_2 emissions while still using fossil fuels, which raises questions about its role in the broader strategy for moving towards renewable energy sources. Continued investment in fossil fuels creates lock-ins that effectively prevent the transition to a clean-energy system.[17]

There are also risks associated with storing carbon in geological formations. The most significant risk from geologic carbon sequestration is leakage of CO_2. Two types of CO_2 leaks are possible— atmospheric and subsurface. These might be caused by slow leaks through slightly permeable cap rock or catastrophic releases due to a rupture of a pipeline, the failure of a field well, or the opening of a fault.

CCS to reach net zero

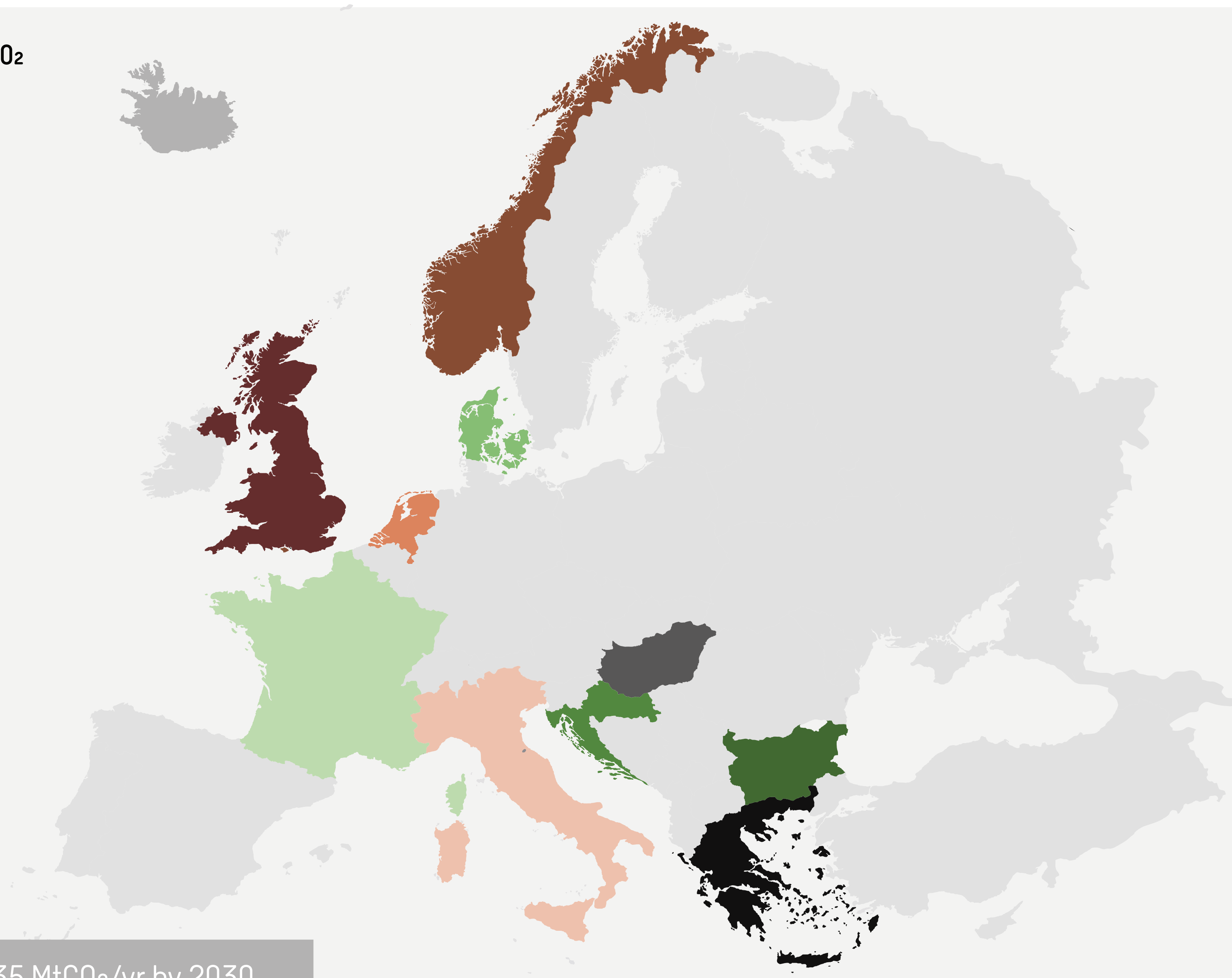


Source: IEA. Licence: CC BY 4.0 International Energy Agency (2023). Published online at iea.org. Retrieved from: 'https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage' [Online Resource]

Overview of existing and planned CO_2 storage projects in Europe

- Bulgaria (1)
- Croatia (4)
- Denmark (5)
- France (1)
- Greece (1)
- Hungary (1)
- Iceland (4)
- Italy (1)
- The Netherlands (3)
- Norway (8)
- United Kingdom (7)

( ) Number of projects



EU	**17 projects** – 35 $MtCO_2$/yr by 2030
Europe	**36 projects** – 110 $MtCO_2$/yr by 2030

IOGP, International Association of Oil and Gas Producers, Published online at iogp.org, Retrieved from: https://iogpeurope.org/wp-content/uploads/2023/10/Map-CO2-Storage-Projects-in-Europe.pdf

Smeaheia CO_2 Highway

Sweco is supporting Equinor in the concept phase of a project for a CO_2- pipeline from mainland Europe to permanent storage facilities in the Norwegian North Sea. Sweco will do mapping services for permitting requirements, ground conditions and other potential impacting factors for landfall locations in France, Belgium, the Netherlands and Germany. Further on, Sweco will also assist with services for landfall methods, including geotechnical- and structural disciplines and tunnelling.

What is the role of carbon capture, utilisation and storage (CCUS) in clean energy transitions?

CCUS can be retrofitted to existing power and industrial plants, allowing for their continued operation. It can tackle emissions in hard-to-abate sectors, particularly heavy industries like cement, steel or chemicals. Additionally, CCUS is an enabler of least-cost low-carbon hydrogen production, which can support the decarbonisation of other parts of the energy system, such as industry, trucks and ships. Lastly, CCUS can remove CO2 from the air to balance emissions that are unavoidable or technically difficult to abate.

Further industries under transformation

The chemical industry

The chemical industry is the largest industrial consumer of both oil and gas, as well as the largest industrial energy consumer overall. This is because it uses fossil fuels as raw material and not only as a source of energy. Using sustainable waste or bio-based materials, such as plant matter, sugar, lignin, hemicellulose, starch, corn or algae can lead to the carbon neutrality of the chemical sector, as well as industrial symbiosis. Industrial symbiosis is created by using waste from one operation as a resource in another operation and is a subset of the circular economy.

Transport and logistics

Transport CO_2 emissions grew at an annual average rate of 1.7% from 1990 to 2022, faster than any other end-use sector except for the industrial sector (which also grew at around 1.7%). To get on track with the Net-Zero Emissions (NZE) by 2050 scenario, CO_2 emissions from the transport sector must fall by more than 3% per year by 2030. Strong regulations and fiscal incentives, as well as considerable investment in infrastructure and new fuels to enable low- and zero-emission vehicle operations will be needed to achieve these CO_2 emissions reductions.

The automotive industry

The automotive industry's transition to fossil-free is far reaching, large scale and complex, where electrification plays an important role including new battery development and production. Setting up large battery plants places huge demands on the local community in terms of infrastructure, energy supply, permits, skills supply and access to housing in the relevant municipalities and regions.

The automotive industry has also been a strong contributor to the demand for green steel that has caused the steel industry to launch its far-reaching conversion plans. Much of the pressure of these adjustments falls on subcontractors. 70% of a vehicle is made by the supplier industry, while the vehicle manufacturers themselves make only 30%.

The industry also has to develop a lot in terms of circular business models. The vehicle industry in Europe is on average 1% circular according to the Scandinavian Automotive Supplier Association.

"I usually ask the question, how long does it take to disassemble a car? No one knows. A lot of research and development goes into how we build things. None is done about how we take them apart again," says Peter Bryntesson.

New fuels

Power-to-X technology will play a key role in climate-change control and the energy transition by converting surplus renewable energy into storable fuels like hydrogen or methanol to power the transportation sector and a variety of other industries. Power-to-X acts as a kind of energy storage with the basic idea of converting electricity into another form and back to electricity as needed. It is a key technology in the energy transition, as the role of storage and flexibility will be of great importance as the production of renewable energy increases. Clean electricity can be turned into synthetic fuels that could replace oil as a raw material in the chemical industry.

Electrofuels

Electrofuels, also known as eFuels, are gaining ground as sustainable alternatives to fossil fuels. In essence, they are synthetic fuels based on hydrogen (H2O) and carbon dioxide (CO_2). They can be produced in either gas (e-hydrogen or e-methane) or liquid form (e-diesel or eMethanol). eFuels are typically produced using electricity generated from renewable sources like solar, wind,

Vehicle manufacturers have what they call four hotspots in order to reduce their carbon footprint, namely steel, batteries, cast iron and aluminium. These four areas cover approximately 70-80% of an OEM's product's CO_2 footprint

Peter Bryntesson, CEO of the Scandinavian Automotive Supplier Association.

or hydropower. eFuels offer a practical solution for industries and sectors that are struggling to electrify directly, such as shipping, aviation and certain industrial processes.

eFuels can also serve as a means of storing renewable energy. They allow for the conversion of surplus electricity generated during periods of high renewable-energy production into chemical energy, which can then be stored and used when renewable energy generation is low or unavailable.

Some eFuels, like eMethanol, are liquid at ambient temperature and pressure, making them easy to transport and store using existing infrastructure such as pipelines, trucks, ships and rail.

Challenges remain in the widespread adoption of e-fuels. The cost of e-fuels is heavily dependent on the price of hydrogen, which must be produced from renewable energy sources to qualify as e-fuel. Establishing a stable and cost-effective hydrogen production and supply infrastructure is crucial for enabling the proliferation of e-fuels.

Sustainable aviation fuels

Sustainable aviation fuels (SAF) are defined as renewable or waste-derived aviation fuels that meet sustainability criteria. Skyfuel H2 in Långsele, Sweden, is a project to produce sustainable jet fuel. Production uses a combination of biomass from Swedish forests and green hydrogen.

Europe’s largest electrofuel plant

Sweco was responsible for the work with environmental permits for one of the world’s first full-scale facilities for the production of eMethanol, a completely fossil-free liquid fuel for heavy shipping and other heavy transport. The project in Örnsköldsvik, Sweden, is run by Liquid Wind. The production is based on wind power electricity and carbon dioxide that is separated from the flue gases from Hörneborgsverket, a biofuel-fired cogeneration plant, which means that eMethanol is a carbon dioxide-neutral fuel. Full environmental permit was grated in August 2022. The project was acquired from Liquid Wind by the Danish energy company Ørsted in late 2022 and is Europe’s largest project of its kind to have reached final investment decision (FID) in Europe. The plant in Örnsköldsvik is just the beginning, until 2030 Liquid Wind intends to build ten plants in Scandinavia.

The new energy solutions laying the foundations for the green industrial transformation

Drastic changes in the energy landscape in Europe are needed to make the industrial sector green and sustainable. In this chapter, we highlight the most accurate trends and possibilities, as well as the new risks that the energy transition brings.

At COP 28, more than one hundred countries committed to significantly increasing energy efficiency and renewable energy capacity. The conference saw the launch of the Global Renewables and Energy Efficiency Pledge, supported by 130 national governments, including the EU. Signatories aim to triple global renewable energy capacity to at least 11,000 GW and double the annual rate of energy efficiency improvements to over 4% by 2030.

The energy transition is a pathway toward the transformation of the global energy sector from fossil-based to zero-carbon by the second half of this century. At its heart is the need to reduce energy-related CO_2 emissions to limit climate change. The energy transition is not limited to the gradual closure of fossil power stations and the development of clean energies; it is a paradigm shift that affects the entire system.

The industrial sector accounts for about one-third of today's global total energy consumption. Industrial energy consumption has steadily risen in recent years, by around 1.3% per annum from 2010 to 2022.

- Since 2000, total global energy consumption by industry rose by almost 70%.
- Around 38% of global industrial energy consumption is in China, greater than the European Union, the United States, India and Japan combined (28%).
- Between 2010 and 2022, consumption grew at an annual rate of 2% in China, 4.5% in India and 0.7% in the United States, while it fell by 0.8% in the European Union and 1.4% in Japan.[18]

According to BloombergNEF, global investments in green energy increased by 17 per cent in 2023. This includes investments in renewable energy, electric cars, hydrogen projects and the like. To reach net-zero emissions by 2050, however, the world must invest twice as much annually between 2024 and 2030.

Generating power from renewables (wind, solar, hydro, hydrogen) is only part of the energy transition. The onset of electrification and improvements in energy efficiency due to technology and digitalisation are all key drivers of the energy transition.

Since 2000, total global energy consumption by industry rose by almost 70%, according to the IEA.

Renewable energy - a prerequisite for a successful transition

The transition to renewable energy sources such as solar and wind is one of the most important aspects for the global energy sector.

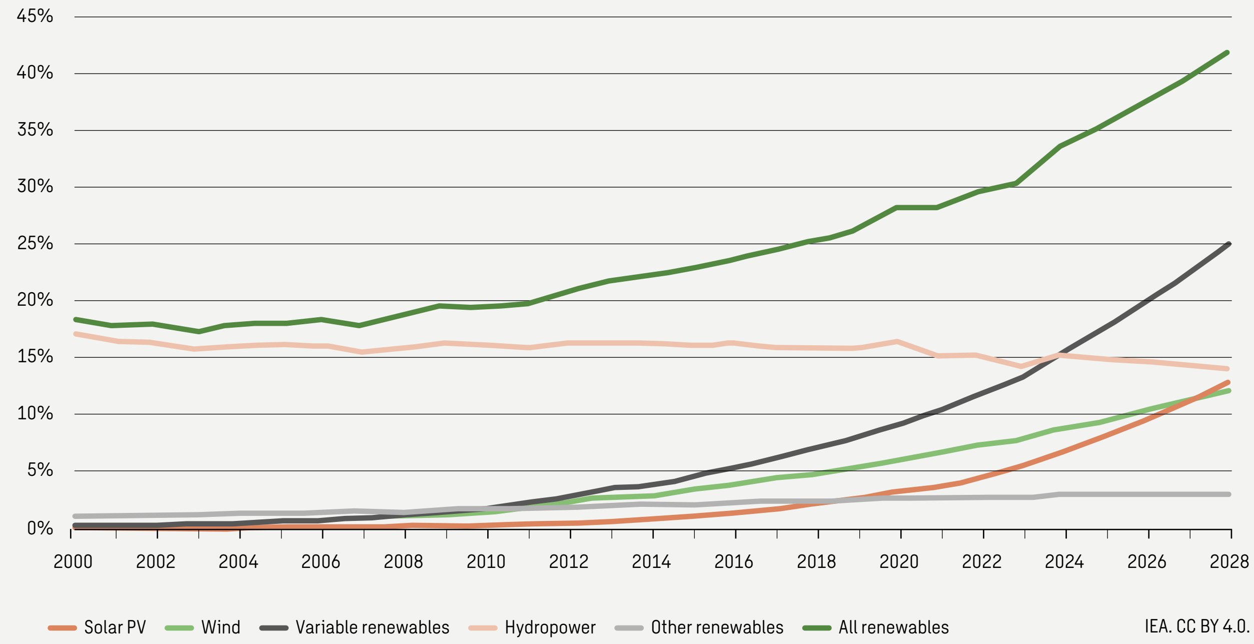
The world is experiencing a continued rapid expansion of renewable energy. In 2023, capacity increased by almost 510 gigawatts or 50%, according to the IEA.[19] Solar energy accounted for three-quarters of this increase, as the price of solar panels continued to drop by nearly 50% compared to 2022.

Renewable energy will make up more than a third of total electricity production by the beginning of 2025.

Nuclear power is also expected to reach a record level globally when production from France and Japan increases, at the same time as new reactors start up in many markets such as China, India, Korea and elsewhere in Europe. It will lead to record electricity production from low-emission sources, i.e. renewable-energy sources such as solar, wind and hydropower as well as nuclear power, which is expected to account for almost half of the world's electricity production by 2026, up from just under 40% in 2023.

The construction of offshore wind farms (OWFs) can have significant side effects on the marine environment if they are not designed and planned with careful consideration for ecosystems. These impacts include a potential reduction in marine biodiversity and the degradation of marine ecosystems both due to the construction and operation of wind farms.

Electricity generation by technology, 2000 – 2028



IEA. CC BY 4.0.

Notes: Electricity generation from wind and solar PV indicate potential generation including current curtailment rates. However, it does not project future curtailment of wind and solar PV, wich may be significant in a few countries by 2028.

The electrification revolution

The global demand for electricity is expected to increase at a faster rate in the next three years and grow by an average of 3.4% annually until 2026.[20] Electricity's share of final energy consumption is estimated to have reached 20% in 2023, up from 18% in 2015, but it must increase to 30% by 2030 according to the IEA's scenario for net-zero emissions by 2050.

Electricity prices for energy-intensive industries in the EU in 2023 were on average almost twice as high as in the US and China, despite an estimated price drop of 50% from 2022. Electricity price differences already existed before the war in Ukraine and the energy crisis, but they have increased further. The IEA notes that this is putting the competitiveness of the EU's energy-intensive industries under pressure.

As electrification takes off and both demand and supply of electricity become increasingly dependent on the weather, electrical safety and reliability become more important than ever. Many power systems around the world continue to face problems of sufficiency during increased demand for electricity during periods of extreme cold or heat, together with increasing weather-dependent interruptions.

As power systems develop in parallel with digitisation, protection against cyber threats will also become increasingly important. According to the IEA, between 2020 and 2022, the number of cyberattacks against power companies worldwide more than doubled.[21]

Electricity's share of final energy consumption must increase to

30% by 2030

according to the IEA's scenario for net-zero emissions by 2050.

Storage - the holy grail

Another central factor for the success of renewable energy and electrification (and the energy transition overall) is renewable energy storage, which could solve the production problems that many renewable energy technologies face. Though long seen as the missing link between intermittent renewable power and constant reliability, energy storage made possible by batteries, hydrogen and other solutions has begun to play a broader and increasingly important role in the energy transition.

As of 2020, there were more than 48 gigawatts worth of pumped hydropower storage capacity in operation in the EU (including the UK).[22] At this time, planned projects would have contributed an additional 20 gigawatts of capacity, while facilities under construction would have added some 2.4 gigawatts of pumped hydro-storage capacity to the EU. Italy has the highest installed capacity of pumped storage in Europe. In 2022, nearly 7.9 gigawatts were able to be stored across the country. It was followed by Germany, with some 6.4 gigawatts of pumped storage capacity.

Pumped-storage plants provide more than 90% of the EU's storage capacity today and work with a much higher efficiency when compared to hydrogen and on a larger scale than batteries.

Water will have a big role to play in large-scale storage in combination with industry adapting its production and producing when electricity is available and cheap. Another option for the industries is using intermediate storage possibilities between different process steps," says Fredrik Axby.

There is continuing investment in hydropower, which accounts for over half of Sweden's electricity production today and is of great importance to the green transition. For instance, Vattenfall, a European energy company, is investing in Juktan which, with its 315 MW, is Sweden's largest pumped-storage power plant and has an energy storage capacity equivalent to 300 000 electric cars.

Today, we use hydropower as a balance power. Currently, several times more hydropower is produced in Norrland than is consumed there but, in the future, there will be no balance power to export to southern Sweden. Then you have to follow the example of Denmark, where you have power plants for balancing purposes

Fredrik Axby, Acting Division Manager for Energy & Industry at Sweco Sweden

The EU Commission launched a research programme in 2022, ETIP Hydropower, whose goal is to provide consensus-based strategic advice to the European Commission covering analysis of market opportunities, research and development funding needs, biodiversity protection and ecological continuity.[23]

According to the IEA, battery storage needs to grow significantly to get on track for net zero. But with costs on a downward trend, batteries are currently in the spotlight. In Europe, installed battery storage capacity is projected to grow nearly sixfold in the next decade.[24]

The availability of material is critical. Just for electric vehicle batteries and energy storage, the EU will need up to 18 times more lithium and five times more cobalt by 2030 compared to the current supply.

Green hydrogen is also one of the storage technologies in the spotlight, even though the conversion rate is currently a bit poor. Hydrogen storage needs in Europe are expected to add up to some 72-terawatt hours by 2030. By 2050, storage needs for the 28 countries in the European Hydrogen Backbone (EHB) initiative are expected to surpass 466 terawatt hours.[25] Gas can be stored below ground in salt caverns, depleted gas fields, aquifers and hard-rock caverns. In terms of large-scale energy storage, hydrogen-energy storage has obvious cost advantages over lithium battery energy storage.

Other storage technologies include compressed air and gravity storage, but they play a comparatively small role in current power systems.

Batteries need to be built better

The growth of large-scale battery storage capacity is still at a relatively early stage, with BloombergNEF estimating that global capacity will grow tenfold to 411 gigawatts by 2030.[26] That is still a long way from the 680 gigawatts required by 2030 to meet the IEA's net-zero scenario.

Today, lithium-ion technology still dominates, but new battery chemistries are emerging, such as sodium ion. There are a number of advantages to sodium ion batteries: they cost less than lithium-ion batteries, there are more raw materials available to make them and they are more environmentally friendly, which can make them suitable for large-scale storage.

Another dedicated battery technology track for large-scale energy storage is flow batteries. They can operate for 25-30 years without performance degradation and are capable of being sized according to energy storage needs with limited investment.

First large-scale green hydrogen plant in the Benelux

Hydrogen is seen as an important element in making our energy mix more sustainable and it is one of the cornerstones of the energy transition that will be receiving a lot more attention in the coming years. Today, however, hydrogen is largely produced from natural gas. The two planned hydrogen plants will generate green hydrogen using electricity from wind energy at sea. VoltH2 has commissioned Sweco to perform the permit design and subsidy trajectory for two green hydrogen plants in the North Sea Port area in Vlissingen and Terneuzen (the Netherlands). Thanks to these 25 MW hydrogen electrolysis plants millions of kilos of hydrogen will be produced from wind energy within a few years.

Positive impact on the entire value chain of hydrogen VoltH2's 25 MW green hydrogen plant in Vlissingen can produce up to 3,500 tonnes of green hydrogen per year, scalable up to 100 MW (14,000 tonnes). For context, one kilo of hydrogen is enough to drive a car 100 km. The production plant can be connected to the European Hydrogen Backbone – the dedicated hydrogen infrastructure traversing Europe. VoltH2 is also actively developing additional sites in Belgium, France and Germany.

Read more at Swecogroup.com

Hydrogen - the universal solution

Produced by splitting water using renewable electricity, green hydrogen has been praised by many as the multi-tool of the energy transition for its potential to reduce carbon emissions, especially in hard-to-abate sectors.

Finland aims to be carbon neutral by 2035, an ambitious goal compared to the European Union's target of 2050. To be successful, the Finnish government has approved a plan in which Finland aims to produce at least 10 per cent of all green hydrogen within the EU by 2030. It is estimated that the amount of hydrogen used in Finland, which currently stands at approximately 140 kilotons per year, will double within the next 10–15 years. The hydrogen industry represents a number of great opportunities for Finland, thanks to the country's low-carbon electricity production capacity and powerful electrical grid. Additionally, Finland has great potential for expanding wind power, which in turn means a substantial increase in production capacity for hydrogen and electro fuels for both domestic use and foreign export.

> Hydrogen is a significant trend, representing one of the key large-scale solutions with considerable potential, yet it is part of a broader array of options in the quest for sustainable energy

Erik Skogström, Division Director, Industry & Energy, Sweco Finland.

Converting plastic waste to low-carbon hydrogen

Client: Hydrogen Utopia International PLC

Plastic waste is a global problem, with just 16 per cent of plastic waste recycled to make new plastics, while 40 per cent is sent to landfills worldwide. A waste-to-hydrogen project in central Poland is being developed to address this problem by using novel technology, which will also provide low-carbon hydrogen for the energy transition that is currently underway.

Modular waste-to-hydrogen plants will be converting 40 tonnes of unrecyclable plastic waste to about 2.7 tonnes of 99.9% pure low-carbon hydrogen daily, depending on the composition of the plastic waste. Process line is capable to produce 2,5 to 3 tonnes / day of hydrogen, depending on the type of raw material to the process. The process will be fully electrified and able to run on renewable power. The project is predicted to save hundreds of thousands of tCO_2e during its lifetime and will replace the heat that is currently produced from lignite, as well as increasing the use of hydrogen. Tail gas will supply gas engines to produce electricity and heat while, in the future, it could also be used as feedstock in the chemical and petrochemical industries.

Read more at Swecogroup.com

Finland's first industrial-scale green hydrogen production plant

Sweco is designing a P2X Solutions green hydrogen production plant in the Harjavalta Industrial Park. The facility, scheduled to be completed in 2024, will become the first industrial-scale green hydrogen production plant in Finland.

This 20-megawatt P2X facility will turn renewable energy into hydrogen fuel. The Harjavalta plant is estimated to reduce Finland's CO_2 emissions by 40,000 tonnes annually, the equivalent of removing around 20,000 gasoline-powered cars from the roads. Hydrogen and synthetic fuels refined from the plant, such as methane, play a key role in adapting energy-intensive road transport, aviation and sea shipping to stricter emission limits.

The plant is just one of several projects that are underway. Other similar projects have not yet reached construction phase. Similar facilities will be able to reduce CO_2 by even higher quantities in the future, which illustrates the potential that P2X and green hydrogen have in the race towards carbon-neutrality.

Read more at Swecogroup.com

The Netherlands and Belgium's combined import targets could meet up to 62% of the EU's 10Mtpa hydrogen import target. The same infrastructure that was built 50 years ago in The Netherlands, with thousands of kilometres of gas pipelines throughout the country, is being mobilised to enable a second gas revolution, replacing fossil fuels with carbon-neutral hydrogen.

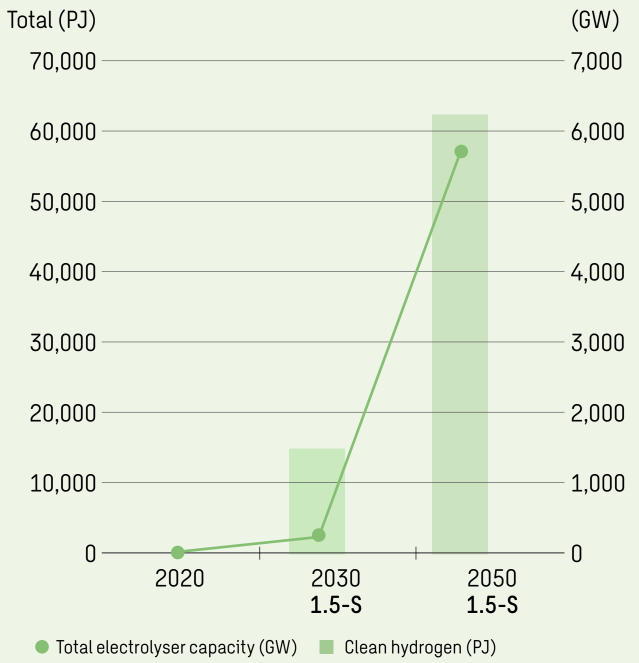
Currently, 95% of hydrogen produced around the world is 'grey hydrogen', produced from fossil materials such as natural gas and coal. For hydrogen to play a pivotal role in the energy transition, the first challenge is to scale up the production of clean hydrogen produced from renewable energy sources. Wind power, in particular, is a crucial enabler. The Netherlands have committed to installing 11 GW of offshore wind capacity by 2030 and to produce another 35 TWh of renewable energy on land.

Germany is also investing in hydrogen in the country's industrial transition, not least for steel production, and aims to have 10 GW of green hydrogen production capacity in place domestically by 2030. However, much more will be needed. As much as 50-70 % of the country's supply will be imported, mostly by ship, in the form of ammonia, a hydrogen-rich molecule that is easier to store and transport than liquid hydrogen.

There are plans for imports from Canada, as well as from neighboring countries such as Norway and Denmark, or through a pipeline that would connect North Africa to Germany via Italy and Austria. For this, 20 billion euros are being invested in hydrogen ports and storage facilities in reused and newly built pipelines, which will stretch almost 10,000 kilometers across all 16 of the country's states.

A major problem with importing green hydrogen is that so much energy is lost at each step of the conversion process. It is estimated that 45-60 per cent of the electricity used to produce hydrogen is lost in the process. Likewise, the process of converting electricity into hydrogen for storage and shipping, and then converting it back to electricity in a fuel cell, can be highly inefficient. In some cases, the energy delivered falls below 30 per cent of the initial electricity input.[27]

Global clean hydrogen supply in 2020, 2030 and 2050 in the 1.5°C Scenario



Notes: 1.5-S = 1.5°C Scenario; GW = gigawatt; PJ = petajoule.

Source: International Renewable Energy Agency (2023) - "World Energy Transitions Outlook 2023VOLUME 1" Published online at irena.org. Retrieved from: 'https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2023#page-2' [Online Resource]

Energy efficiency - still a lot to do

At COP28 last year, over 120 countries pledged to double global average annual energy efficiency. According to the IEA, this development is needed to achieve net-zero emissions from the energy sector by 2050, which is crucial to limiting global warming to the Paris Agreement's goal of 1.5 degrees. Global improvements in energy intensity, a primary measure of energy efficiency, must thus double from a level of 2% in 2022 to more than 4% per year on average until 2030. Last year, however, global energy intensity improved by only 1.3%.[28]

However, in the wake of Russia's invasion of Ukraine and the subsequent energy crisis, political momentum for energy efficiency has increased in many parts of the world. According to the IEA, investments in energy efficiency have grown by 45 per cent since 2020.

According to the industry forum Energy Efficiency Movement, systemic measures such as the Internet of Things, smart building management and industrial heat integration have the highest CO_2 emissions savings potential from energy efficiency measures.[29] However, they identify industrial motors as having the highest potential of any single technology for reducing the energy intensity of light industry processes.

100%

energy efficiency increase by 2030 to achieve net-zero emissions from the energy sector by 2050, which is crucial to limiting global warming to the Paris Agreement's goal of 1.5 degrees

Power grids - a tangled bottleneck

Expansion of renewables demands an increase in transmission and distribution networks. The digitalisation of smart grids and greater interconnectivity amongst grids can counter renewables' intermittency and create more stable networks.

There are increasing signs of grid congestion and bottlenecks in connecting renewable projects in many places. While investment in renewables has almost doubled in the last decade, investment in grids has remained stagnant. Over the next two decades, the IEA calculates that 80 million km of grid needs to be added or replaced, as much as the global grid length today, meaning that grid investment needs to double by 2030.[30]

Electricity grid development is complex, involves many stakeholders and can take many years, requiring decisions to be taken well in advance in order to support electrification and renewables, which can be deployed more quickly.

It can take over a decade to build a typical, high-voltage transmission line or a distribution line, this is due to democratic participation, protection of citizens' rights, protection of property rights, etc. Building infrastructure with long lead times can be challenging in terms of risk, which will impact the economics. On a windy summer day, Germany can produce about 70% of its energy from wind and solar, and close to zero on a still winter day. On the other hand, on a windy summer day, renewables can produce more power than the grid infrastructure can handle, leading to 'curtailments' or the deliberate limitation of electricity production to avoid overloading the system. This requires both a major upgrade of the electricity grid, which will need to be bigger, more interconnected, smarter and more flexible. Investments in distribution and transmission must increase dramatically. While global investment in electricity grids has been flat for the past 10 years, at about USD 300 billion annually, it will need to increase to about USD 700 billion annually by 2030 in a 1.5°C scenario.

USD **300 billion**

has been the level of global investment in electricity grids during the past 10 years. But now this has to increase to about USD 700 billion annually by 2030 in a 1.5°C scenario.

80 million km

is the length of grid that needs to be added or replaced over the next two decades, according to the IEA. This means that grid investment needs to double by 2030.

The expected sharp increase in electricity use in Sweden, mainly by large electricity users in the north, means that the energy landscape is changing dramatically. This was outlined in a report that Sweco prepared on behalf of Ellevio.[31] In the report, called 'What does the future cost?', electricity use in 2045 is analysed, as well as what it means in terms of investment and costs for electricity grid infrastructure. The report's authors talk about Sweden being turned upside down and refer to the fact that electricity use today is higher in the south of Sweden, while production takes place in the north. However, this would change if a number of individual large electricity users are added, especially in northern Sweden. The estimated investment needed for the electricity grid at all levels as a result of this is SEK 668 billion by 2045, and the lion's share of these investments, as well as investments in expanded electricity grid infrastructure, will have to be made in the next 10-12 years.

The challenge of matching supply and demand in the future power system will likely require large-scale energy storage. This can happen in several ways and, depending on how it happens, it might mean an increased need for network capacity. If it happens, for example, through demand flexibility in the industrial processes that are expected to use hydrogen produced by electrolysis, it means that the electrolyser effect will have to be higher. This in turn means that the network investment need is greater.

While investment in renewables has almost doubled in the last decade, investment in grids has remained stagnant. Over the next two decades, the IEA calculates that 80 million km of grid needs to be added or replaced, as much as the global grid length today, meaning that grid investment needs to double by 2030.

Rhein-Main-Link project. Image by Amprion

Danish ports' green-energy analysis

Sweco was commissioned by the Danish Transport Authority to analyse the availability of electricity and green fuels in 39 commercial ports. This analysis is part of the Ministry of Transport's port map initiative, with a Sweco multidisciplinary team providing insights into the energy infrastructure in the ports to provide clarity on the need for green energy investments.

Investments in Norway's transmission grid

Statnett is set to substantially increase investments in Norway's transmission grid to facilitate the realisation of Norway's climate objectives, creation of value for Statnett's customers and the society in general. Sweco is pleased to continue its collaboration with Statnett, aiming to reinforce Norway's electricity supply and contribute to the country's sustainable development.

The Rhein-Main-Link project in Germany

Sweco is contracted by Amprion to provide project management during the entire planning phase of the Rhein-Main-Link, an essential project for Germany's energy goal to be climate-neutral by 2045. This connection will carry wind energy from the North Sea over a 600-kilometer corridor to Hessen, aiming to satisfy the Rhine-Main region's increasing energy needs by 2033.

Read more at Swecogroup.com

New risks in the wake of the green industrial transformation

Doing business is always connected with a certain amount of risk, such as financing or developing a new technology that may not work. However, sometimes we act with the intention of solving a problem, but in acting, we create new issues. This could be the case in the race for the industrial sector to become greener, if resilience is not part of the equation. In this list, we highlight some of the new risks and challenges that could occur in the wake of the green industrial transformation.

1. Electricity: shortages, not available all the time, higher prices.
2. Shortages of skilled labour for the transition.
3. Shortages of raw materials needed for the transition.
4. Social exclusion if leaving carbon-intensive regions and workers in the fossil industry behind.
5. If the raw materials required for the green transition aren't sourced responsibly, there could be many negative impacts, from environmental pollution and biodiversity losses to carbon emissions from plant and soil disruption.
6. Use of more land for renewable energy and new mines can affect indigenous people.
7. Industries affect use of land, water, raw materials etc. The risks of negative effects on the environment, marine environment and ecosystems.
8. Cyberattacks against power companies worldwide more than doubled.
9. Carbon capture and storage (CCS) is a key technology in our efforts to mitigate climate change but isn't a standalone solution. It should complement, not replace, the shift to renewable energy. Moreover, the long-term risks related with geological storage of carbon must be actively managed.
10. Good intentions in connection with the green transition in Europe can lead to unintended consequences for sustainability and justice in lowand middle-income countries. Booming commodity demand often aggravates socio-environmental issues and inequality.

New business models and collaborations

Multi-stakeholder collaborations, between suppliers and customers, between industry and cross-industry colleagues and between the wider industrial ecosystem of stakeholders, is an important and sometimes crucial way to accelerate the green transition.

For the large green industrial projects in Sweden, such as those carried out by the battery company Northvolt and the steel companies SSAB/Hybrit, the support of customers in the form of large pre-orders has helped to finance very costly projects. Northvolt, which was founded as recently as 2015, had an order backlog of SEK 600 billion at the end of 2023 from customers such as BMW, Scania, Volkswagen and Volvo Cars.

”The so-called offtake agreements, i.e. a contract with a customer who undertakes to buy products when they are produced, are very important for investors in high-risk technologies. With these agreements in hand, you can go to the bank and get a loan,” says Aaron Maltais, researcher at SEI.

The Swedish green steel investment company Hybrit is a good example of the value of cooperation in the event of major societal changes and challenges, between companies, between companies and customers and between the public sector and the private sector. Hybrit is a joint-venture company with the steel company SSAB, together with the mining company LKAB and the energy group Vattenfall. Important prerequisites for the transition to fossil-free steel for SSAB are raw materials in the form of ore with a high iron content (from LKAB) and access to large amounts of fossil-free electricity for hydrogen production (from Vattenfall).

In the same way that the collaboration between Ericsson and Televerket once created solutions that gave Sweden telephony and a world-leading mobile phone company, Asea together with Vattenfall electrified Sweden and Saab's collaboration with FMV and the defence forces means that the country still has one of the world's most advanced fighter aircraft.

To address climate change effectively, a holistic perspective is necessary – one that balances global challenges with local conditions. Existing industries must adapt to enable the creation of new businesses. This represents an enormous challenge, and time is of the essence. All hard-to abate-sectors need to be involved.

Martina Söderström, Division manager Environment & Planning at Sweco Sweden.

Modernisation of Værket ved Sønde

In order to provide clean and softer drinking water to citizens in Greater Copenhagen, the utility HOFOR is transforming the Værket waterworks at Søndersø into a modern, fully automated waterworks with state-of-the-art technology. Sweco is one of the consultants on the project and is responsible for managing the construction of the new water softening plant and ensuring the feasibility of the waterworks design. The aim of the new Værket at Søndersø is to create a sustainable waterworks with the lowest possible environmental impact while ensuring safe drinking water.

Circular industrial processes

The circular economy is key to meeting global material needs without exceeding the available carbon budget. A more circular economy can cut CO_2 emissions from heavy industry by 56% by 2050.[32]

Much of the materials that the EU economy will need by 2050 have already been produced, 75% of steel, 50% of aluminium and 56% of plastics. Recirculating materials cuts CO_2 emissions and requires much less energy than new production does.

”In Europe, and in other developed economies, where we already have a built-up material stock, circularity is extremely important. The higher the degree of material recycling and the higher the degree of energy recovery you can have, the less impact heavy industry makes”, says Björn Nykvist, researcher at SEI.

”But, even if we solve these issues in Europe and the USA, we have the rest of the world. Today, 70 per cent of all steel production takes place in China. So, if we zoom out, it is even more important that we find new technological solutions to produce steel if we are to reach global climate goals in time.”

Steel recycling is already happening at a significant level and will only increase as global scrap metal supplies increase.[33] The same scale and circularity must be used for other materials.

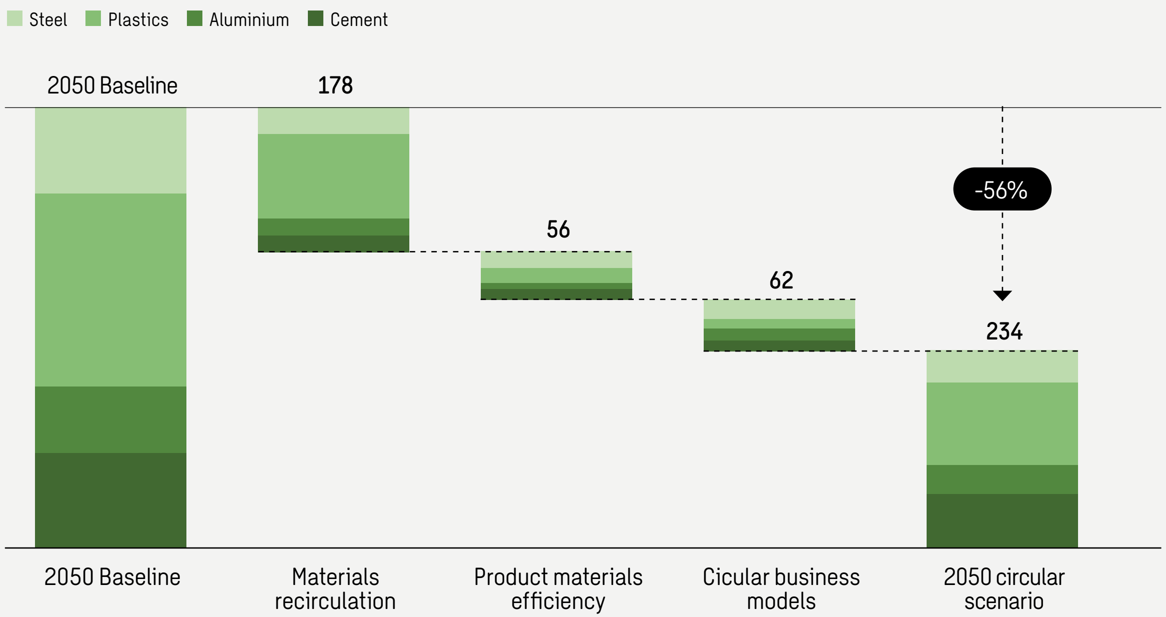
”Today, 80-85 per cent of all steel is recycled. Steel scrap is integrated in a common manufacturing process using electric arc furnaces. In the plastics sector, it is very challenging to recycle because of the different types of plastic and the fact that it’s spread around in so many places, but it has to be done. Much more investment needs to be made here and more regulations should be introduced”, says Björn Nykvist, researcher at SEI.

Designing products with circularity in mind, whether it is industrial products or consumer products, is key. This means considering the impact of a product not just in its first use phase, but assuming it will be resold, remanufactured, or repaired to extend its lifetime. Designing for circularity requires the incorporation of new core design principles and insight into materials use.

“Circularity provides increased business opportunities and will make us more independent. We cannot continue to feed in raw materials from other countries, industries must become much more cautious”, says Erik Skogström, Division Director, Industry & Energy at Sweco, Finland. He highlights a Finnish circular economy concept by Honkajoki Oy and GMM Finland Oy. This agro-ecological concept recycles nutrients from animal-based by-products to different industries such as pet food, animal feed, and biofuel manufacturers. Additionally, they have an industrial symbiosis with other partners, i.e., with a local tomato producer who utilizes the excess heat.

EU emissions reductions potential from a more circular economy, 2050

Mt of carbon dioxide per year



Source: Material Economics, "The Circular Economy - a Powerful Force for Climate Mitigation", Published online at materialeconomics.com. Retrieved from: https://materialeconomics.com/publications/publication/the-circular-economy-a-powerful-force-for-climate-mitigation [Online Resource]

Industrial symbiosis

What is industrial symbiosis? Industrial symbiosis is created by using waste from one operation as a resource in another operation and is a subset of the circular economy. Industrial symbiosis is a method for increasing industrial circularity by promoting transactions of information and residues to provide economic and environmental synergies in a network of industry actors.

One of the earliest examples of industrial symbiosis on a large scale in Europe is the Kalundborg industrial park in Denmark.[34] It brings together an increasing number of partners that are currently exchanging 20 resources, as diverse as biomass, gypsum and steam.

Kalundborg annually saves 635,000 tonnes of carbon dioxide emissions by circulating resources, a figure that corresponds to emissions from 63,000 laps around the world by car. The water saving amounts to 3.5 million tonnes of drinking water per year, the business benefits that the symbiosis creates are estimated at 28 million dollars per year and the socio-economic value for Kalundborg municipality is estimated to be 15.6 million dollars.

The companies in this symbiosis include everything from pharmaceutical giant Novo Nordisk to energy companies, biogas plants, a municipal waste company and Gyproc, a manufacturer of light construction materials. The water and sewage supplier Kalundborg Utility is responsible for a large part of the infrastructure and water treatment.

Increased resource efficiency is a key component in the industrial transition towards net zero.

Reimagining industrial sites

Resilience in the green transition extends beyond climate adaptation, requiring holistic solutions to diverse threats and challenges. Resilience is about balancing progress and preservation, a dual-support approach is needed to support both legacy industries and emerging sectors Industrial hubs like ports, central transportation networks and industrial production sites are redefining their roles, offering opportunities for businesses to re-purpose materials and energy and to share resources.

Integrated multidisciplinary approach
As industries aim to reduce their environmental footprint, it is essential to consider not just individual processes, but the entire system in which they operate. This calls for a holistic and collaborative effort that brings together various stakeholders, including businesses, governments and local communities. The way in which different disciplines are able to effectively cooperate on the many scales of the industrial transformation is fundamental to increase their environmental performance, but also to minimise future risks. Furthermore, an integrated approach to industrial development has the capacity to boost resilience in other economic, environmental and social sectors.

Carbon emissions reduction is at the heart of the green transition, but just as with the heart, it won't work without the rest of the body. The transition must include fostering biodiversity and empowering local communities. Otherwise, the transition won't be green or just, or even happen. So, the challenge for the greening industries is to understand that they are societal developers, and they need to take that role, just the way that property developers did when they understood that they were developing cities and not only into buildings. We see the same thing happening in the industrial sectors now.

Andreas Gyllenhammar Chief Sustainability Officer, Sweco

Industrial sites as sustainable, productive ecosystems, a systemic approach

Productive spaces are crucial for the daily functioning of cities and their economies. Contemporary forms of industrial production are increasingly more compatible with urban activities and natural environments thanks to new types of tailored manufacturing with increased electrification, automation and digitalisation, less pollution and new forms of multi-modal logistics.

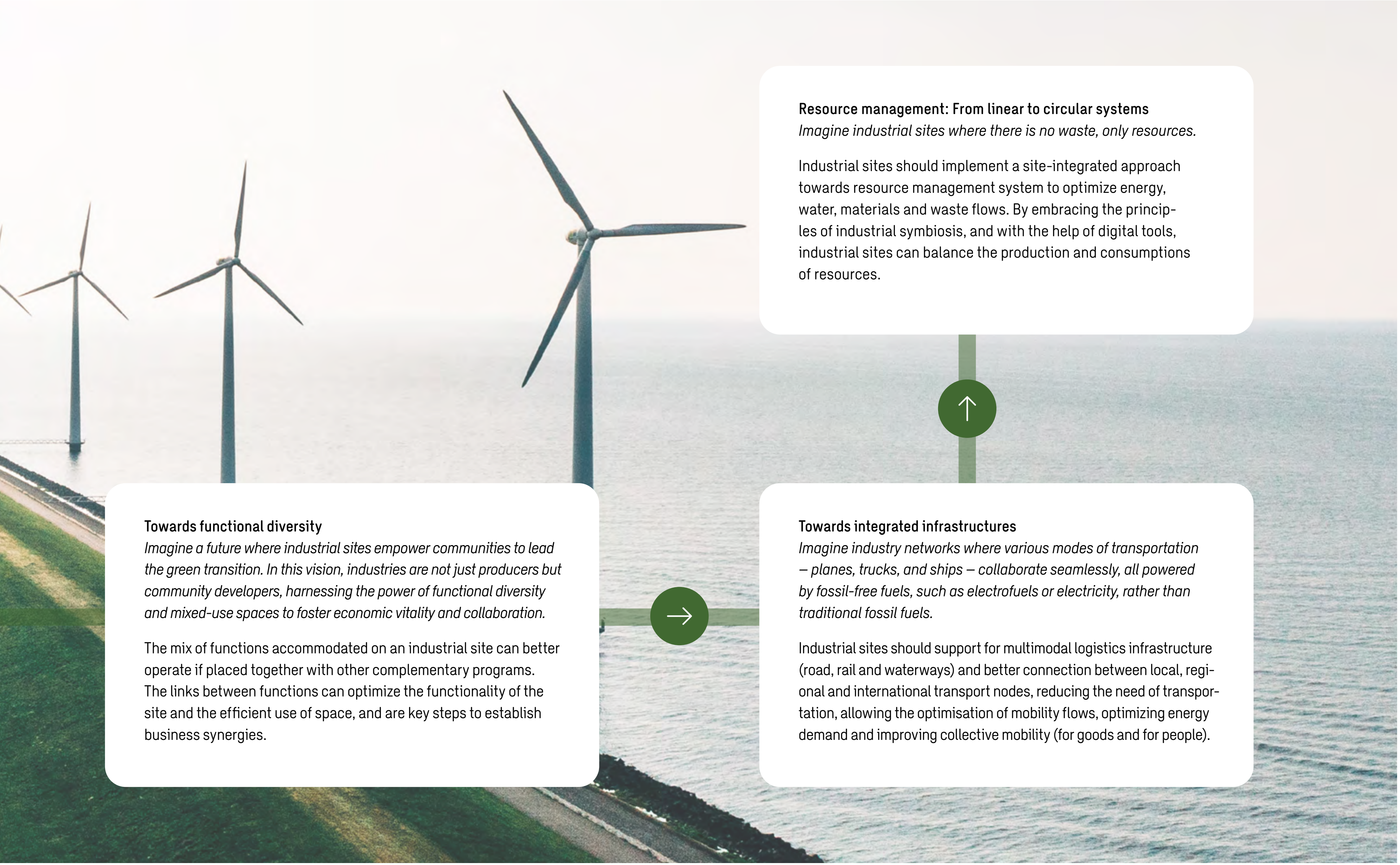
To foster a positive transformation of industrial sites into sustainable, productive eco-systems, an integrated approach to the different systems that organise our cities should consider the following aims:

Transition management and co-creative dialogue models
Imagine a future where industrial sites are dynamic urban spaces, increasing local economic growth through co-creative dialogue and inclusive transition management.

Industrial sites should create functional and spatial links with local communities - adding value to its economic context by including local business and residents in opportunities for engagement. Transition management is needed to find the common ground between various stakeholders, and draft roadmaps to effectively guide the transition.

Regenerative ecologies
Imagine a future where industrial sites thrive with regenerative ecologies, bolstering the resilience of territories, beyond mere restoration, aiming to enrich biodiversity, remediate damage, rewild spaces, and regenerate ecosystems.

Industrial sites should provide maximum integration with supra-local ecological networks such as blue and green networks. The approach towards the natural systems should be guided by nature-based solutions and circular practices.



Resource management: From linear to circular systems
Imagine industrial sites where there is no waste, only resources.

Industrial sites should implement a site-integrated approach towards resource management system to optimize energy, water, materials and waste flows. By embracing the principles of industrial symbiosis, and with the help of digital tools, industrial sites can balance the production and consumptions of resources.

Towards functional diversity
Imagine a future where industrial sites empower communities to lead the green transition. In this vision, industries are not just producers but community developers, harnessing the power of functional diversity and mixed-use spaces to foster economic vitality and collaboration.

The mix of functions accommodated on an industrial site can better operate if placed together with other complementary programs. The links between functions can optimize the functionality of the site and the efficient use of space, and are key steps to establish business synergies.

Towards integrated infrastructures
Imagine industry networks where various modes of transportation – planes, trucks, and ships – collaborate seamlessly, all powered by fossil-free fuels, such as electrofuels or electricity, rather than traditional fossil fuels.

Industrial sites should support for multimodal logistics infrastructure (road, rail and waterways) and better connection between local, regional and international transport nodes, reducing the need of transportation, allowing the optimisation of mobility flows, optimizing energy demand and improving collective mobility (for goods and for people).

Conclusion, key insights and recommendations

This report emphasises the need for industries to become both greener and more resilient, highlighting the challenges and opportunities, but also the potential risks and unintended consequences associated with this transformation that must be addressed to ensure a resilient and equitable shift.

Risks and challenges
Some of the new, potential risks that have to be addressed in the green industrial transformation are shortages of various kinds, such as that of electricity, skilled labour and raw materials needed for the transition. At the same time, there are challenges associated with the increasing need for new energy and new raw materials, together with new technologies that can negatively affect the climate, the environment and biodiversity, as well as people and societies. All risks and challenges need to be carefully managed in order to create a fossil-free future as well as a resilient industrial sector.

However, there is no doubt that the climate transition of the industrial sector is important and increasingly urgent. The industrial sector is a significant contributor to climate emissions, responsible for roughly 5% of global emissions and a third of CO_2 emissions from global energy use, which sums up to between 25% and 30% of total global CO_2 emissions. It also influences the CO_2 emissions from the transport and agriculture sectors.

Increased market demands, capital and technical advancements
The green industrial transition is definitely underway, closely connected to and enabled by the decarbonisation and transformation of the energy sector. Regulatory compliance, increased market demands - especially in the steel sector where the automotive industry is pushing hard for green products, a large inflow of capital and especially technological advancements are accelerating the whole transition.

Electrification, sustainable energy alternatives, battery technology, hydrogen energy, carbon capture utilisation and storage, energy storage systems, power-to-x processes, synthetic fuels, the circular economy, intelligent manufacturing with sensors, interconnected equipment, artificial intelligence and data analytics are all innovations and new technologies leading the transition towards a future free from fossil fuels.

Transformative leaders
The global push towards net-zero emissions challenges companies, especially those needing to shift production methods. That's why we also see some of the largest emitters taking the lead in the green industrial transition today, such as the steel, cement and transport industries. Leadership that draws on integrated, systemic and multidisciplinary thinking will be paramount in managing the complexities of industrial transformation. An integrated approach will not only enhance environmental performance and risk management but also strengthen the resilience of various sectors.

This report emphasises the complexity of the transition and the need for industries to become both greener and more resilient, highlighting the challenges, opportunities and potential risks associated with this transformation. Resilience in the green transition extends beyond climate adaptation, requiring holistic solutions to diverse threats and challenges. Resilience is about balancing progress and preservation, a dual-support approach is needed to support both legacy industries and emerging sectors.

Technological advancements are aligning industrial production with urban life, characterised by customised manufacturing, increased electrification, automation, and digitalisation. Today, transition management is increasingly about engaging local communities in the transformation process and creating a shared vision for the future of industrial sites.

In conclusion, as we have explored throughout this report, transformative leadership is not just a theoretical concept but a driving force behind the green transition.

Together we can turn the green transition from a vision into a reality. Let this report not just be a collection of insights but a springboard for action. Transformative leadership is our key to unlocking a sustainable future. Let's use it wisely and with urgency.

Key Insights and actions

1 Regulations and capital are falling into place - but is it enough?
The industrial sector is at the heart of the green transition. It contributes to about 5% of global CO2 emissions and a third of CO2 emissions from global energy use, which adds up to between 25% and 30% of total global CO2 emissions.

Regulations, market forces, and increased investment are shaping the industrial landscape. The Inflation Reduction Act came into law in 2022, marking the most significant action Congress has taken on clean energy. The latest addition to the European Green Deal was the Net-Zero Industry Act, which aims to scale up the manufacturing of clean technologies in the EU and make sure that the Union is well equipped for the clean-energy transition.

Billions of euros have been invested in the green transition, yet there remains a gap between current investment levels and the amounts needed to achieve net zero. The industrial sector must accelerate its efforts and close this gap. A more circular economy could cut CO2 emissions from heavy industry by 56% by 2050.

2 The steel industry takes the lead, cement industry runner up
New innovative production methods and large investments have placed the steel industry in the lead of the green industry transformation. There is also a strong green momentum in the cement industry, but the transition is still relying heavily on Carbon Capture Storage, CCS.

Europe is taking the global lead in some industrial sectors; for example, 95% of the full-scale projects in green cement worldwide are taking place in Europe, as well as 61% of all fossil-free steel projects.

3 The transformation of the energy sector is key
The decarbonisation and transformation of the energy sector are enabling the industrial transition with a wave of new solutions and technological advancements with electrification, batteries, hydrogen, carbon capture utilisation and storage, power-to-x processes and much more.

In some sectors, the pace of technical investments and implementation is too slow to meet net-zero targets by 2030. For instance, grid investment needs to double by 2030. Tripling renewable power and doubling energy efficiency by 2030 are crucial steps toward the 1.5°C goal. Renewable energy sources such as solar, wind and hydropower, along with nuclear power, which is expected to account for almost half of the world's electricity production by 2026, up from just under 40% in 2023, are essential.

4 Accelerating the green shift: the dynamic interplay of regulation, market forces, and innovation in industry
Regulatory compliance, increased market demands, especially in the steel sector where the automotive industry is pushing hard for greener products, a large inflow of capital and innovations are also powerful driving forces in the green industrial transition.

To address climate change effectively, a holistic perspective is necessary, one that balances global challenges with local conditions. From a European standpoint, to expedite the shift toward a sustainable and low-emission economy, countries need effective and expedited permitting procedures that enable the swift progress and implementation of innovative, environmentally friendly technologies.

5 Resilience plays a crucial role

Resilience within the context of industrial transformation refers to the capacity of industries to absorb, adapt to and recover from various challenges and changes while maintaining their core functions. This concept is particularly relevant in the face of environmental, economic, technological and societal shifts.

Resilient industries can navigate uncertainties, economic downturns, technological shifts and other challenges, while continuing to evolve, innovate and contribute to the economy.

In the industrial sector, resilience involves:

- ***Adaptability:*** the ability to modify production processes, business models and strategies in response to changing market demands, regulations, or technological advancements.
- ***Robustness:*** designing systems and infrastructure that can withstand disruptions, such as supply chain interruptions, cyber-attacks or natural disasters.
- ***Redundancy:*** having backup systems in place to ensure continuous operation during unforeseen events. This could mean having alternative suppliers, extra inventory, or emergency power supplies.
- ***Resource efficiency:*** efficiently using resources to reduce dependency on scarce materials, which also helps in coping with fluctuating resource prices and availability.
- ***Collaboration:*** working with other businesses and sectors, as well as organisations to create a supportive network that can provide assistance and resources when needed. The industrial transition calls for industrial symbiosis and new business models.
- ***Sustainability:*** embracing environmental and social governance to ensure long-term viability and to align with global efforts such as the United Nations Sustainable Development Goals. Innovative strategies are necessary to facilitate a transition towards more sustainable practices. This transition is not just a technological shift but also a fundamental change in the underlying economic structures that govern industrial operations.

In summary, resilience in industrial transformation is about building systems that are not only robust in the face of disruptions but are also flexible and capable of evolving over time to meet future challenges and opportunities.

Recommendations

1. For the industrial sector to become sustainable, it not only needs to reach net zero but become more resilient as well.
2. The knowledge needed to manage the complexity and goal conflicts is key in order to avoid good intentions leading to unintended consequences for people, the environment and societies.
3. Multi-stakeholder collaborations and new business models between suppliers and clients, industry and cross-industry colleagues and the wider industrial ecosystem of stakeholders are crucial to accelerating the green transition.
4. The competition is intense and transformative leadership is key. Countries and companies not transforming risk losing out.
5. Let the leading industrial sectors, new technologies and innovation in this report inspire you to turn the green transition from a vision into a reality.

Contributing experts

Andreas Gyllenhammar, Chief Sustainability Officer, Sweco Group
Martina Söderström, Division Manager, Environment & Planning, Sweco, Sweden
Tom Van Den Noortgaete, Division Manager, Energy & Environment, Sweco, Belgium
Erik Skogstrom, Division Director, Industry & Energy, Sweco, Finland
Fredrik Axby, Acting Division Manager for Energy & Industry at Sweco, Sweden
Gaëlla Delcour, Business Unit Manager, Industry, Sweco, Belgium
Björn Nykvist, researcher at the Stockholm Environment Institute
Aaron Maltais, researcher at the Stockholm Environment Institute.
Peter Bryntesson, CEO of the Scandinavian Automotive Supplier Association.
Kathleen Van de Werf, Business Development Manager, Sweco, Belgium
Diego Luna Quintanilla, Expert Leader Urban Insight, Sweco, Belgium

Special thanks to:

Kristina Jakobsen, Construction Manager, Sweco, Norway
Erkki Härö, Energy Transformation Driver at Sweco, Sweco, Finland
Marek Kolasiński, Technology Development Department Manager, Sweco, Poland
Monica Welander, Head of Sustainability Communications, Sweco Group
René Salomon, Project Director, Sweco, Denmark
Linn Arvidsson, Specialist Environmental permits and regulations, Sweco, Sweden
Ludmilla Wedel, Project Lead, Sweco, Germany
Sara Vander Beken, Business Unit Manager, Sweco, Belgium
Anders Bostad, Business Unit Manager, Sweco, Norway
Jill Bederoff, Journalist and writer
Per Olof Lindsten, Journalist and writer
Emma Sterner Oderstedt, Project Manager, Urban Insight, Sweco Group

Reference list

1) Crippa, M., et al. (2023). GHG emissions of all world countries. Publications Office of the European Union, Luxembourg. Retrieved from: https://op.europa.eu/en/publication-detail/-/publication/0cde0e23-5057-11ee-9220-01aa75ed71a1/language-en
2) Ritchie, H. (2020). Sector by sector: where do global greenhouse gas emissions come from?. Retrieved from: https://ourworldindata.org/ghg-emissions-by-sector
3) Breque, M. De Nul, L. Petridis, A. (2021). Industry 5.0 - Towards a sustainable, human-centric and resilient European industry. European Commission. Retrieved from: https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/industry-50-towards-sustainable-human-centric-and-resilient-european-industry_en
4) Breakthrough Energy. (2022). The Data, Sectoral Analysis. Retrieved from: https://breakthroughenergy.org/our-approach/the-data/sectoral-analysis/
5) Mission Possible Partnership. (2021). The Power of Partnership. Retrieved from: https://missionpossiblepartnership.org/about/
6) European Commission. (2023). Net-Zero Industry Act: Making the EU the home of clean technologies manufacturing and green jobs. Retrieved from: https://ec.europa.eu/commission/presscorner/detail/en/IP_23_1665
7) Payne, J. (2023). EU needs over $760 bln/yr to hit green transition targets – Commission. Retrieved from: https://www.reuters.com/sustainability/climate-energy/eu-needs-over-760-blnyr-hit-green-transition-targets-commission-2023-07-06/
8) Bloomberg NEF. (2023). Green Steel Demand is Rising Faster Than Production Can Ramp Up. Retrieved from: https://about.bnef.com/blog/green-steel-demand-is-rising-faster-than-production-can-ramp-up/
9) Global Energy Monitor. (2023). Global Steel Plant Tracker. Retrieved from: https://globalenergymonitor.org/projects/global-steel-plant-tracker/
10) The Institute for Energy Economics (IEEFA). (2023). MENA poised to become a leading green iron and steel hub. Retrieved from: https://ieefa.org/articles/mena-poised-become-leading-green-iron-and-steel-hub
11) International Renewable Energy Agency (IRENA). (2023). Geopolitics of the Energy Transition - Critical Materials. Retrieved from: https://www.irena.org/Digital-Report/Geopolitics-of-the-Energy-Transition-Critical-Materials
12) Dikau, S. Miller, H. Nobletz, C. Svartzman, R. Kyriacou, G. (2023). What are 'critical minerals' and what is their significance for climate change action?. LSE (The London School of Economics and Political Science). Retrieved from: https://www.lse.ac.uk/granthaminstitute/explainers/what-are-critical-minerals-and-what-is-their-significance-for-climate-change-action/
13) Fern. (2021). Critical minerals. Retrieved from: https://www.fern.org/issues/critical-minerals/
14) International Renewable Energy Agency (IRENA). (2023). Geopolitics of the Energy Transition - Critical Materials. Retrieved from: https://www.irena.org/Digital-Report/Geopolitics-of-the-Energy-Transition-Critical-Materials
15) Morgado, A. Hugues, P. Vass, T. (2023). Cement – Tracking Cement. IEA, Paris. Retrieved from: https://www.iea.org/energy-system/industry/cement
16) IEA. (2023). Cement. IEA, Paris. Retrieved from: https://www.iea.org/reports/cement-3, Licence: CC BY 4.0
17) Stephens, J. C. (2014). Time to stop investing in carbon capture and storage and reduce government subsidies of fossilfuels. Wiley Interdisciplinary Reviews: Climate Change, 5(2), 169-173. Retrieved from: https://www.problemshifting.directory/case/carbon-capture-and-storage-ccs/
18) IEA. (2023). Energy Efficiency 2023. IEA, Paris. Retrieved from: https://www.iea.org/reports/energy-efficiency-2023, Licence: CC BY 4.0
19) IEA. (2024). Renewables 2023. IEA, Paris. Retrieved from: https://www.iea.org/reports/renewables-2023, Licence: CC BY 4.0
20) IEA. (2024). Electricity 2024. IEA, Paris. Retrieved from: https://www.iea.org/reports/electricity-2024, Licence: CC BY 4.0
21) IEA. (2023). Cybersecurity – is the power system lagging behind?. IEA, Paris. Retrieved from: https://www.iea.org/commentaries/cybersecurity-is-the-power-system-lagging-behind, Licence: CC BY 4.0
22) Jaganmohan M. (2024). Pumped hydropower storage capacity in the European Union as of 2020, by facility status. Statista. Retrieved from: https://www.statista.com/statistics/1336074/eu-pumped-hydro-storage-power-capacity-by-status/
23) The International Hydropower Association (IHA) (2022). Region profile Europe. Retrieved from: https://www.hydropower.org/region-profiles/europe
24) Statista Research Department. (2024). Energy storage in Europe – statistics & facts. Statista. Retrieved from: https://www.statista.com/topics/10030/energy-storage-in-europe/#topicOverview
25) Statista Research Department. (2024). Forecast need for hydrogen storage in Europe in 2023 and 2050. Statista. Retrieved from: https://www.statista.com/statistics/1336052/forecast-hydrogen-storage-demand-europe/
26) BloombergNEF. (2022). Global Energy Storage Market to Grow 15-Fold by 2030. Retrieved from: https://about.bnef.com/blog/global-energy-storage-market-to-grow-15-fold-by-2030/
27) Umbach, F. (2020). Hydrogen: Decarbonization´s silver bullet?. GIS-reports. Retrieved from: https://www.gisreportsonline.com/r/eu-hydrogen-strategy/
28) IEA. (2023). Energy Efficiency 2023. IEA, Paris. Retrieved from: https://www.iea.org/reports/energy-efficiency-2023, Licence: CC BY 4.0
29) The Energy Efficiency Movement. (2021). IEA Executive summary. Retrieved from: https://www.iea.org/reports/energy-efficiency-2023/executive-summary
30) IEA. (2023). Electricity Grids and Secure Energy Transitions, IEA, Paris. Retrieved from: https://www.iea.org/reports/electricity-grids-and-secure-energy-transitions, Licence: CC BY 4.0
31) Krönert, F. Bergerlind, J. (2022). Elnätet blir nyckeln när elanvändningen i Sverige vänds upp och ner. Sweco. Retrieved from: https://www.sweco.se/aktuellt/nyheter/ny-rapport-fran-sweco-elanvandningen-i-sverige-vands-upp-och-ner/
32) Material Economics. (2023). The Circular Economy – a Powerful Force for Climate Mitigation. Retrieved from: https://materialeconomics.com/publications/publication/the-circular-economy-a-powerful-force-for-climate-mitigation
33) NetZeroClimate. (2023). Heavy Industry. Retrieved from: https://netzeroclimate.org/sectors/heavy_industry/
34) Dalväg, E. Jansson, T. (2022). Symbios: om hur avfall blir resurser i den cirkulära ekonomin. Emma Dalväg & Tobias Jansson. ISBN: 9789152716236

Urban
Insight
By Sweco

Urban Insight is Sweco's international knowledge platform, where experts come together to develop and share insights, facts and solutions for how to plan and design sustainable cities and the societies of the future. Global and local initiatives will be organised throughout the year to inspire and open up discussions about sustainable urban planning.

In this trend report, the focus is on the green industrial transformation with the goal of highlighting pertinent examples, projects and trends within the industry that are instrumental in the quest to achieve net-zero emissions and enhance resilience.

Find out more by visiting our website:
swecogroup.com/urban-insight

SWECO