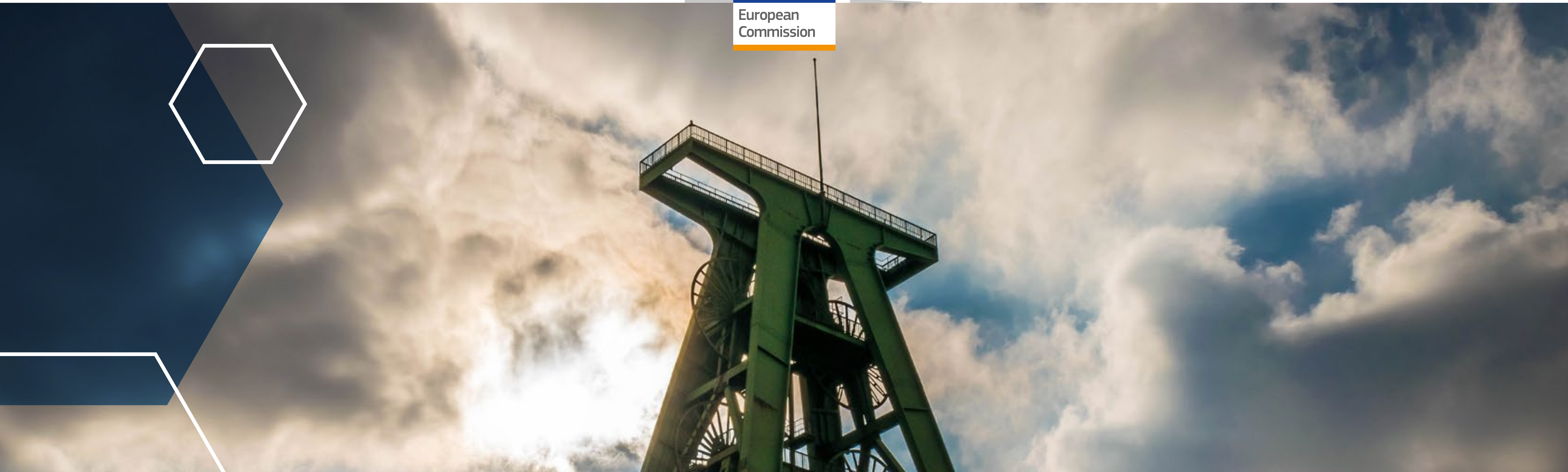

European Commission

Toolkit

Technology options

Transforming industries in coal regions for a climate-neutral economy

Energy

SUPPORT MATERIALS

Providing support materials to coal regions in transition

The Initiative for coal regions in transition developed the following support materials to assist practitioners in coal regions (including peat and oil shale regions) across Europe.

Transition strategies toolkit

Guidance on how to:

- develop a transition strategy in coal regions;
- identify actions and projects to support the strategy;
- monitor, evaluate and continuously adapt the strategy.

Link

Governance of transitions toolkit

Guidance on how to:

- design the right governance model to support a transition process in coal regions;
- facilitate stakeholder engagement;
- enhance the role of social dialogue and of civil society in the transition process.

Link

Sustainable employment and welfare support toolkit

Addresses the issues of:

- skill needs and reskilling for coal regions in transition;
- cooperation among stakeholders;
- support options for workers who are at risk of losing their jobs;
- economic diversification of coal regions as a means for long-term job creation.

Link

Environmental rehabilitation and repurposing toolkit

This toolkit gives advice on:

- securing finance;
- knowledge and tools;
- governance and institutions to support mine closure, environmental rehabilitation of mines and repurposing of coal related infrastructure.

Link

European Commission

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How to use this toolkit

Slides / Pages 6-33

This section features key ideas and concepts behind technology options for EU coal regions.

It can also be used as a stand-alone presentation. For each slide, more detailed information can be found in the accompanying notes.

Accompanying notes / Pages 34-59

The accompanying notes follow the same structure as the slides and offer a more in-depth look at each section, including further resources, links, examples, and case studies.

AIMS AND SCOPE

This toolkit explicitly addresses:

- the repurposing of infrastructure related to coal-fired power plants;
- the decarbonisation of coal-intensive industry with a focus on steel production;
- the role of hydrogen production for regional development;
- the potentials of non-energetic uses of coal.

WHO IS THIS TOOLKIT FOR?

- Policy makers in regional government.
- Stakeholders engaged in strategic industrial transition processes.

WHY DO WE NEED THIS GUIDANCE?

This toolkit focuses on what technology options exist and which technological developments are likely in the future. The information gathered will provide decision-makers in coal regions with a general overview of the current state of knowledge regarding the available technologies, enabling them to explore new business models, which also make use of the already existing coal related infrastructure in their region. This in turn to help with the development of regional strategies.

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Technology options for a climate-neutral economy by 2050

Being **climate-neutral by 2050** means that, from today on, all investments in long-term infrastructure must be compatible with a zero-carbon economy.

For coal regions, the key questions are:

- what elements of existing infrastructure can be useful in this energy transition?
- what parts of the regional industrial value chains are to be sustained?

Therefore, this toolkit focuses on the question:

- which industrial technology options are in line with long-term climate-neutrality targets, while making use of today's existing infrastructure?

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APPROACH

Technology options for industries in a climate-neutral economy

This toolkit covers four key topics

RE-USE OF COAL POWER PLANTS

Energy storage

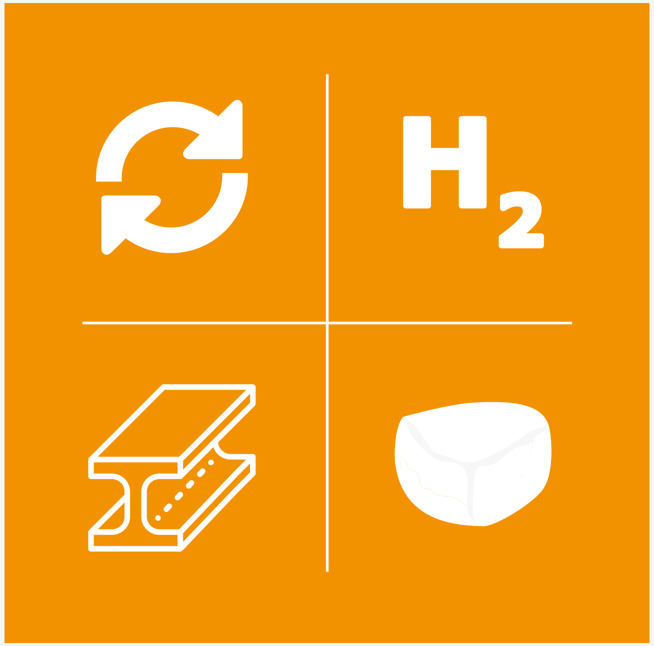
Conversion to gas or renewable energy

Non-energy uses

DECARBONISING ENERGY-INTENSIVE INDUSTRIES

Relevance of energy-intensive industries for coal regions

Decarbonising steel production



HYDROGEN

Future application

The EU hydrogen strategy

Hydrogen demand projections

Hydrogen in coal regions

OPTIONS FOR NON-ENERGY USES OF COAL

Future prospects of coal products

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European Commission

Background

Transitioning to a climate-neutral economy

The transition to a climate-neutral economy has the potential to attract large investments and act as a driver of the innovation system, thus supporting the future well-being and economic sustainability of coal regions.

Multi-billion EUR investments in new infrastructure (e.g. hydrogen) and technologies (for power plants and factories) will hardly come from individual players alone. They need a collective effort by many regional stakeholders, including policy-makers, the private sector, research and civil society.

1. A key first step is to understand **what technology options exist and what their characteristics are**. This is what this toolkit can help with.
2. The second step is to bring together key regional stakeholders and develop a tailor-made strategy. This is addressed in the following toolkits:
   - Transition strategies
   - Governance of transitions

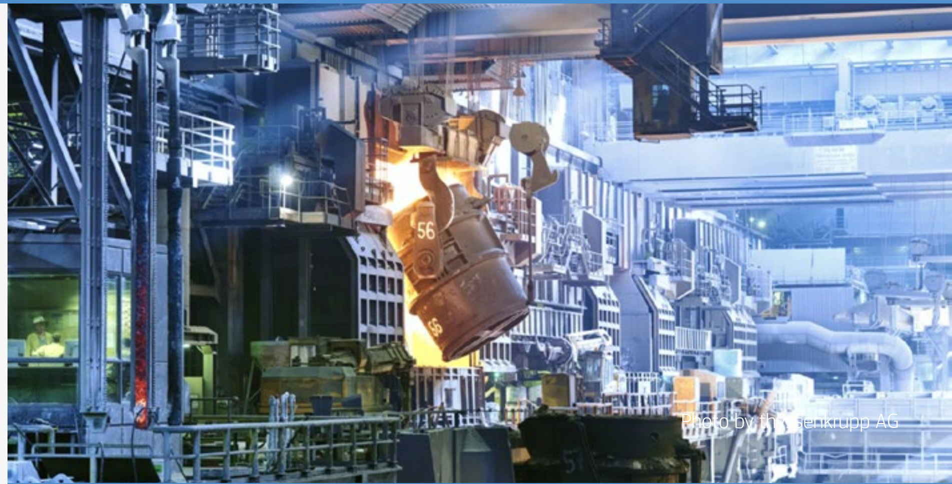

Photo by thyssenkrupp AG

IN4CLIMATE

In North Rhine-Westphalia (NRW), Germany's industrial heartland, the state government has launched the initiative 'IN4climate.NRW' to shape and accelerate the transformation of NRW's industry to a climate-neutral industrial base.

> *'We will demonstrate that successful climate protection and a strong economy are not mutually exclusive, but rather the foundations and drivers of prosperity and quality of life in our state.'*
>
> *Andreas Pinkwart, Minister of Economic Affairs, Innovation, Digitalisation and Energy of the State of North Rhine-Westphalia, Germany*

Around 30 companies and associations from the fields of steel and metals, chemicals, cement, glass, paper and building materials are participating in the initiative alongside six research institutes and the NRW state government.

Read more

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Re-use of coal power plants

Re-use of coal power plants

Energy Storage

Energy storage technologies will play a key role as a supplement for intermittent renewable sources like solar and wind.

The integration of energy storage systems within existing power plants has some major advantages.

- The re-use of coal-power plants stops the facilities from becoming stranded assets.
- Using the existing infrastructure reduces the cost of plant closures, while also reducing the investment costs for setting up the new energy storage systems.
- Reskilling can help former workers keep their jobs.
- The region's identity as a power producer will remain, which can help with public acceptance.

Thermal energy storage

Pumped hydro energy storage

Chemical battery storage systems

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Re-use of coal power plants

Thermal energy storage

Market-ready technology

Molten salts energy high-temperature storages. Alternatives currently under development: Carnot batteries / miscibility gap alloys.

Potentials:

- interlinking power and heat energy systems;
- reducing costs as existing infrastructure and power plant technologies can be further used.

Challenges:

- overall efficiency and maximum capacities are still limited.

Photo by Goldorak (CC BY 2.0)

ENERGY STORAGE PLANT CONVERSION BASED ON MOLTEN SALTS, SPAIN

In Asturias, northern Spain, the coal-fired power station 'Aboño I', with a capacity of 342 MW, is planned to close in 2021. The owning company EDP is evaluating the potential to replace the facility with an energy storage system consisting of molten salt electrical heaters that allows electric charge and discharge from the power network. A first evaluation showed the potential conversion could include a 358 MW storage facility with a discharge time of 2 hours. The total estimated cost of the project is EUR 201 million, with foreseeable job options for 300 workers during construction and 50 workers after completion.

Read more

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Re-use of coal power plants

Pumped hydro energy storage

Potentials:

- high capacities;
- long-time storage possible;
- market-ready;
- unconventional use in abandoned (underground) mines might become a feasible option in some coal regions.

Challenges:

- geographic requirements limit applicability;
- environmental impacts.

Photo by Genex Power Limited

THE PUMPED STORAGE HYDRO PROJECT IN KIDSON, AUSTRALIA

To be finalised in 2022, the AUD 700 million K2-Hydro Project will utilise two existing mining pits from an abandoned gold mine as the upper and lower reservoirs for a pumped hydro energy storage facility that will have a capacity of 250 MW and will be able to provide up to 2 000 MWh in eight hours. The project is forecast to contribute AUD 353 million in net public benefit and will provide 510 jobs during construction and 20 operational jobs.

Read more

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Re-use of coal power plants

Chemical battery storage systems

Market-ready technology

Mostly Li-ion and sodium sulfur, in the megawatt range.

Potentials:

- relatively cost-effective;
- easy to install;
- high power-to-energy ratio;
- stabilises the electricity grid.

Challenges:

- short lifespan of 10-20 years;
- limited lithium resources.

Photo by LEAG

LEAG 'BIGBATTERY' PROJECT AT COAL-FIRED POWER PLANT 'SCHWARZE PUMPE', GERMANY

In August 2020, the energy company LEAG finished the installation of a 53 MWh capacity lithium-ion battery storage on-site of their still running lignite power plant 'Schwarze Pumpe'. LEAG is investing EUR 25 million in the lithium-ion storage facility, comprising 13 containers full of battery racks. The German state of Brandenburg takes EUR 4 million of total investments. The main use of the facility will be to provide primary load balancing electricity to stabilise the grid.

Read more

Re-use of coal power plants

Conversion to natural gas

Potentials:

- a technologically simple solution to reduce emissions in the short term;
- reduced conversion costs as existing infrastructure and power plant technologies can be used;
- high degree of flexibility thus complement intermittent renewables.

Challenges:

- risk that conversions become stranded assets and produce lock-ins;
- methane leakages question the climate benefits of gas compared to coal.

Take-away

As the combustion of natural gas still produces emissions, the share of gas in the energy mix is projected to decrease significantly after 2030. Taking into account that there are already 270 GW of installed gas power plants in Europe, additional coal-to-gas conversions are at high risk of becoming stranded assets.

Photo by Serge Ottaviani (CC BY-SA 3.0)

COAL TO COMBINED-CYCLE GAS TURBINE POWER PLANT TRANSFORMATION PROJECT IN BOUCHAIN, FRANCE

In Bouchain, northern France, the energy company EDF transformed its coal-fired power plant, which was shut down 2015, into a combined cycle gas turbine (CCGT) with a capacity of 606 MW. The company invested a total of EUR 400 million into the converted power plant, which started running again in 2016.

Read more

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Re-use of coal power plants

Conversion to biomass

Potentials:

- co-firing, conversion, replacement or relocation & decentralisation options;
- reduced costs as existing infrastructure and machinery only need to be adjusted;
- reskilling options for the local workforce.

Challenges:

- concerns regarding climate neutrality and to 'local' aspects of biomass sourcing;
- very limited in terms of scalability due to land and water consumption, and biodiversity concerns;
- the efficiency of biomass is lower than coal (it can be increased by using CHP technology).

Take-away

Coal-to-biomass conversions will be dependent on approved sustainable, secure and long-term efficient feedstock supply. Biomass is not a promising alternative for most regions and, especially, cannot be recommended for large scale power plants.

Photo by rizox

IRELAND'S UTILITY STRUGGLES TO FIND SUSTAINABLE BIOMASS SOURCES

In County Offaly, Ireland, the local utility ESB had planned to switch one peat-fired power plant to using biomass. However, in 2019, the government refused to give permission to this conversion due to biodiversity and climate concerns. The lack of information provided by the running company ESB on the potential sources of biomass was the major issue for that decision, as the company could not reasonably determine that the direct and indirect impacts on the environment would be sufficiently mitigated. The regional authorities stated that a foreseeable 'high dependence' on imported biomass would not be in line with both national and EU climate goals.

Bord na Móna, another Irish company running a co-fired biomass plant, priorly raised public concerns as it mostly used palm kernel shells from environmentally questionable palm oil monocultures as their source for biomass. Since then, the company tried to switch to more sustainable sources, but acknowledges that reliable, local and cost-effective biomass supply at scale remains a 'significant challenge'.

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Re-use of coal power plants

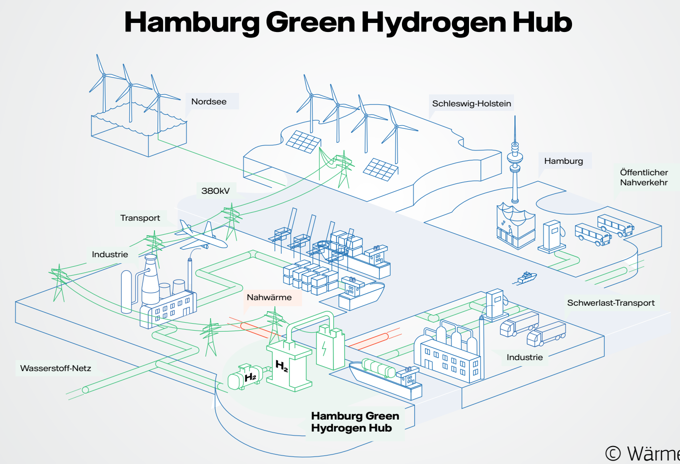
Combined renewable energy production and sector coupling

Depending on site-specific requirements, other renewable energy technologies can be developed on coal plant sites, such as:

- solar power (PV or CSP);
- solar heating;
- wind farms;
- deep geothermal energy.

In many cases, a combination of renewables and energy storage will be beneficial.

Former coal-fired power plant sites might develop into **clean energy hubs** combining energy production, and processing (e.g. hydrogen) with demand.



© Wärme Hamburg

A 'GREEN HYDROGEN HUB' AT FORMER COAL-FIRED POWER PLANT SITE IN HAMBURG, GERMANY

A consortia of Mitsubishi Heavy Industries, Shell, Vattenfall and the local energy company Wärme Hamburg are planning to build a 100 MW green hydrogen production facility at the site of the coal-fired power plant Moorburg in Hamburg, which only operated from 2015 to 2020. Due to it's position in the port of Hamburg, closeby to energy-intensive industry companies and with access to the existing gas network and electricity grit connection, the project is expected to be key for the decarbonization efforts in Hamburg and aims to become a 'Green Hydrogen Hub' powered by renewable energy from offshore wind parks in the north sea. The project is expected to start operation in 2025.

Read more

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Re-use of coal power plants

Non-energy uses of coal-fired power plant infrastructure

Despite the benefits to keep coal-fired power plants as sites for energy production or storage, there are also options for non-energy uses of coal-fired power plant infrastructure. This is especially true in cases where valuable geographic conditions make non-energy options feasible, such as sites with access to ports and sites in densely populated urban areas.

Examples:

- conversion of coal-fired power plants into data centres;
- conversion to logistical ports for off-shore wind;
- conversion to industrial parks;
- redevelopment to offices, student union centres, cultural sites.

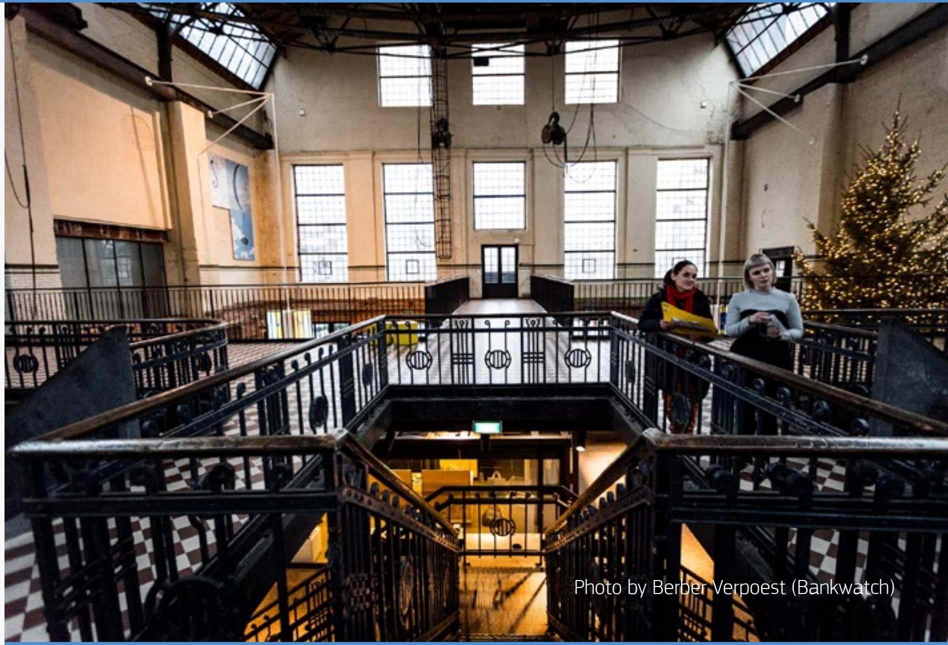
Photo by Berber Verpoest (Bankwatch)

GENK'S ONGOING TRANSITION

Genk has successfully shifted from a mining to manufacturing and knowledge economy, and is, together with the surrounding region, an example of redevelopment of industrial and mining infrastructure. Instead of demolishing existing mining facilities, Thor Central and C-Mine are great examples of creating unique landmarks that respect heritage as an important part of regional history, while transforming heritage spaces into modern workplaces.

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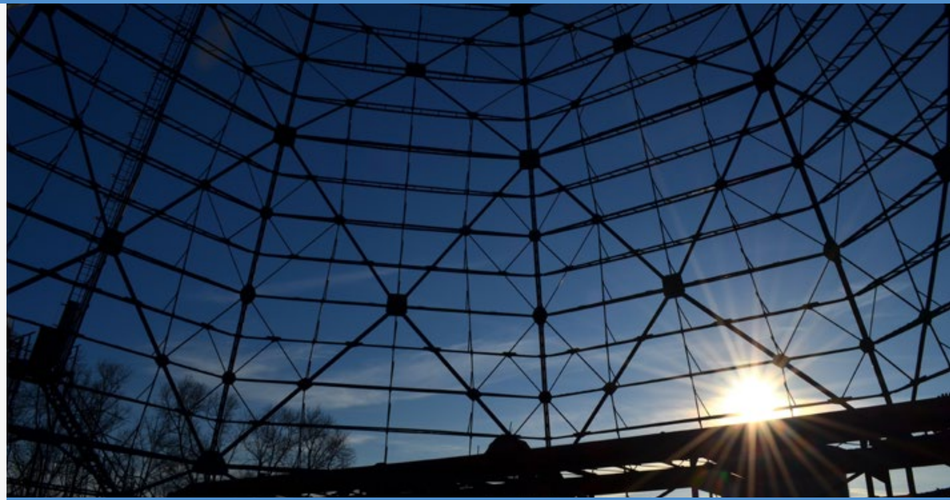
European Commission

Decarbonising energy-intensive industries

Decarbonising energy-intensive industries



A paradigm shift

For a long time, the debates about climate neutrality focused primarily on the energy sector. The industry sector was left out, as its emissions were considered too hard to abate. Yet, the industry sector is responsible for 25% of Europe's greenhouse gas emissions.

With the European Green Deal, there is a broad consensus that industry must be climate-neutral by 2050 at the latest. The question is no longer *if*, but *how*.

COMPANIES' ROADMAPS TO CLIMATE NEUTRALITY

Various companies in energy-intensive industries have already developed their own roadmaps to climate neutrality.

The Swedish steel company SSAB strives to become fossil-free by 2045 by replacing its coal-based steel production with hydrogen-based steel production.

Read more

The German steel company Salzgitter aims at reducing its CO_2 emissions by 95% by 2050, also through hydrogen-based steel production.

Read more

However, the transition will not be manageable by the private sector alone, but will need both support from and collaboration with public authorities.

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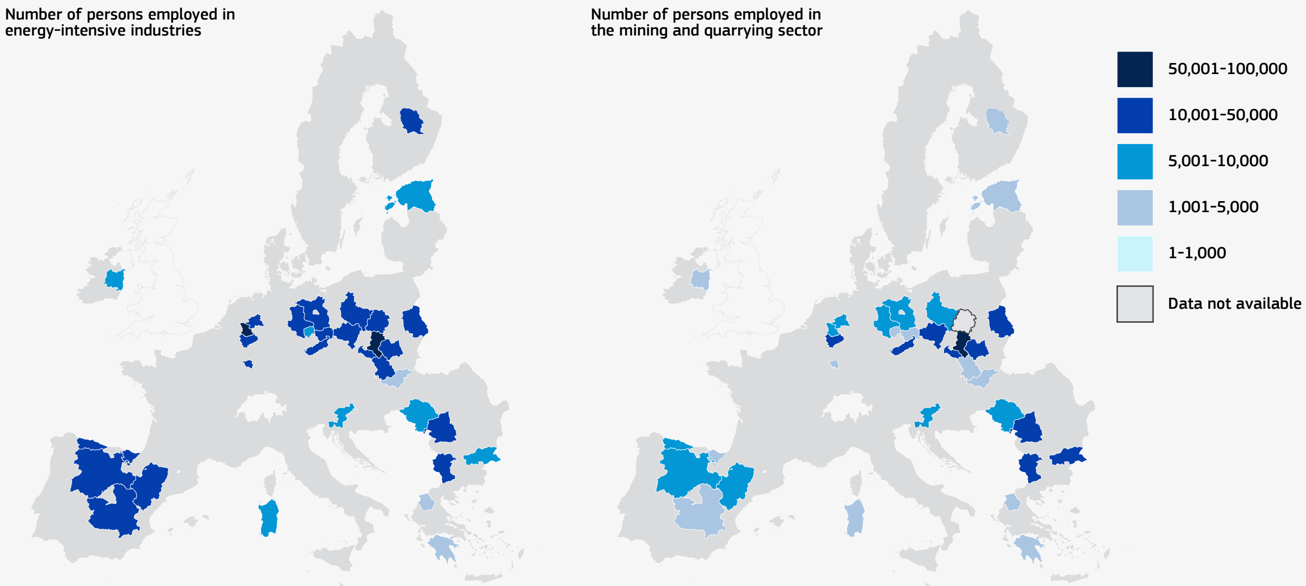
Decarbonising energy-intensive industries

Relevance of energy-intensive industries for coal regions

Many coal regions have a high share of energy-intensive industry, such as steel, cement and chemicals. Often, jobs in energy-intensive industries outnumber jobs in coal-mining.

These regions are facing a double transformation: the phase-out of coal and the transition to a climate-neutral industrial base. Managing these transformations successfully and timely is key to keep jobs and wealth creation in the regions.



JOBS IN COAL MINING AND IN ENERGY-INTENSIVE INDUSTRY

The map shows the number and regional distribution of jobs in coal mining compared to the jobs in energy-intensive industries per NUTS2 region. Indicators for energy-intensive industry: manufacturing of basic metals, other non-metallic mineral products, chemicals and chemical products, paper and paper products.

Source: Eurostat

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Decarbonising energy-intensive industries

Challenges

Long investment cycles in many energy-intensive industries (30-50 years or more): investments should be in line with a climate mitigation plan, which allows zero emissions by mid-century following the EU's 2050 target.

The need for new technologies and production processes: climate-neutral production of steel, cement and chemicals cannot be achieved with conventional production techniques.

Immaturity of zero-carbon technologies and high potential costs: zero-carbon technologies for the primary production of steel, cement and chemicals are still in the development phase and unlikely to be economically competitive once they do become available.

Opportunities

The need to decarbonise energy-intensive industries can spark innovation and bring significant investments into regions. Companies can improve their competitiveness by offering innovative products like green steel and green cement. It is also a way to keep industrial jobs in Europe, in the regions.

'The steel sector is currently the largest industrial consumer of coal'

IEA technology perspectives, 2020

-

Among the energy-intensive industries, the steel industry is most closely linked to the coal industry and responsible for 4% of the EU's overall CO_2 emissions.

Therefore, this toolkit takes a closer look at the steel sector and its technology options for a transition to climate-neutrality.

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European Commission

Decarbonising energy-intensive industries

Steel production: technology options for decarbonisation

Decarbonising primary steel-making processes requires the development of new technologies, massive investments in new production facilities and, depending on the technology, large amounts of (clean) hydrogen as a feedstock.

Research is currently focusing on three technology options for the production of CO_2 -free or low-CO_2 steel:

- direct reduction with hydrogen and smelting in the electric arc furnace (H-DRI);
- alcaline iron electrolysis (Electrowinning);
- CO_2 capture and utilisation (CCU) of waste gases from integrated blast furnaces.

Key indicators

Three key indicators are crucial to assess the potential of different technology options for a green steel production:

CO_2 reduction potential

How big is the CO_2 reduction compared to today's technology standard (conventional blast furnace route)?

Expected technical maturity

When is the technology expected to be ready for commercial use?

CO_2 abatement costs

At what CO_2-price is the technology cost-competitive compared to conventional steel production?

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Decarbonising energy-intensive industries

Technology options to decarbonise steel production

	Direct reduction with hydrogen and smelting in an electric arc furnace (H-DRI)	Alcaline iron electrolysis (Electrowinning)	CO_2 capture and utilisation (CCU) of waste gases from integrated blast furnaces
CO_2 reduction potential	-97%	-87%	-50 to -65%
Expected technical maturity	2025-2030	Only after 2050	2025-2030
CO_2 abatement costs	2030: 100-165 €/t CO_2 2050: 85-140 €/t CO_2	2050: 170 to 290 €/t CO_2	2030: 230-440 €/t CO_2 2050: 180-380 €/t CO_2
KEY FEATURES	It requires hydrogen.	Requires only renewable electricity and is more energy-efficient than the other options.	Still requires coking coal and does not avoid the generation of CO_2, but only its direct emission into the air.

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Decarbonising energy-intensive industries

Direct reduction with hydrogen and smelting in the electric arc furnace (H-DRI)

Potentials:

- highest CO_2 reduction potential;
- likely to be ready for application in 2025-2030;
- lower production costs than other green steel technologies.

Challenges:

- it requires the development of large-scale hydrogen production and large amounts of renewable electricity to produce CO_2-free hydrogen.

Take-away

H-DRI seems to be a very promising technology for climate-neutral steel production.

Photo by Luleå University of Technology

HYBRIT-PROJECT IN LULEA, SWEDEN

The HYBRIT initiative of the Swedish companies SSAB, LKAB and Vattenfall, investigates how to replace coal with hydrogen in the steel-making process and aims at achieving a fossil-free steel value chain in 2026. After a pilot plant in Lulea (Northeast Sweden) was successfully put into operation in 2020, a demonstration plant shall be constructed by 2025.

Read more

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Decarbonising energy-intensive industries

Alcaline iron electrolysis (Electrowinning)

Potentials:

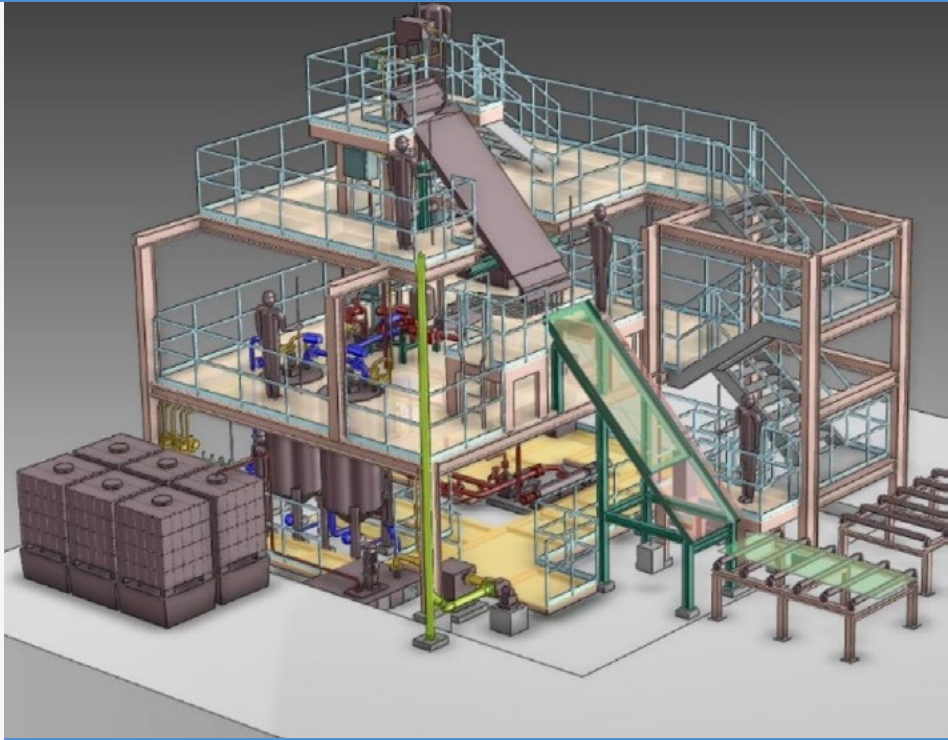
- high CO_2 reduction potential;
- it requires solely renewable electricity;
- it is the most energy-efficient technology for climate-neutral steel production.

Challenges:

- it is at a very early stage of development.

Take-away

Electrowinning is expected to be ready for application too late for the transformation of most of the European steel industry. However, due to its comparatively low energy demand, it is worth keeping an eye on it.



SIDERWIN IN MAIZIÈRES-LÈS-METZ, FRANCE

In Europe, a consortium led by ArcelorMittal is currently constructing a pilot plant in France (Maizières-les-Metz) in order to further investigate Electrowinning technology.

Read more

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Decarbonising energy-intensive industries

CO_2 capture and utilisation (CCU) of waste gases from integrated blast furnaces

Potentials:

- it can be retrofitted to existing blast furnaces;
- it is likely to be ready for application in 2025-2030.

Challenges:

- low CO_2 reduction potential;
- comparably energy-intensive;
- comparably expensive.

Take-away

CCU can, at most, be a bridging technology for short-term CO_2 reduction of existing conventional blast furnaces. However, the risk of stranded assets is very high.

© thyssenkrupp Steel Europe AG

CARBON2CHEM® IN DUISBURG, GERMANY

The Carbon2Chem® project, led by the steel company ThyssenKrupp together with companies from the chemical industry, explores how waste gases from conventional steel production can be captured and made usable for the chemical industry. After the successful operation of a pilot plant in Duisburg, the processes are currently being scaled up for industrialisation.

Read more

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H_2 Hydrogen

H_2 Hydrogen

Main future applications

Hydrogen will play an important role in the future energy system; but, due to high production costs, its use is limited to applications for which direct electrification is not a viable option.

Main future applications for hydrogen will be:

- feedstock in the refining and chemical production industries;
- sustainable energy supply for energy-intensive industries;
- transport technologies (especially heavy-duty transport);
- renewable integration in the electricity system.

Photo by audioundwerbung

HYDROGEN IS NOT A FUEL, BUT AN ENERGY CARRIER

Hydrogen is often called a fuel and, from and end-user's view, it will be consumed as such. But, unlike natural gas or oil, hydrogen needs to be produced. It is therefore more so a means to store, transport and redistribute energy. Today, the largest share of hydrogen is used in the chemical industry (as a feedstock, more than an energy carrier). It is mainly produced using fossil energy from coal and gas. In the future, the production of hydrogen will need to be low-carbon and, eventually, zero-carbon. Consequently, the EU's hydrogen strategy focuses on clean hydrogen, which is to be produced with renewable energy, mainly wind and solar.

Read more

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H_2 Hydrogen

The EU hydrogen strategy

A roadmap to 2050

The EU hydrogen strategy stresses the urgency to scale up hydrogen production and application.

2024

- 6 GW of renewable hydrogen electrolysers
- Replace existing hydrogen production
- Regulation for liquid hydrogen markets
- Start planning of hydrogen infrastructure

2030

- 40 GW of renewable hydrogen electrolysers
- New applications in steel and transport
- Hydrogen for electricity balancing purposes
- Creation of “Hydrogen Valleys”
- Cross-border logistical infrastructure

2050

- Scale-up to all hard-to-decarbonise sectors
- Expansion of hydrogen-derived synthetic fuels
- EU-wide infrastructure network
- An open international market with € as benchmark

HYDROGEN ROADMAP EUROPE

For many applications, hydrogen technologies already exist today. However, they are often not yet competitive or their use is restricted to niches. The Hydrogen Roadmap Europe gives an overview of the status quo and potentials of hydrogen technologies across different scenarios of transitions to a low-carbon energy system.

Read more

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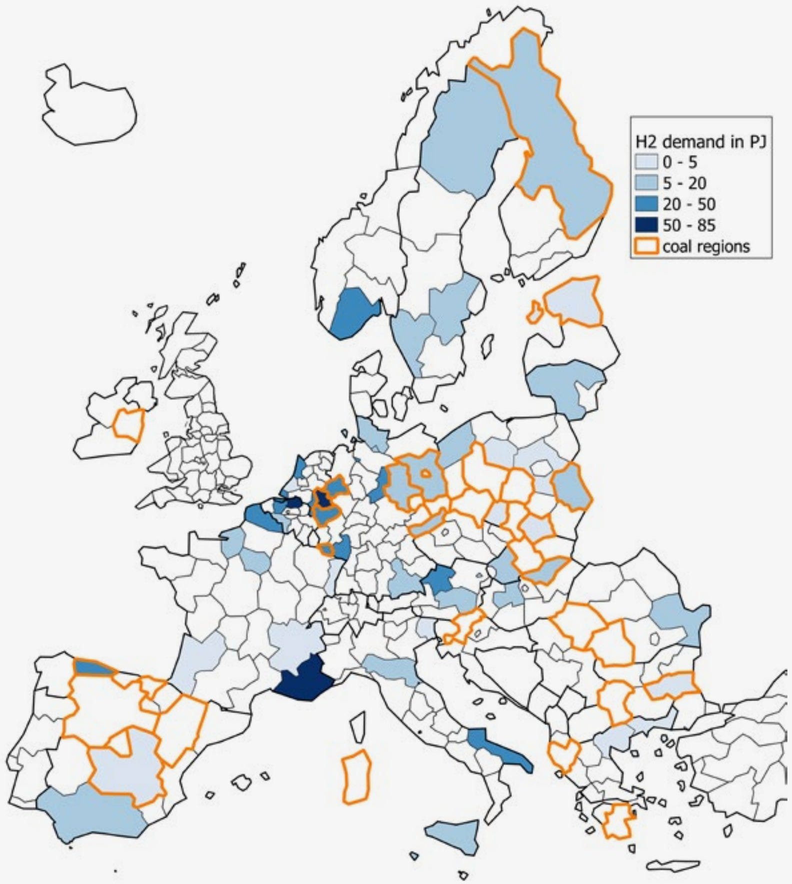
H_2 Hydrogen

Future hydrogen demand will vary widely in different coal regions

Demand hot-spots will be:

- urban areas;
- regions with energy-intensive industry.



HYDROGEN DEMAND FOR DECARBONISED STEEL, CEMENT AND CHEMICAL INDUSTRY IN 2050

The map shows regional distribution of additional industrial hydrogen demand in 2050 (blue colour shading). Orange boundaries indicate NUTS2 regions with coal mining, peat and oil-shale production.

Source: Wuppertal Institute

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H_2 Hydrogen

Providing green hydrogen can be a business opportunity for some regions

The transition to a climate-neutral hydrogen economy will bring **massive investment needs.**

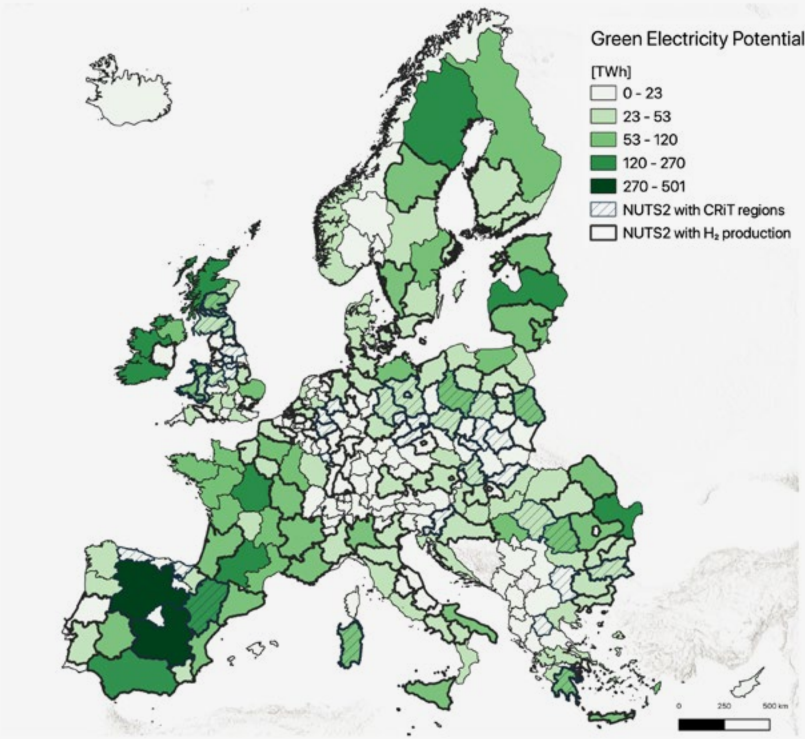
Regions with high renewable potential can become providers of green hydrogen.

Hydrogen: an investment agenda

The **EU hydrogen strategy** estimates that:

> *'from now to 2030, investments in electrolysers could range between EUR 24-42 billion. (...) In addition, investments of EUR 65 billion will be needed for hydrogen transport, distribution and storage, and hydrogen refuelling stations.'*

A larger amount of money will need to be invested into the energy supply infrastructure to produce the required amounts of hydrogen. Until 2030, *'EUR 220-340 billion would be required to scale up and directly connect 80-120 GW of solar and wind energy production capacity to the electrolysers to provide the necessary electricity.'*



POTENTIAL FOR GREEN ELECTRICITY IN THE EU

The map shows the technical potential for green electricity per NUTS 2 region. Coal regions (hatched) and regions in which hydrogen is currently produced (bold boundaries) are shown.

Source: JRC 2020

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H_2 Hydrogen

Developing a regional hydrogen strategy

High investment costs and long lead times require regions to rapidly develop their own hydrogen strategies.

Key questions are:

- what will be the hydrogen demand in your region?
- what is the potential to produce clean hydrogen in your region?
- what can future hydrogen infrastructure look like?

REGIONAL HYDROGEN STRATEGY IN NORTHERN NETHERLANDS

The Province of Groningen in Northern Netherlands has developed a regional hydrogen strategy that clearly looks at the necessary investments into a future hydrogen economy, and determines that it holds great economic and job potential for the region. The strategy assesses both regional hydrogen demand and renewable energy supply options and integrates them into a consistent picture of energy import and hydrogen export with neighbouring regions and countries.

➲ Presentation at the Coal Regions Virtual week (November 2020)

➲ The Northern Netherlands Hydrogen Investment plan 2020 (PDF)

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Options for non-energy uses of coal

Options for non-energy uses of coal

Future prospects of coal products

There is a diverse field of research and projects regarding the use of coal as feedstock for new technologies, such as:

- carbon fibres;
- carbon electrodes;
- nanomaterials;
- and the application of coal as a fertilizer for agriculture.

However, most technology options for non-energy uses of coal today are not considered to be market-ready, scalable and/or future-proof due to high-emissions production routes. Therefore, these technologies are not a viable option for coal regions.

IEA REPORT NON-ENERGY USES OF COAL (2018)

A number of new carbon-based industries and technologies are emerging in fields like energy storage, aerospace and in areas that use composite materials to take advantage of the properties of carbon. The declining use of coal power generation in Western economies may release this resource for other purposes. The topics covered by this report include: rare earth element extraction from coal, activated carbon products, carbon electrodes, carbon fibre and composite production; carbon nanotubes and graphene; and the production of humates agrichemicals from lignite.

Read more

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Accompanying notes

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Introduction

Why do we need this guidance?

The energy transition towards a climate-neutral economy implies a fundamental shift in technologies (from fossil to clean energy) and requires large and long-term investments.

Making use of existing infrastructure and sustaining existing value chains in the coal and coal-related sectors will be key to making this transition more cost-efficient and to keep jobs and wealth creation in the regions.

With long investment cycles in the energy sector, it is clear that investments today need to be in line with the long-term goal of a climate-neutral economy. Generally, investment decisions are made by private companies (e.g. energy utilities and companies in energy-intensive industries). However, the specific conditions of a region (e.g. infrastructure, skilled workforce, potential partners along the value chain) will be decisive for the competitiveness of a site over global alternatives. So, a key question for regional decision-makers is: under which conditions are companies willing to further invest in a specific site? Many of these conditions are beyond what individual private investors can influence directly. Building future-proof infrastructure (e.g. for electricity and hydrogen), establishing new research facilities and improving the innovation system of a region – all this requires collective effort from the public and private sectors, companies, administrations, research and educational institutions.

To facilitate this collective effort, it is necessary that all stakeholders in a region have some basic knowledge of key technology options which exist and are in line with the requirements of the transition to a climate-neutral economy. Against this background, this toolkit gives a brief overview of key technology options with high relevance for coal regions; specifically, it explores low-carbon options for infrastructure linked to coal-fired power plants, for energy-intensive industry and for hydrogen.

This toolkit takes a technological perspective: which technology options exist and which technological developments are likely in the future? The information gathered in this toolkit provides decision-makers in coal regions with a general overview of the current state of knowledge regarding the available technologies, enabling them to explore new business models, which make use of the existing coal related infrastructure in their regions.

This toolkit complements the existing toolkits for coal regions in transition. Questions about the re-use of existing energy infrastructure (e.g. coal-fired power plants) and the transformation of regional energy-intensive industries should be embedded in the overall strategy development of the region (see Strategy Toolkit) and serve to make the regional economy viable for the future while retaining jobs in the region (see Sustainable Employment Toolkit). Aspects of mine rehabilitation and repurposing of other coal related infrastructure is addressed in the Rehabilitation and Repurposing Toolkit.

IN4CLIMATE.NRW

In North Rhine-Westphalia (NRW), Germany's industrial heartland, the state government has launched the initiative 'IN4climate.NRW' to shape and accelerate the transformation of NRW's industry to a climate-neutral industrial base. The initiative is driven by a joint effort of politics, companies and research institutes. It is important to note that the transition towards a low-carbon economy is not only perceived as a challenge, but rather as an opportunity to bring innovation and investments to a region, which in the past used to be the biggest coal mining region in Europe.

We will demonstrate that successful climate protection and a strong economy are not mutually exclusive, but rather the foundations and drivers of prosperity and quality of life in our state.

Andreas Pinkwart

Minister of Economic Affairs, Innovation, Digitalisation and Energy of the State of North Rhine-Westphalia, Germany

Around 30 companies and associations from the fields of steel and metals, chemicals, cement, glass, paper and building materials are participating in the initiative alongside six research institutes and the NRW state government. The platform is structured in so-called innovation teams that span the topics of circular economy, hydrogen, political conditions, narratives and heat.

As a platform for knowledge-sharing, dialogue and collaboration between representatives from industry, science and politics, the initiative offers a space in which to develop innovative strategies for a climate-neutral industrial sector, including new production processes and methods, suitable infrastructure, and appropriate political conditions. IN4climate.NRW is accompanied by the scientific competence centre SCI4climate.NRW, which comprises prominent research institutes in the state, provides scientific support, and investigates options for the development and organisation of a climate-neutral and future-proof primary sector. At present, IN4climate is considering how civil society can be involved in the initiative.

Read more

List of innovative projects

Aims and scope

This toolkit explicitly addresses the following themes.

- What are viable alternatives for **coal-fired power plants and coal-related infrastructure** with regard to decarbonisation pathways and regional economic development? Technology examples and their assessment (e.g. thermal storage units in power plants) are underpinned with existing pilot projects.
- For many coal regions the coal-using **energy-intensive industry** sector of steel plays an important role. This sector is not equally relevant to all coal (mining) regions, but for some the jobs in energy-intensive industry outnumber the jobs in coal mining and power plants by far, and therefore play a crucial role in transition. The toolkit summarises key technology roadmaps for the decarbonisation of the steel industry, which can serve as a basis for decision-makers when tasked with crafting a regional development strategy.
- **Hydrogen** could play an important role in the future energy system and coal regions are both potential hotspots for future hydrogen use and / or potential providers of hydrogen. However, the role for hydrogen in specific regions may vary strongly. There is a need for regional (tailor-made) hydrogen strategies, which align across regions into appropriate national and EU-wide approaches. In consequence, the toolkit stresses the necessity for integrated planning with respect to hydrogen, highlighting some key techno-geographical interdependencies with respect to hydrogen infrastructure and showcasing first examples of hydrogen production and use as future business models for coal related infrastructure.
- The potential of a **non-energetic use of coal** as a resource are explored. In many cases, this potential is too small to economically justify the continuation of coal mining, but there are a few options for non-energetic uses, like the application of carbon as fertilizers, for carbon fibre production, or for nanotechnologies that may become a viable alternative beyond economic niches.

Re-use of coal power plants

Introduction

Without a doubt, coal plant sites, including their connections to power grids, water, and transportation, as well as the associated skilled workforce, have significant value for their regions. Their connected value chains must be taken into account. With falling electricity prices of renewable competitors and pressure on national governments to fulfil their climate obligations to decarbonise the economy, maintaining the status quo in coal regions is being increasingly challenged. Next to the option to demolish the power plant and possibly reuse the built-in materials (e.g. steel), the conversion of coal plant sites can be a valuable option, which reduces decommissioning costs, while also reducing the cost of new site uses. In addition to being economically beneficial, the conversion of coal plants can also play an important role for a region's overall transition efforts and preserve its historic identity as an energy region.

While the toolkit on 'Environmental Rehabilitation and Repurposing' looks into questions of governance, institutions and tools to support regional decision-makers in the process of repurposing coal related infrastructure, this toolkit focuses on technical options to (re-)use the infrastructure and sites of coal-fired power plants.

It includes options to convert power stations to alternative energy facilities such as energy storage, renewable energy hubs, gas and biomass plants, and provides examples and ideas for non-energy-related options. If a region decides to keep the site for energy purposes, a combination of different technologies will be most suitable in most cases, as co-production approaches show the highest efficiency rates. For gas and biomass, special attention needs to be given to limiting factors related to carbon neutrality goals and long-term applicability.

Generally speaking, as every region is different with regards to existing infrastructure, economic specialisation, geology, workforce and political contexts, each coal region faces different challenges. Therefore, the arguments for or against a certain option for after-use of coal-fired power plants and their related infrastructure must be carefully considered and fit into an overall transition strategy for the region. This process must take into account existing political strategies such as the EU Green Deal, by, for example, following the EU's smart specialisation approach. Furthermore, there will be site-specific challenges for every re-purposing project to be taken into account, such as more limited options for plants in rural areas or complicated and cost-intensive renaturation of ponds of coal ash.

Energy storage

Technology overview

The increasingly complex framework conditions of power generation paired with the classic challenges associated with network expansion call for the integration of new types of power generation facilities to serve as back-up supply when solar and wind provide less power. Storage solutions are recognised as a key enabling technology for this purpose. Most studies expect a significant increase in the demand for electricity storage between 2030 and 2040. Accordingly, the demand for energy storage is expected to grow very rapidly in the coming years.

A large number of energy storage technologies are already available today, ranging from thermal storage, and pumped hydro storage (which is mostly an option for coal mines), to various electrochemical battery-based storage solutions. They differ fundamentally in terms of their operating principles and associated capacities (storage volume) and performance (input/output capacity). The competitiveness of electrochemical battery-based storage has increased significantly over the past few years and it is already competitive in some markets. However, some estimates indicate that even in the case of further significant cost reductions, batteries may

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still struggle to achieve high market share as long as carbon prices stay low. Long-term and seasonal storage volumes in particular tend to be more expensive, while storage suitable for short-term balancing will be more competitive.

Thermal energy storage theoretically has many advantages over electrochemical battery-based storage systems, including generally lower costs (both on an upfront and total cost of ownership basis), longer system life expectancy, non-toxic designs and materials, and ease of recycling at the end of a project's life. However, the abilities of lithium-ion battery systems to provide both peak demand reduction and backup power with a more compact physical footprint also make them a viable option.

Generally, the integration of energy storage systems within existing power plants will take advantage of several benefits: it uses the existing infrastructure and keeps the site as a place for power production. This might also increase public acceptance and may even provide job opportunities for former workers at these sites. In any case, a careful assessment of the different technological options needs to be considered, including approaches to combine several technical and non-technical options.

Thermal energy storage

Thermal energy storage (TES) will be a key component of future energy systems. This is not only due to the fact that there is a need to help balance energy demand, but also that half of the total final energy consumption worldwide can be attributed to heat. New technologies with higher efficiencies are expected to become market ready by 2025 to 2030.

KEY CHARACTERISTICS OF ENERGY STORAGE TECHNOLOGIES

	Max Power Rating (MW)	Discharge time	Lifetime	Efficiency	Development stage
Thermal storage	50-400 (molten salt)	1-24 h	Approx. 30 years	40-80% (molten salt)	Market ready
	up to 1 000 (carnot battery)			80-90% (carnot battery)	Pilot stage
Pumped hydro storage	Up to 3 000	4h - seasonal	30-60 years	70-85%	Market ready
Li-Ion battery	Up to 1 000	1min to 8 h	10-20 years (1 000 -10 000 cycles)	65-95%	Market ready

Retrofitting coal-fired power plants into such thermal energy storages can be considered as a viable option for future use of coal sites, as such a transformation largely benefits from reduced costs for infrastructure. Only the boiler, coal- and flue-gas cleaning and handling- systems needs to be discarded. Other components, such as steam turbines, generators, condensing heat exchangers and water treatment equipment plants, as well as high value components for switching, transforming and transmitting high voltage power can be re-used in their original forms and positions (Figure 1). The costs of such transformation can be estimated around USD 23-27/MWht, which also covers the instalment of heaters, storage and steam generators.

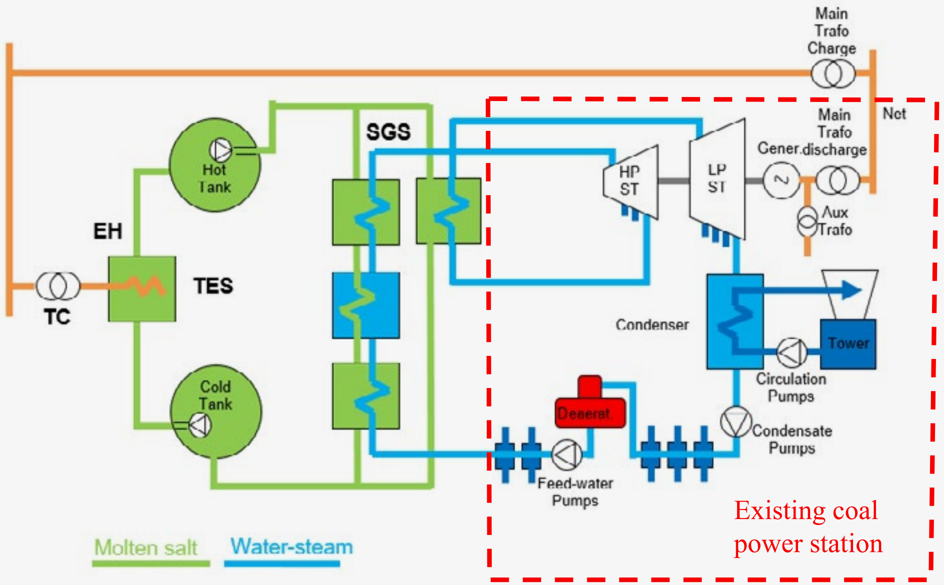

FIGURE 1: INTEGRATION OF MOLTEN SALT ENERGY STORAGE IN EXISTING COAL POWER PLANTS – SCHEMATIC FIGURE
Source: DLK

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There are currently a range of different materials used for such thermal storage facilities, ranging from (molten) salts, to water, silicon, volcanic stones, compressed air or miscibility gap alloys. Some of these options are already in use, e.g. molten salt energy high temperature storages based on nitrate salts have been used commercially in solar thermal power plants (CSP) for several years, with efficiency rates of 40-80%. Other options are still in the development stage. Based on current knowledge, capacities up to 1 GWh can be realised.

Examples

Energy storage plant conversion based on molten salts, Spain

In Asturias, northern Spain, the coal-fired power station 'Aboño I' with a capacity of 342 MW is planned to close in 2021. EDP – the company that owns the power station – is therefore evaluating the potential to replace the facility with an energy storage system consisting of molten salt electrical heaters, that allows electric charge and discharge from the power network. A first evaluation showed that the potential conversion could include a 358 MW storage facility with a discharge time of 2 hours. Total estimated costs of the project are EUR 201 million, with foreseeable job options for 300 workers during construction and 50 workers after completion.

Read more

New technology developments

Carnot batteries are an emerging technology for comparably inexpensive and site-independent storage of electric energy with high capacities up to 1 000 MWh. A Carnot Battery also uses molten salt or water as media for storage, and transforms electricity into thermal energy and back to electricity as required. Compared to other thermal storage technologies such as pressurised water tanks, the Carnot Battery is able to achieve higher storage efficiencies (from electricity to electricity) with fewer energy losses. First prototypes of this technology are currently being tested by several institutions, e.g. at energy start-up MALTA and at the German Aerospace Centre (DLR), with aims to start pilots at thermal power plants.

Read more

Miscibility Gap Alloys (MGA) is a new material used for thermal heating that works with phase change storing, which provides additional storage for sensible heat and can work up to very high temperatures of over 1 400 ºC. Research shows that the technology can be cost-competitive with other thermal storage methods. Its modular scalability also offers opportunities for a gradual transition away from coal-fired power plants, an approach that is currently under development, with a first pilot to be set up in 2021-2022.

Read more

Pumped hydro energy storage

By pumping water vertically into a storage pond for later use, pumped hydro energy storage is a method of converting excess electrical energy into stored energy. From an energy management point of view, these rank among the peak load power plants and, due to their high capacities (up to 3 GW) among the largest storage options. In general, overall efficiencies of 70-85% can be assumed for pumped storage power plants. In contrast to other forms of storage, either very short or very long storage periods have no influence on the efficiency of the overall system.

The application of pumped hydro energy storage is limited by the demand for suitable geographic locations with a height difference, enough space for the reservoirs, a waterway and supply centres. In many coal regions, natural geographic characteristics will prevent the standard application of pumped hydro energy storage. Especially the sites of coal power plants will most likely not have the desired characteristics. However, it is worth noting that depending on the vertical scale of prior mining activities, both abandoned open-pit and underground coal mines may be suitable locations for an unconventional hydro power application. The unconventional use of pumped storage in abandoned underground mines is currently being explored in Poland, Belgium and Germany , assessing geological and geographical conditions, technical and engineering complexity, and feasibility of construction and operation. Open pit mines are technically easier to handle, yet have comparably lower capacities. The first application of pumped hydro storage in open-pit mines is currently under construction in an old gold mine in Australia (see example below).

Examples

Underground-pumped storage hydro power plants project, Poland

In 2017, the closure of the Silesian Krupinski underground coal mine initiated a discussion about potential use of the site and its assets for future development. As one prominent alternative, the mines could be used for an 2 underground pumped hydro storage. A first

FIGURE 2: COAL-TO-STORAGE CONVERSION IN COMBINATION WITH WIND AND SOLAR – ILLUSTRATION

Source: DLR

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assessment revealed possibilities for the installation of a power generation potential of 93 MW with estimated investment costs of EUR 174 million.

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The pumped storage hydro project in Kidson, Australia

To be finalised in 2022, the AUD 700 million K2-Hydro Project will utilise two existing mining pits of an abandoned gold mine as the upper and lower reservoirs for a pumped hydro energy storage facility that will have a capacity of 250 MW and can provide up to 2 000 MWh in eight hours. The project is forecast to contribute AUD 353 million in net public benefit and will provide 510 jobs during construction and 20 operational jobs.

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Chemical battery storage systems

The greatest prospect for electrochemical storage is the stabilisation of frequency and voltage within hourly and daily fluctuations. So far, the most readily available technology is lithium-ion batteries, which have long been used in laptops and mobile phones; sodium sulfur batteries are also increasingly becoming an alternative for station-based application due to their slightly lower material costs and longer service life. Both methods have high energy densities and power-to-energy ratios. This makes them particularly suitable for short-term storage over minutes or hours. Large battery storage systems can already be set up relatively cost-effectively today and quickly. The market prices are below EUR 1 million per MW of installed capacity with a storage capacity in the range of MWh. It needs to be taken into account that electrochemical energy storage systems have typical operation time spans between 10 and 20 years due to limited cycle stability and durability. As lithium-ion batteries are also used for electric cars and other mobility solutions, demand for lithium and therefore prices may increase in the future. However, as technology development on chemical batteries, including other types such as solid-state batteries, has been expanded over the last years, it can be expected that more applicable solutions will be available in coming years.

Examples

LEAG BigBattery project at coal-fired power plant 'Schwarze Pumpe', Germany

Finished in August 2020, the energy company LEAG installed a 53 MWh capacity lithium-ion battery storage system on-site of their still running lignite power plant Schwarze Pumpe. LEAG is investing EUR 25 million in the lithium-ion storage facility comprising 13 containers full of battery racks. The German state of Brandenburg takes EUR 4 million of total investments. The main use of the facility will be to provide primary load balancing electricity to stabilise the grid.

Read more

Conversion to (fossil) natural gas

As carbon prices increase in the EU Emission Trading System, coal-fired power plants face increasingly strong economic pressure. As a result, the conversion to natural gas is being considered by some actors for power plant redevelopment projects and has been implemented already at 67 former power plant locations in the EU (GEM 2020).

Retrofitting existing sites of coal-fired power plants to use natural gas has the advantage that gas fired power plants are technically better suited to provide flexible supply than coal-fired alternatives (similar to the above-described energy storage solutions), which will be needed and valued in systems with high shares of wind and solar energy. Furthermore, gas power plants can continue to supply heat in case of combined heat and power (CHP) plants and benefit from using existing infrastructure and technical installations. The modifications and replacements required depend greatly on the age of the equipment, access to gas infrastructure and regulations to follow. The majority of already completed coal-to-gas conversions tend to be replacements rather than retrofittings.

The primarily reasons for a conversion to natural gas are the aforementioned advantages of the technical flexibility and cost reductions conferred by using existing infrastructure. Another argument that is often raised is that gas combustion produces almost 45% fewer CO_2 emissions than coal and emits less other pollutants, so that other EU emission standards (e.g. for mercury) are easier to fulfil with gas-fired power plants.

However, current research shows that the environmental benefits of gas for energy use are less clear than previously estimated (Figure 3). Taking into account new findings regarding methane emissions along the value chain and the fact that burning natural gas still produces emissions which need to be drastically reduced in the upcoming decade, the risk to produce lock-ins and stranded assets is high. Therefore, the conversion of coal-fired power plants to natural gas can only be a short-term option in the majority of cases.

Example: coal to combined cycle gas turbine power plant transformation project in Bouchain, France

In Bouchain, northern France, the energy company EDF transformed its coal-fired power plant that was shut down in 2015 into a combined cycle gas turbine (CCGT) with a capacity of 606 MW. The company invested a total of EUR 400 million into the converted power plant, which started running again in 2016.

Through modern CHP production, the plant reaches high efficiency rates of 62%. By comparison, efficiencies of coal-fired power plants range between 35-46%. Higher efficiency generally also means fewer CO_2 emissions; however, as stated above, the overall emissions also depend on the climate impacts of the whole production chain. The plant can work as a flexible counterpart in a system with renewables as it accelerates to top capacity in less than 25 minutes and can also be turned down to 30% without major emission drawbacks.

ENVIRONMENTAL IMPLICATIONS AND ECONOMIC RISKS REGARDING NATURAL GAS

CO_2 reduction potential and alignment with EU climate targets

In a climate-neutral energy system, there is only very limited space to use natural gas (if any). Consequently, achieving the EU's climate target of becoming climate-neutral by 2050 is only achievable with a massive reduction of natural gas within the next decades. The necessary pace of this reduction depends on assumptions related to, for example, emission from other sectors, the availability of cheap storage options which would make high shares of renewables cost-competitive in a nearer future, and the role of carbon capture and storage (CCS). Despite these insecurities stemming from those different assumptions, it is clear that the use of natural gas will need to be reduced drastically in the long-term.

Methane leakage

Methane, the primary component of natural gas, is a relatively potent greenhouse gas with a high global warming potential 87 times that of carbon dioxide (averaged over 20 years); even averaged over 100 years, the impact of methane is still 36 times that of CO_2. The overall emission assessment of using natural gas for energy production mainly relies on the prerequisite that this gas is indeed burned, and that only very little of the highly potent greenhouse gas methane gets lost over the whole product chain. An increasing share of climate research indicates that the methane impacts of fossil fuel extraction has been greatly underestimated by up to 40% (Hmiel et al. 2020), revealing more uncertainties regarding methane emissions. That means, potential climate benefits of natural gas use may be offset by leaks at gas drilling fields or other stages of natural gas production and transportation. Therefore, increased power generation from natural gas remains a risk as better understanding about actual impacts of methane leakages might question its greenhouse gas benefits over coal.

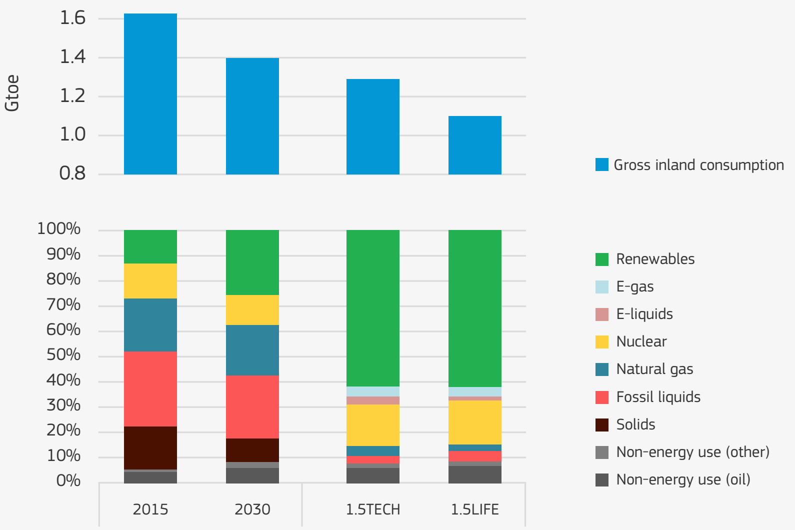

FIGURE 3: GROSS INLAND CONSUMPTION AND GROSS INLAND ENERGY CONSUMPTION IN 2015, 2030 AND 2050 IN THE EU

According to the EU scenarios aiming for carbon neutrality in 2050 (1.5TECH and 1.5LIFE), the share of natural gas (excluding non-energy uses) should decrease slowly from 21% in 2015 to 20% in 2030, and then decrease more sharply, reaching 3%-4% in 2050 scenario cases.

Source: European Commission

Risks for stranded assets and lock-ins

The life span of new gas-powered power plants is approximately 20 years, while large pipelines, terminals and infrastructure for Liquified Natural Gas (LNG) are designed to run for several decades. Consequently, there is an increasing number of studies that point out the risk that natural gas investments increasingly become stranded assets, given the long lifetime of gas infrastructure projects, and the need to phase-down natural gas use in order to meet climate targets. It needs to be carefully considered whether investments are still valuable, taking into account potential effects for long-term decarbonisation (lock-ins) and the future use of alternative gaseous fuels in the energy mix.

An option which could prolong the use of gas infrastructure is the use of climate-neutral gas from renewable sources like e-gas, biogas and hydrogen. However, it is doubtful whether this can be considered as a mid- to long-term alternative for gas power plants, as it will be relatively expensive to first produce carbon-free gas and then burn it. As projections show, the share of e-gas in the energy mix of 2050 will be significantly lower than the consumption today and in 2030 (Figure 3). For biogas, scalability is additionally limited due to feedstock. Therefore, biogas will be predominantly used for other sectors, such as industry, transportation, and buildings.

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Conversion to biomass

Using biomass in coal-fired power plants is a technologically fairly simple solution to reduce CO_2 emission and/or to continue to use power plant sites. One can distinguish four general approaches, which differ in terms of the degree of investments needed.

- Co-firing: a share of the coal used in the power plant is replaced by biomass. Depending on specific technology, investment needs are low, but percentages of biomass in the fuel mix are limited and efficiencies in older power plants cannot compete with the other options.
- Conversion: the coal-fired power plant switches to biomass use as (the predominant) fuel. Boilers and fuel handling technologies will need changes, leading to significant investment needs.
- Replacement: the coal-fired power plant is fully replaced by a new biomass plant, but existing infrastructure (electricity and possibly heat grids, buildings as well as fuel stock facilities) could still be used. This requires major investment, but provides greater options in the choice of technology and fuel.
- Relocation & Decentralisation: Instead of maintaining the site of the original coal-fired power plant, new locations for several smaller biomass CHP systems are set up in the same region, closer to heat consumers. This could increase overall energy efficiency.

Technologies to convert biomass into electricity are quite mature and readily available. However, their efficiency is generally lower compared to using coal, which makes larger volumes of fuel necessary. In contrast to gas power plants, most biomass power plants are not designed to provide peak power, but rather large capacities of baseload power (e.g. see example of Drax power station), which will require a large amount of feedstock. The first two of the general approaches previously described in particular will generally not provide more flexibility compared to existing coal-fired power plants.

There are currently 67 coal-to-biomass project proposals in the EU on the table, corresponding to 64 TWh of electricity, which accounts for roughly 2% of the EU's gross electricity production (Sandbag 2020).

Regardless of the current popularity of coal-to-biomass conversion, there is a critical debate about whether biomass should be considered as a renewable resource at all, and several sources point out that the amount of biomass needed for energy purposes is extremely high, and that sustainable, reliable and cost effective biomass sources are very limited (see '*Serious concerns to use biomass for energy production*' box).

In conclusion, it can be said that using biomass in coal-fired power plants requires less changes to the plant itself than the other mentioned options. However, as much as this may be inviting in individual cases, substituting coal with biomass in power generation is clearly not scalable to all coal regions and coal-fired power plants in the EU. Given concerns of environmental sustainability, it is advisable to carefully mirror the new policy framework towards bioenergy. Feedstock limitations call for strategies to secure reliable and efficient feedstock supply chains. All in all, biomass will not be able to become a long-term strategy for most coal regions.

Example: Biomass conversion at Drax Power Plant UK

As one of the largest power plants in Europe and the biggest plant in the UK, the 3.9 GW coal-firing Drax power plant was converted to co-fire with biomass (2.6 GW) from 2010 to 2014. The three-unit conversion cost over GBP 700 million including associated infrastructure like on-site wood storage and processing facilities, as well as pelleting and export facilities in the US. The power plant uses approx. two million tonnes of biomass annually, 83% of which is imported from the US and Canada. In 2021, the plant will fully stop using coal. Instead, the two remaining coal boilers will be replaced by combined cycle gas turbines (running with natural gas) and additional battery storage. In the long term, the company aims to add additional carbon capture storage applications; the first pilot started running in 2019.

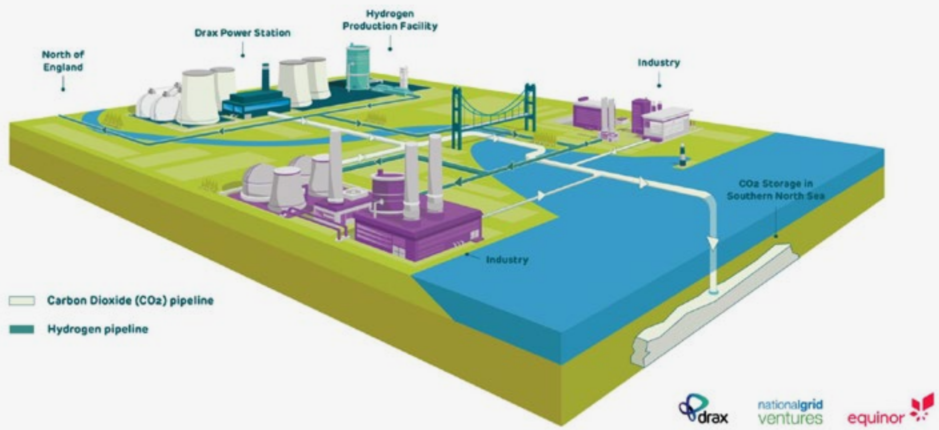

FIGURE 4: CREATING A ZERO-CARBON ENERGY CLUSTER AT FORMER DRAX POWER PLANT

Source: Drax

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SERIOUS CONCERNS TO USE BIOMASS FOR ENERGY PRODUCTION

Biomass materials are often described as 'climate-neutral,' as they set free the same amount of carbon when burned as they remove from the atmosphere while growing. In the case of using increasing shares of woody biomass, this has been questioned. Obviously, when wood is burnt the carbon contained in the wood gets emitted immediately. But it takes a long time for trees to regrow and extract that amount of CO_2 from the atmosphere again. It may thus take decades before net climate benefits are realized with a shift from burning coal to burning wood.

Furthermore, not only the direct source of wood that can cause negative environmental effects; the removal of residues (typically branches and tree tops left after felling, as well as stumps and roots) for bioenergy can have negative impacts on soil quality and biodiversity.

Assessing different management methods for woody biomass production, the JRC concludes in its report 'The use of woody biomass for energy production in the EU' (JRC 2021) that only one out of 24 studied biomass development pathways (burning of fine woody debris and slash) is actually carbon neutral or positive with respect to both emission reductions and biodiversity.

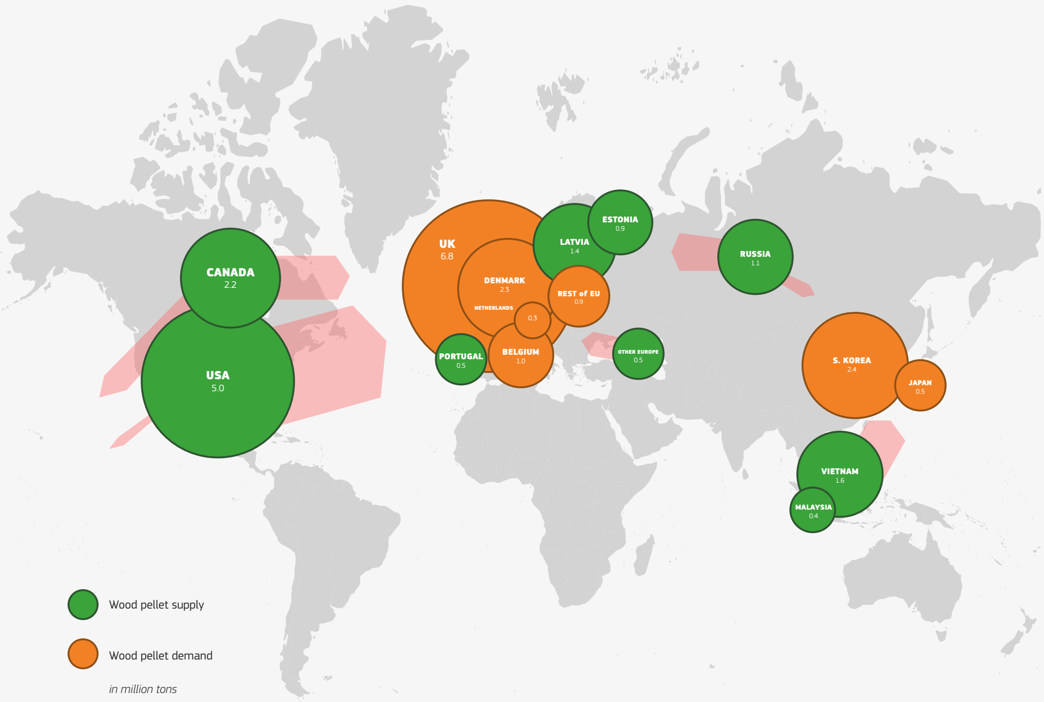

FIGURE 5: DEMAND AND SUPPLY OF INDUSTRIAL WOOD PELLETS (2017)

Source: Environmental Paper Network

Feedstock limitations

Biomass feedstock can come from very different sources (wood, agri- and forest residues, municipal solid waste, sewage sludge, food waste, industrial waste etc.). Depending on the source, concerns have been raised on their environmental sustainability, and on whether these materials should be used for energy at all, or if they are better used for other purposes such as food, timber or paper. This indicates that biomass is unlikely to be as easily available as it may appear.

This development is already quite visible for wood (pellets), which can directly replace coal for energy purposes and is today's most common source of biomass. Today, the majority of wood pellets used in the EU are imported (see graph above). Large import rates are a symptom of a much bigger issue: the amount of biomass needed for energy purposes is extremely high, and sustainable sources, that are reliable, local and cost-effective may be very limited (see *'Ireland's utility struggles to find sustainable biomass sources'* box). According to calculations from the JRC, coal regions' potential for biomass production ranges from 0.1 to 5GW for forest biomass, heavily depending on the region and scenario. Other materials like crop residues, livestock methane or municipal solid waste have significantly lower potentials, below 1GW.

For the above mentioned 67 coal-to-biomass project proposals, it has been calculated that their realisation would triple the amount of biomass burnt in current and former coal power plants in the EU. The amount of feedstock needed to fuel these power plants would be 36 million tonnes (MT) of wood pellets, which is the equivalent of the entire current global wood pellet production. To harvest this amount of wood it would be necessary to cut down approx. 2,700 km^2 of forests every year - more than the size of the state of Luxembourg (Sandbag 2020). The resulting increasing demand may result in higher feedstock prices and, in the mid-term, also increase deforestation (a trend that can be already seen today), which indicates additional carbon losses that would – as a result - require extra emission reductions in other sectors in order to reach climate neutrality by 2050.

Re-assessment of sustainability of energetic biomass use

Responding to the above mentioned and various other critiques towards the energetic use of biomass, the EU has started various processes to re-assess the sustainability of energetic biomass use (a good overview of the issues discussed is given in the 2015 briefing to the European Parliament on 'Biomass for electricity and heating'). In the EU strategy for a carbon neutral economy 'A clean Planet for all' it is stated that: 'Increasing biomass imports could also raise concerns indirectly related to emissions from land use change in exporting countries.' In the EU's biodiversity strategy it is outlined that: 'In line with the Renewable Energy Directive, the Commission will also develop operational guidance in 2021 on the new sustainability criteria on forest biomass for energy. It will also review in 2021 the data on biofuels with high indirect land-use change risk and establish a trajectory for their gradual phase out by 2030.'

The proposed reinforced EU sustainability criteria for biomass are extended to cover solid biomass and biogas used in large heat and power plants (above 20 MW fuel capacity), which should deliver at least 80% fewer GHG emission compared to fossil fuels by 2021 and 85% less by 2026. Large-scale new biomass electricity plants will need to use high efficient Combined Heat and Power (CHP) technology, reaching efficiencies above 80%.

IRELAND'S UTILITY STRUGGLES TO FIND SUSTAINABLE BIOMASS SOURCES

In County Offaly, Ireland, the local utility ESB had planned to switch one peat-fired power plant to using biomass. However, in 2019, the government refused to give permission to this conversion due to biodiversity and climate concerns. The lack of information provided by ESB on the potential sources of biomass was the major reason for that decision, as the company could not reasonably determine that the direct and indirect impacts on the environment would be sufficiently mitigated. The regional authorities stated that a foreseeable 'high dependence' on imported biomass would not be in line with both national and EU climate goals.

Bord na Móna, another Irish company running a co-fired biomass plant, had previously raised public concerns, as it mostly used palm kernel shells from environmentally questionable palm oil monocultures as the source for biomass. Since then, the company tried to switch to more sustainable sources, but acknowledges that reliable, local and cost-effective biomass supply at scale remains a 'significant challenge'.

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(Combined) renewable energy production

Wind, solar and geothermal renewable energy

As the chapters on thermal storage, natural gas and biomass show, there are several technology options available for using former coal-fired power plant sites as places for energy production. All options can benefit from the after-use of infrastructures for grid connections, regulation, and power conversion.

Generally speaking, this also applies to geothermal power plants, which use hydrothermal resources in the ground to power a turbine that generates electricity. Deep geothermal energy is a commercially proven renewable form of energy that can be used for base-load or flexible energy production, or a combination of heat and power generation. Its application is dependent on the geographical distribution of heat within the Earth's crust, which is highly variable and mostly found in areas with active tectonic plate boundaries or volcanoes. That means that this technology has limited potential in EU coal regions, ranging only between 0.04 and 0.5 GW.

The major renewable technologies are wind and solar power, which will be the backbone of the future electricity power system, according to the major climate-neutral energy scenarios. The most common solar power system is photovoltaic (PV), where PV cells convert solar radiation into electricity. The other is solar thermal, usually in the form of concentrated solar power (CSP), where radiation is used to produce heat.

Coal-fired power plant sites are, for the most part, just a few hectares, and both technologies benefit more from geographic location than from the power plant's technical equipment. However, they should still be considered as an option due to their huge development potential. The JRC calculates a technical potential of 5-80 GW for ground-mounted- and 1-5 GW for rooftop solar PV energy applications per coal region. For wind energy, the JRC calculates a technical potential of 10-225 GW for onshore wind in coal regions across Europe. The JRC report also stresses the high employment potential for a majority of coal regions when investing in renewable energy capacities. The deployment of renewable energy technologies in coal regions can create up to 315 000 jobs by 2030, and up to 460 000 by 2050. Another study found that an investment of USD 1 million in renewable energy creates, on average, 7.5 direct and indirect jobs, while the same amount in fossil fuel industries would create 2.7 jobs (Garrett-Peltier 2017).

Solar and wind renewables only have limited potential for the redevelopment of coal-fired power plant sites, but they have the potential to play a crucial role and therefore need to be taken into account.

Sector coupling and clean energy hubs

For the future development of coal-fired power plant sites, the first projects show that a combination of different technologies seems to be a promising approach. Storage technologies can be considered as a viable long-term option for coal plant conversions as they have fewer limitations regarding sustainability than gas and biomass. Also, they can make use of the existing grid and power conversion infrastructure and use turbines, generators, and cooling infrastructure. If geographic conditions allow, nearby areas can be also used for solar, wind and/or geothermal renewable energy production.

For thermal coal-fired power plants within existing heat networks (mostly the ones close to urban or industry centres), co-generation of electricity and heat should be considered as it allows to significantly increase efficiency and reduce overall costs and emissions. Primary options would be thermal storage, biomass, and gas, but also solar thermal and geothermal installations if geographic prerequisites are met.

From a long-term perspective, former coal-fired power plant sites might further develop to clean energy hubs as an element of sector coupling through links between the power sector and industry, transport, and heating and cooling (e.g. by using each other's by-products). A higher efficiency can be reached by following a cluster strategy that combines energy production with demand. This will be one of the key mid- to long-term challenges of energy system decarbonisation (see also next chapters on industry decarbonisation and hydrogen). Experts have to propose the most suitable future energy systems to be applied in the regions.

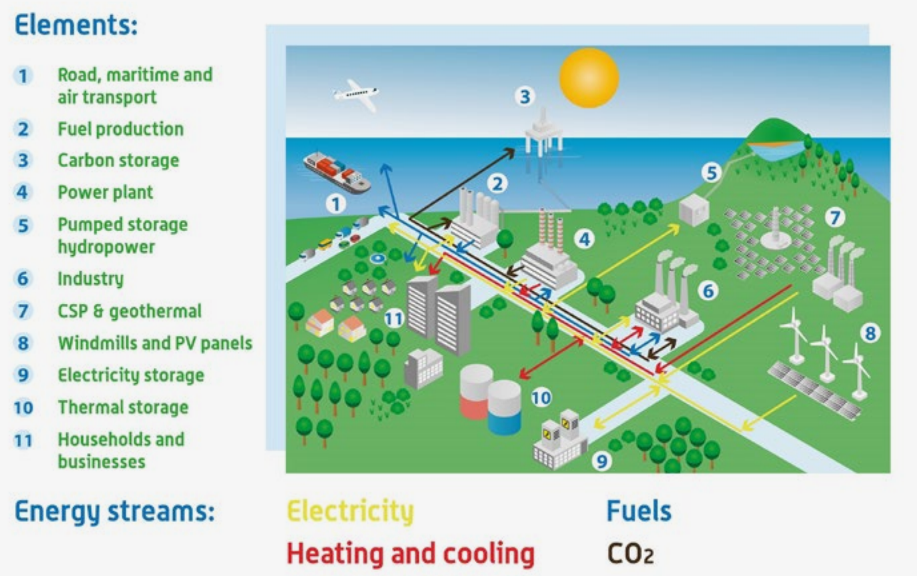

FIGURE 6: CLEAN ENERGY HUBS AS A CENTRAL ELEMENT OF MID- TO LONG-TERM ENERGY SYSTEMS

Source: energy technologies Europe

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Example: transforming the lignite-fired Matra Power Plant into part of a renewable energy cluster, Hungary

The Matra Power Plant in Hungary is an example of a coal power plant transitioning towards renewable energy production combined with the integration of an industry cluster. Today, the power plant uses biomass co-firing and a 36 MW PV facility, with plans to add another 20 MW of PV capacity in the near future. In addition to gradually diversifying its energy production portfolio, the Matra Power Plant developed an industrial park nearby that enables companies to use surplus heat and other by-products from the power plant, and offering companies the option to become providers for biomass feedstock. The cluster aims to further diversify its portfolio, particularly with a long-term perspective of reducing lignite power production capacity. Different options in line with a decarbonisation strategy are on the table, including a gas-fired combined cycle power plant unit, pumped hydro storage, battery storage, an expansion of the PV, and a solar panel factory.

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Non-energy uses of coal-fired power plant infrastructure

Besides using coal-fired power plants as sites for energy production or storage, they can also be used for non-energy uses. This is most likely to be the case when certain valuable geographic conditions make non-energy options more feasible, such as locations in urban environments. The decommissioning of power plant sites can be a step towards a climate-neutral economy when the materials of the scrapped infrastructure are used, for example, for secondary steelmaking (small boilers can provide 650 tonnes of steel). The following examples give an overview of this potential.

Examples

Conversion of coal-fired power plants into data centres

Google transformed the former coal-fired power plant in Widows Creek, US, into a data centre, transforming a former energy producer into an energy-intensive consumer. Data centres need a lot of energy, accounting for approximately 1% (or 205 TWh) of global electricity use in 2018. By transforming the coal plant into a data centre, it can make use of some of the site's infrastructure such as electric transmission lines, buildings and cooling facilities, but also provide opportunities for sector coupling through potential usage of the by-product waste heat. According to Google, the USD 600 million Project in Widows Creek created up to 100 permanent jobs. Similar projects have been realized in Chicago and are at the planning stage in Lansing and Somerset, USA.

Read more

Logistical port for offshore wind

The formerly 1.6 GW coal-fired power plant in Brayton Point, Massachusetts, closed in 2017 and is now transformed into a logistical port for offshore wind in combination with an offshore-grid connection, a 400 MW battery storage, and a solar PV system. The USD 650 million project takes advantage of the location, including a deep-water port capable of berthing large trans-Atlantic vessels.

Read more

Industrial parks

In Lusatia, Germany, a former lignite-based refinery has been transformed into the industrial park 'Schwarzheide' with a mix of chemical and plastics industries. Even though it is not a transformation of a power plant, the project is a good example of an after-use of infrastructure and targeted specialisation.

Read more

In the Rhenish coal region in Germany, after the planned shutdown of the coal-fired power plant in Frimmersdorf, Germany in 2021, the area with a size of approx. 165 hectares will be decommissioned and transformed into an innovation and technology centre with a focus on metal, chemistry, medicine, food, energy or building materials industry.

Redevelopment to offices, student union centre, cultural sites

In urban areas, power plants are predominantly used for other purposes than energy generation after their closure. The potential value of these properties (due to high land prices) often offsets the costs of decommissioning. Therefore, a broader range of alternatives can be considered, and there are several projects around the globe that offer some possibilities. In Beloit, USA, the former coal-power plant of the city has been transformed and expanded into a student union centre for the neighbouring college, including sports facilities, a library, and offices. In Helsinki, Finland, the Hansaari power plant, which will close down in 2024, is planned to be transformed into an arts and culture centre. In Perth, Australia, the East Perth Power Station is being converted to serve a mix of residential, commercial, recreational, and tourism purposes.

Decarbonising energy-intensive industries

Relevance of energy-intensive industries for coal regions

Many energy-intensive industries such as steel, cement, and chemicals, are present in many EU coal regions. That is because the availability of coal as an abundant local energy source attracted those types of industries. In the highly industrialised coal regions, the economic significance and employment rates of the energy-intensive industries can surpass that of coal mining.

The urge to massively reduce greenhouse gas emissions in the industry sector has increased in recent years. Increasing costs for CO_2 emission certificates put pressure on conventional production processes in energy-intensive industries. Moreover, increasing ambition in climate mitigation, the long-term vision of a climate-neutral economy as stipulated in the Clean Planet for All-Strategy, the European Green Deal and the New Industrial Strategy for Europe make radical technology innovation in sectors like steel, cement, or chemical industry inevitable. Thus coal regions with energy-intensive industries are facing a double transformation: the phase-out of coal and the transition to a carbon-neutral industrial base.

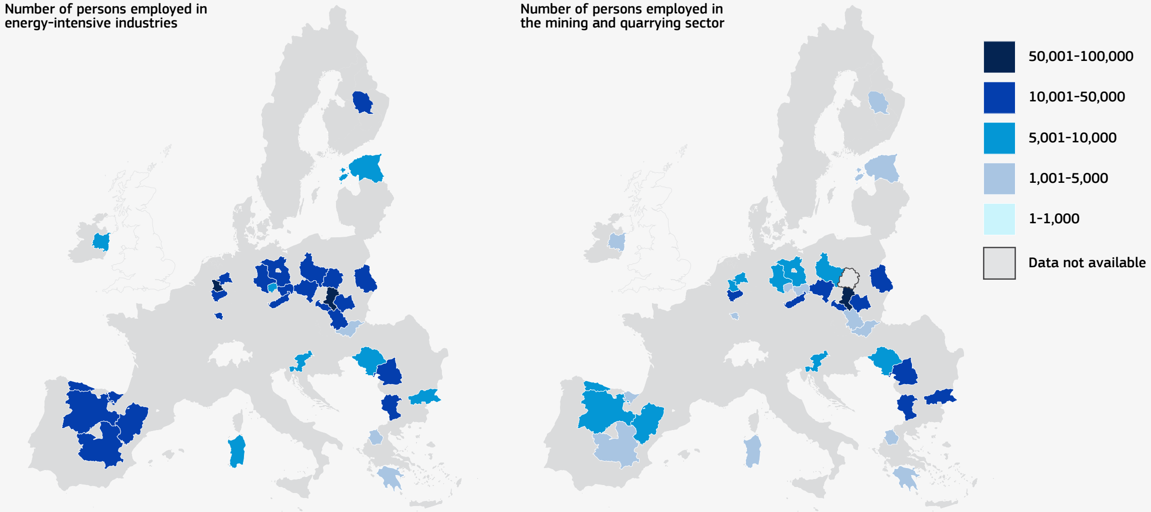

FIGURE 7: JOBS IN COAL MINING AND IN ENERGY-INTENSIVE INDUSTRY

The map shows the number and regional distribution of jobs in coal mining compared to jobs in energy-intensive industries per NUTS 2 region. Indicators for energy-intensive industry: Manufacturing of basic metals, other non-metallic mineral products, chemicals and chemical products, paper and paper products.

Source: Eurostat

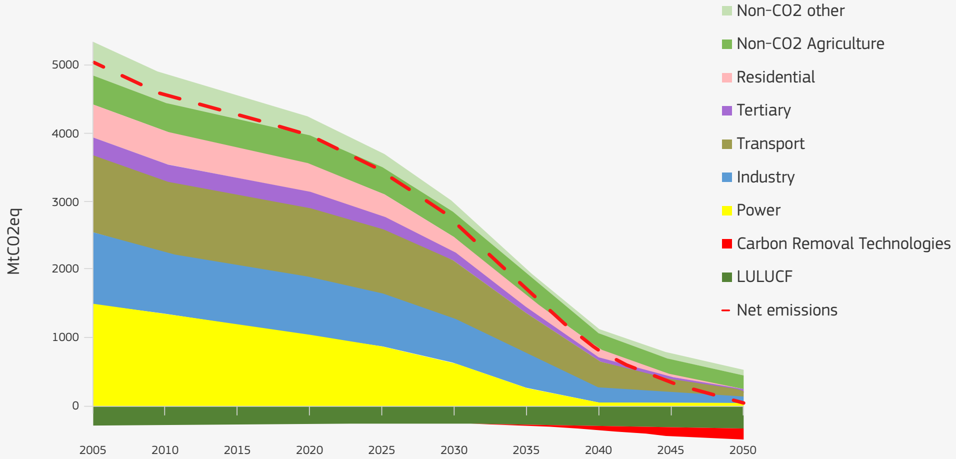

FIGURE 8: GHG EMISSION PATHWAYS TOWARDS CLIMATE NEUTRALITY 2050 (EU)

In total, the industry sector is currently responsible for 25% of Europe's greenhouse gas emissions and therefore critical to reaching the Paris Agreement and the European goal of climate-neutrality until 2050.

Source: European Commission

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Challenges and opportunities

One key challenge in this transition is the long investment cycles in many energy-intensive industries. A blast furnace for steel production has a technical lifetime of about 50 years, key technologies like a steam cracker in the chemical industry or cement kilns have even longer lifetimes. This means that key infrastructure in the energy-intensive industries, which is to be built from now on, will still be used in 2050 if stranded assets are to be avoided. Following the EU's 2050 climate-neutrality targets, investments in those industries need to be in line with a climate mitigation plan, which allows zero-emission by mid-century.

In steel and cement industries, climate-neutral technologies are in the development phase and are not available yet. This means that companies in these sectors might not invest in new capacities with the fear of stranded assets in the future. Moreover, climate-neutral technologies are unlikely to be economically competitive once they do become available unless they are heavily subsidised or the carbon price increases significantly. These challenges could lead to a further decline of regional steel and cement industries, with negative impacts on jobs in carbon-intensive regions, which would be a doomsday scenario for the affected coal regions.

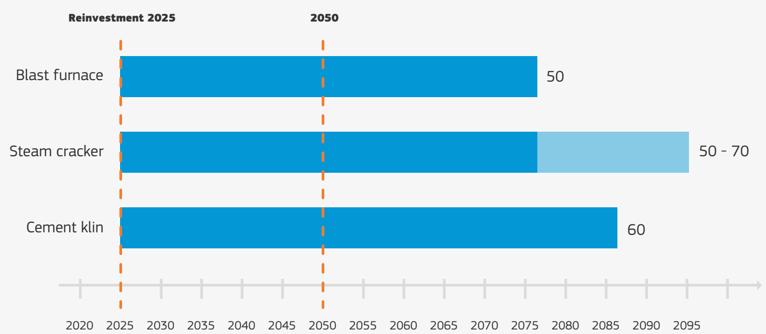

FIGURE 9: TECHNICAL LIFETIME OF PRIMARY PRODUCTION PLANTS IN THE STEEL, CHEMICAL AND CEMENT SECTORS WITH REINVESTMENT IN 2025'

Source: *Agora Energiewende and Wuppertal Institute*

EMISSIONS FROM HEAVY INDUSTRY ARE 'HARD TO ABATE'

A climate-neutral production of steel, cement and chemicals will not be achieved with conventional production techniques. One reason for this is that the potential for further improvements in energy efficiency is very limited. For example, in steel production, incremental efficiency improvements can only further reduce emissions by about 10%. The second reason is, that in addition to energy-related CO_2 emissions the production of steel, cement and some chemicals also creates so-called process emissions. For example, primary steel production via the currently dominant blast furnace route is dependent on the use of (today mostly coal-based) coke as a reducing agent, which results in process emissions (in addition to energy-related emissions). These process emissions cannot be avoided by simply switching the energy source in existing production processes. Thus, achieving a climate-neutral heavy industry by 2050 is only possible through new technologies and production processes.

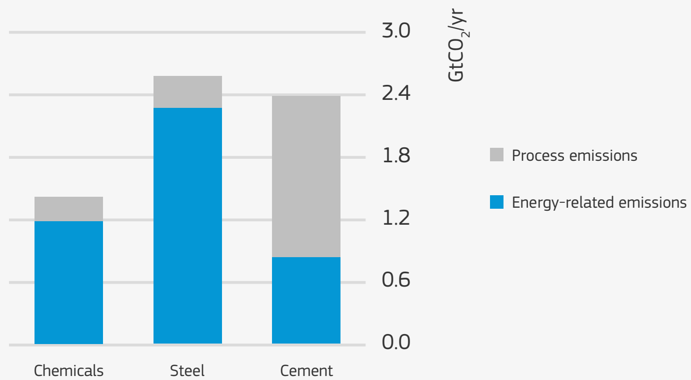

FIGURE 10: PROCESS AND ENERGY-RELATED EMISSIONS FROM HEAVY INDUSTRY SECTORS.

Source: *IEA*

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However, this transition process offers some opportunities. The need to decarbonise energy-intensive industries can spark innovation and attract large investments into the regions. Companies can improve their competitiveness by offering innovative products like green steel and green cement, which will be a necessary backbone in the transition to a climate-neutral economy.

Due to i) the large investments necessary, ii) the immaturity of key technologies, and iii) the necessity of accompanying infrastructure development, this transition will not be manageable by the private sector alone, but will need support and collaboration with the public authorities. Many financial support tools are available at the EU level. However, it is important that regional decision-makers in coal regions have a good overview of the different technology options available for a climate-neutral energy-intensive industry.

Among the energy-intensive industries, the steel industry is most closely linked to the coal industry. With that in mind, this toolkit takes a closer look at the steel sector and its technology options. For information regarding technology options in the cement and chemistry industry please see: European Union/Joint Research Centre, 2020 for cement.

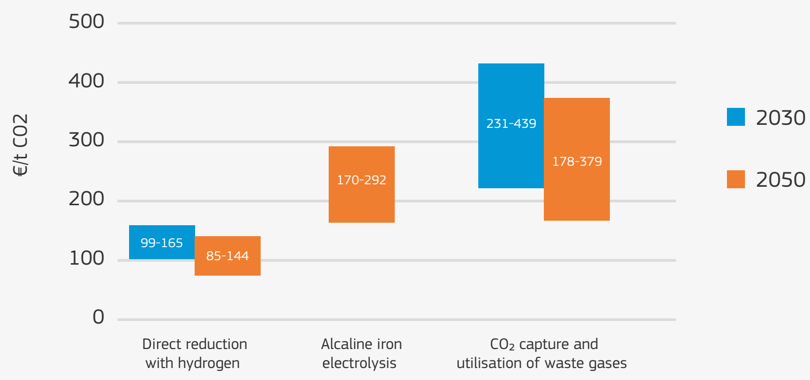

FIGURE 11: ESTIMATED CO_2 ABATEMENT COSTS OF FUTURE STEEL TECHNOLOGIES VERSUS TODAY'S CONVENTIONAL REFERENCE PROCESS FOR 2030 AND 2050

Source: Own graph, based on Agora Energiewende and Wuppertal Institute

Technology option	CO_2 reduction potential (compared to conventional blast furnace route)	Expected technical maturity	CO_2 abatement costs	Key features
Direct reduction with hydrogen and smelting in an electric arc furnace (H-DRI)	-97%	2025-2030	2030: 100-165€/t CO_2 2050: 85-140 €/t CO_2	Requires hydrogen
Alcaline iron electrolysis (Electrowinning)	-87%	Only after 2050	2050: 170 to 290 €/t CO_2	Requires solely renewable electricity and is more energy-efficient than the other technologies
CO_2 capture and utilisation (CCU) of waste gases from integrated blast furnaces	-50%	2025-2030	2030: 230-440 €/t CO_2 2050: 180-380 €/t CO_2	Does not avoid the generation of CO_2 itself, but only its direct emission into the air

Technology options to decarbonise the steel production

> **'The steel sector is currently the largest industrial consumer of coal'**
>
> *IEA technology perspectives 2020*

In 2017, the European steel sector produced 168 million tonnes of steel and was responsible for 128 million tonnes of CO_2 emissions (4% of the EU's overall CO_2 emissions). There are two routes through which the bulk of steel is produced.

- Primary steelmaking: the blast furnace in which iron ore is converted to pig iron using coal and then converted to steel - accounting for 60% of the steel produced in the EU.
- Secondary steelmaking: the remaining steel is mainly produced by recycling scrap in an electric arc furnace.

Projections are that demand for steel in 2050 will be approximately at the same level. However, the shares of recycled steel are assumed to increase driven by the EU's circular economy strategy.

Technologically speaking, reducing CO_2 emissions in the secondary steelmaking route is fairly easy, as the melting of scrap is done by using electricity and can require the provision of zero-carbon electricity. The greater challenge is decarbonising primary steelmaking processes, which requires the development of new technologies, massive investments in new production facilities, and, depending on the technology, large amounts of (clean) hydrogen as a feedstock. Research is currently focusing on three technological processes for the production of CO_2-free or low-CO_2 steel.

Direct reduction with green hydrogen and smelting in the electric arc furnace (H-DRI)

Technology description

In the direct reduction with hydrogen, iron ore is reduced with hydrogen rather than coke. As a result, there are no process-related CO_2 emissions. The resulting sponge iron is then melted in an electric arc furnace (together with scrap, if necessary) to produce crude steel. This technology option reduces CO_2 emissions thanks to the switch to greener energy sources. It builds on the existing process of direct reduction with natural gas (DRI).

Development stage today and expected application maturity

This technology is currently in the pilot and demonstration phase and it is expected to be ready by 2025-2030. In principle, it is also possible to start with natural gas and increasing proportions of hydrogen.

CO_2 reduction potential and alignment with EU climate targets

If renewable electricity is used by the hydrogen plant and by the electric arc furnace (which further processes the sponge iron to crude steel) this technology option is almost CO_2-neutral, reducing emissions up to 97% compared to the integrated blast furnace route. Since the technology can be ready for the market before 2030, it also enables significant CO_2 reductions at a comparatively early stage.

Production costs

The future production costs of hydrogen direct reduction depend heavily on the hydrogen production costs, which in turn depend on the electricity costs, among other things. Experts assume that the cost for a tonne of crude steel produced by hydrogen direct reduction could be EUR 530-630 in 2050. This would be an increase of 36-61% over the current costs of producing one tonne of crude steel in the integrated blast furnace route. However, with an increasing CO_2 price, the costs of the latter will also rise considerably by 2050. Hydrogen direct reduction is expected to be cost-competitive from a CO_2 price of approx. EUR 100 per tonne of CO_2 (indication for 2030).

Renewable energy and infrastructure needs

The H-DRI technology requires the development of large-scale hydrogen production and large amounts of renewable electricity to produce CO_2-free hydrogen (about 3,3 MWh/t crude steel). In principle, regions with a low potential for the production of renewable electricity could also consider importing hydrogen instead of producing it themselves.

Potentials and limitations

Of the technologies currently being researched for climate-neutral steel production, direct reduction with hydrogen seems to be very promising. It achieves the highest CO_2 reduction, is in an advanced state of development, and generates lower additional costs compared to conventional steel production than other green steel technologies.

Example: HYBRIT-Project (Lulea, Sweden)

HYBRIT is a joint venture between the Swedish companies SSAB (steel), LKAB (mining), and Vattenfall (energy). It examines how to replace coal with hydrogen in the steelmaking process. For this purpose, a pilot plant in Lulea (Northeast Sweden) with a capacity of 10 000 tonnes of crude steel a year was put into operation in 2020. The hydrogen required for this is produced directly on-site, mainly using renewable energy electricity provided by wind and water. For scaling up the processes at an industrial scale, a demonstration plant with a capacity of over 1 million tonnes of iron is planned to be constructed by 2025. The project aims at achieving a fossil-free steel value chain in 2026.

The total cost for the pilot phase is about SEK 1.4 billion (EUR 136 million). The Swedish Energy Agency contributed more than SEK 500 million (EUR 49 million).

Read more

Alcaline iron electrolysis (electrowinning)

Technology description

In alkaline iron electrolysis, iron ores are reduced to pig iron in a sodium hydroxide solution and then melted to crude steel in an electric arc furnace. By producing iron directly in an electrolytic process, a carbonaceous reducing agent can be avoided. This means that similar to direct reduction with hydrogen, no process-related CO_2 emissions are produced. However, this technology option has yet to be demonstrated at full scale.

Development stage today and expected application maturity

The technology is still in the early stages of research and large-scale use is not expected until after 2050. Currently, a pilot plant in France is under construction (SIDERWIN) and a demonstration plant in Boston is in the planning stage (Boston Metal).

CO_2 reduction potential and alignment with EU climate targets

Electrowinning could be largely CO_2-neutral, if the full process uses only electricity from renewable energy. It is expected to reduce the CO_2 emissions up to 87% compared to the conventional integrated blast furnace route. However, as this technology is not expected to be ready for the market until after 2050, it may not help to achieve the EU goal of climate-neutrality by 2050.

Production costs

The electrowinning process is in the early stages of research, and a cost forecast is uncertain. Experts assume that the specific costs for a tonne of crude steel produced by electrowinning will be EUR 640-840 in 2050. This would be an increase of 65-112% compared to the same tonne by the integrated blast furnace route, and significantly more than by the H-DRI process. Electrowinning is expected to be cost-competitive from a CO_2 price of approx. EUR 170-290 per tonne of CO_2 (indication for 2050, since the technology is not expected to be ready before). In general, future costs of the process depend strongly on the future electricity costs.

Renewable energy and infrastructure needs

This technology requires large quantities of renewable electricity of about 2.5 MWh per tonne of crude steel. This is around seven times as much as for conventional primary steel production in the blast furnace. However, the electrowinning process is more energy-efficient than other processes for producing green steel, such as H-DRI or CCU.

Potentials and limitations

Electrowinning has the potential to be a promising technology option for green steel production. It has a high CO_2 reduction potential (although not quite as high as H-DRI), it avoids CO_2 emissions during the production process (unlike CCU), it does not require hydrogen and it is significantly more energy-efficient than other green steel technologies. However, its completion might come too late to meet the transformation of the steel industry in line with the EU climate goals. Nevertheless, because of its comparatively lower energy requirement, it is worth it to keep an eye on the future development of this technology.

Example: SIDERWIN

In Europe, the electrowinning process is currently being explored in the Siderwin project. In Maizières-lès-Metz (northern France), a consortium of eleven companies and research institutes led by the steel company ArcelorMittal developed an electrolytic cell prototype to reduce iron oxide to pig iron by electrowinning, proving the viability of iron electrolysis. Currently, a 3-metre industrial electrolytic cell is under construction. In addition to developing and testing a prototype electrolytic cell, the project is researching to which extent the process can be coupled with the use of renewable energies through flexible operation and integration into the power grid. Furthermore, various types of iron ore sources including waste sources as input materials to the electrolysis process will be tested. The project is funded with EUR 7 million by EUHorizon2020 and runs from 2017 to 2022.

Read more

CO_2 capture and utilisation (CCU) of waste gases from integrated blast furnaces

Technology description

The process of CO_2 capture and utilization (CCU) captures some of the waste that gases produced in steel production in a conventional blast furnace instead of burning and emitting them into the air. The captured waste gases can then be used by the chemical industry as feedstock instead of crude oil. For this purpose, however, the waste gases must first be processed into basic materials such as methanol, which requires additional green hydrogen.

Development stage today and expected application maturity

The CCU technology for steel is currently explored in two European pilot plants (Carbon2Chem® in Germany and Steelanol in Belgium). Another one is in the planning stage (Carbon4Pur in France). As all individual components of the Carbon2Chem® pilot plant are already market-ready, it is expected that the technology will be ready for large-scale use between 2025 and 2030.

CO_2 reduction potential and alignment with EU climate targets

The CO_2 reduction potential of CCU is very limited. Firstly, CCU only reduces CO_2 emissions by 50 to a maximum of 65% compared to a conventional blast furnace, because only part of the CO_2 produced in the blast furnace can be captured[1]. Secondly, the actual CO_2 reduction depends on whether the

1 65% will be arithmetically achieved if the CO_2 reduction in the chemical sector induced by CCU in steel production is fully credited to steel production.

carbon is released again at the end-of-life of the resulting chemical products, since CCU – in contrast to H-DRI and electrowinning – does not avoid the generation of CO_2 itself, but only its immediate emission into the air.

For these reasons, the use of CCU is not sufficient for climate-neutral steel production in line with the EU climate targets.

Production costs

CCU is a comparatively expensive CO_2 reduction option for steel production. Production costs are significantly influenced by the cost of hydrogen, since hydrogen is needed for the necessary further processing of the separated waste gases into basic materials usable for the chemical industry. The specific costs per tonne of crude steel produced by CCU (including the costs of the further processing of the waste gases) are estimated to be EUR 640-860 in 2030. This would be an increase of 63-119% over the current costs of producing it in the integrated blast furnace route, and much more than the estimated costs for the H-DRI process. CCU is expected to be cost-competitive from a CO_2 price of approx. EUR 230-440 per tonne of CO_2 (indication for 2030).

Renewable energy and infrastructure needs

With 3.6 MWh per tonne of crude steel, the electricity demand for CCU is higher than the one for H-DRI (3.3 MWh/t) and for Electrowinning (2.5 MWh/t). The higher electricity demand is due mainly because of the processing of waste gases into valuable chemical substances. For these processes, hydrogen and the development of hydrogen production and/or hydrogen infrastructure are needed.

Potentials and limitations

At first glance, CCU in the blast furnace route seems to be a relatively easy solution for steel production as it is expected to be ready for use within the next 5 to 10 years and does not require a new production process, as it can be retrofitted to existing blast furnaces. Nevertheless, these processes are very limited.

Firstly, the CO_2 reduction potential of CCU is too low to achieve a climate-neutral steel production in line with the EU climate targets.

Secondly, it is uncertain how valuable the use of waste CO_2 from blast furnaces will be for the chemical industry in the future. In the course of its transformation to climate-neutrality, this industry will increasingly use non-fossil feedstock. Today, the total industry carbon emissions far surpass the carbon that can be recycled back into the industry. Since this technology uses coking coal as fuel and reducing agent (unlike H-DRI and electrowinning) it only reduces part of the CO_2 emissions, but not other harmful emissions (like mercury, sulfur dioxide and nitrogen) that are caused by burning coal.

Also, the CO_2 capture process requires additional energy compared with the conventional blast furnace route, resulting in higher coke consumption and more pollution.

Overall, CCU is the most energy-intensive CO_2 reduction option for the steel industry and one of the most expensive ones.

For these reasons, and especially due to its insufficient CO_2-reduction potential, CCU does not represent a long-term option for climate-neutral steel production and can, at most, be a bridging technology for short-term CO_2 reduction of existing conventional blast furnaces. However, even in tha case, the risk of stranded assets is very high.

Example: Carbon2Chem®

A pilot plant in Duisburg (Germany) run by the steel company ThyssenKrupp and companies from the chemical industry, shows how CCU technology can be used to capture waste gases from conventional steel production and make them usable for the chemical industry. From 2020 on the processes are scaled up for industrialisation.

Read more

CARBON CAPTURE USAGE AND STORAGE (CCUS)

During the 1990s and early 2000s, there were high expectations of Carbon Capture and Storage (CCS) for climate mitigation and reduce the CO_2 emissions of coal-fired power plants. However, while implementation of projects was slow, the use of the captured CO_2 for chemical products increasingly came into focus (Carbon Capture Usage and Storage, CCUS). The pipeline of CCS projects under development has more than halved between 2010 and 2017. In 2020, only 26 commercial CCS facilities were in operation globally and only the 115 MW Boundary Dam in Canada is connected to a coal-fired power plant. Since 2017, the number of projects under development has increased.

CCS is a controversial issue, perceived differently by diverse experts, institutions, and EU Member States. It is known that the CCUS technology exists and has been used for years, but mainly in specific sectors such as small-scale applications in the industry and subsequent use of the CO_2 in the enhanced recovery of natural gas. However there many unresolved challenges. Storage capacities are limited and there are uncertainties around long-term storage. In power generation, capture costs did not decrease as expected, and CCS could not compete with the cost reductions of renewables. Furthermore, CCS faces acceptance problems in many countries. Regarding CCU, it is key whether the carbon is permanently bound in the resulting products or released again.

Currently, experts see four key fields in which CCUS could play an important role:

1. low-carbon power generation using fossil fuels;
2. production of low-carbon hydrogen at scale;
3. deep decarbonisation in hard-to-abate industry;
4. delivering negative emissions.

1) CCUS can potentially reduce a substantial amount of emissions from coal and gas-fired power plants, but not down to zero. Generally speaking, CCUS in power plants reduces efficiency, which leads to higher energy demand and costs. For new power plants, CCUS would yield higher generation costs compared to new wind and solar facilities in most regions. Retrofitting existing power plants to avoid stranded assets of young coal-fired power plants is discussed as an option as well. This may be an option in countries like China with a high share of young coal-fired power plants. However, considering the age structure of power plants in Europe and the EU's target of carbon neutrality by 2050, this is hardly an economically valid option for domestic coal plants.

2) CCS may be an option for the production of 'blue hydrogen' (from natural gas with CCUS). Expert assessments of the potentials are controversial. Producing hydrogen at the source of natural gas wells can potentially use existing infrastructure (e.g. pipelines) as well as storage facilities (e.g. gas wells) and can help reduce emissions with a mid-term perspective. Issues of costs and long-term implications when lock-ins are to be avoided are currently under debate. The production of blue hydrogen does imply CO_2 emissions and can thus not be seen as a permanent option towards a climate-neutral energy system.

3) Many climate scenarios give CCUS a clear role in reducing emissions in sectors where alternative zero-carbon technologies are not available. Cement is one prominent example where CO_2 is emitted by deacidifying the limestone used as a raw material in cement production. Here CCS is likely to be an important technology to complement other emission reduction solutions in the construction sector (e.g. new construction materials and circular economy approach).

4) From a long-term perspective, CCS can play an important role in achieving negative emissions. Many climate scenarios rely on negative emissions after 2050 – either to compensate for emissions that are extremely difficult to avoid (e.g. in agriculture) or to compensate overshooting the greenhouse gas emission budget before 2050. Negative emissions could be achieved by extracting CO_2 from the air with subsequent storage (direct air capture – DACCS) or from biomass burning with subsequent CO_2 capture and storage (BECCS).

In conclusion, CCUS will likely play a role on the path towards a climate-neutral economy in specific fields. However, there is a shift in the expectations for which sectors and applications it will play a role in. The magnitude of CCUS use and its distribution among countries is still unclear, but for sectors with unavoidable emissions like the cement industry, CCUS is likely to play a role in the future.

➔ CCUS in Clean Energy Transitions, IEA Energy Technology Perspectives, 2020 ➔ Potential for CCS and CCU in Europe, IOGP - the global oil and gas industry trade association, 2020

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Hydrogen

The expectations of the role of hydrogen in the transition to a low carbon energy system have been quite diverse within the last decades. At the beginning of the millennium, some experts have seen fuel-cell driven cars close to commercialisation, while a few years later others coined the term ‘all-electric society’. Today, there is a growing consensus that hydrogen will play an important role in a climate-neutral economy. There are some applications for which the use of hydrogen seems almost inevitable. In many other areas, hydrogen is a reasonable option but will have to compete with other emission-free technologies.

Future application

Below you will find applications for which hydrogen will likely play an important role.

Feedstock in the refining and chemical production industries

Most of the hydrogen produced today is used as feedstock to make other materials, mostly in the refining and chemical production industries. Due to a continued demand growth rate of 1-3% per year, the challenge lies in the decarbonisation of today’s ‘grey hydrogen’. About 95% of current production comes from natural gas or as a byproduct.

Sustainable energy supply for the energy-intensive industry

The steel industry is a major carbon emitter, accounting for 30 million tonnes of CO_2 annually in the EU, and could benefit from the application of hydrogen for the decarbonisation of production processes. However, the switch to hydrogen will be challenging, as it requires the development

HYDROGEN IS NOT A FUEL, BUT AN ENERGY CARRIER

Hydrogen is often described as a fuel and, from an end user’s view, it will be consumed as such. But unlike natural gas or oil, hydrogen needs to be produced. It is thus more a means to store, transport, and re-distribute energy. Today, the largest hydrogen share is used in the chemical industry (as a feedstock, more than an energy carrier). It is produced mainly by the use of fossil energy (coal and gas). In the future, the production of hydrogen will need to be low-carbon and eventually zero-carbon. Consequently, the EU’s hydrogen strategy focuses on clean hydrogen, which needs to be produced with renewable energy, mainly wind and solar.

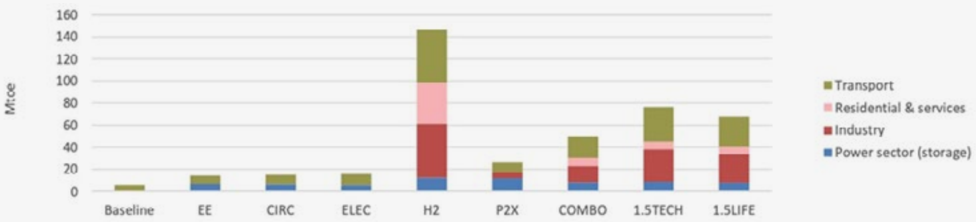

FIGURE 12: HYDROGEN DEMAND 2050 (EU)

The use of hydrogen in 2050 varies strongly based on different scenario assumptions

Source: European Commission

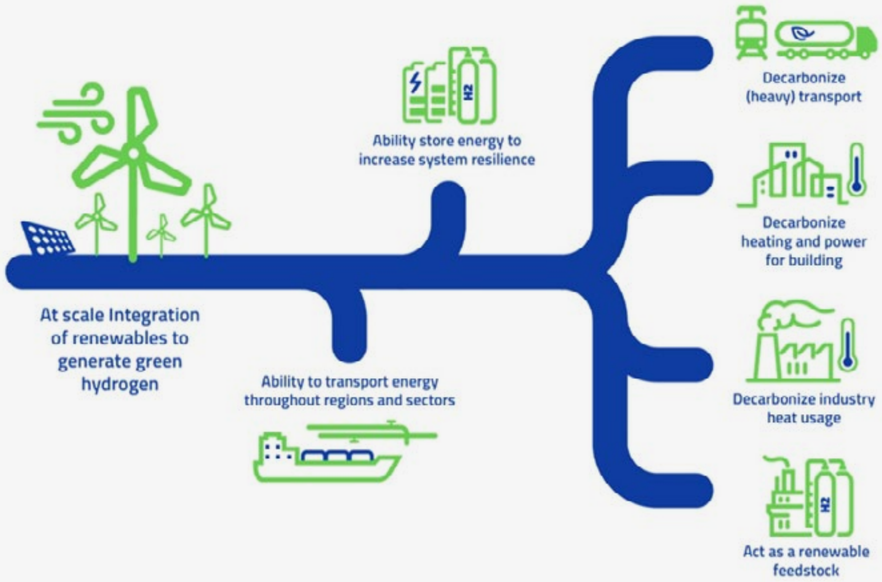

FIGURE 13: THE SYSTEMIC ROLE OF GREEN HYDROGEN IN A ZERO-CARBON ENERGY SYSTEM

Source: EIT InnoEnergy

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of new technologies, massive investments in new production facilities, significantly higher production of hydrogen, and measures to avoid that the more expensive climate-neutral steel (with an expected price increase of an additional EUR 160/t) will be jeopardized by international competition.

Transportation technologies

Hydrogen will be an option for vehicles for which electrification is difficult (e.g. long-range heavy-duty vehicles). Estimates project that fuel cell trucks could account for 35% of overall truck sales or more than 40% of heavy-duty trucks in 2050, with a total hydrogen demand of 675 TWh. Depending on the supporting schemes and regulatory frameworks that will be established in the next years, hydrogen and hydrogen-derived synthetic fuels could also be used to fuel freight ships and aviation.

Hydrogen could potentially play a role as a backup-storage option for electricity generation, heat supply for buildings, and several other applications. The competitiveness will depend on the technology development of alternatives, specific regional conditions (e.g. infrastructure and availability of renewable energy), and carbon prices (see *'Hydrogen Roadmap Europe'* box).

Hydrogen demand projections

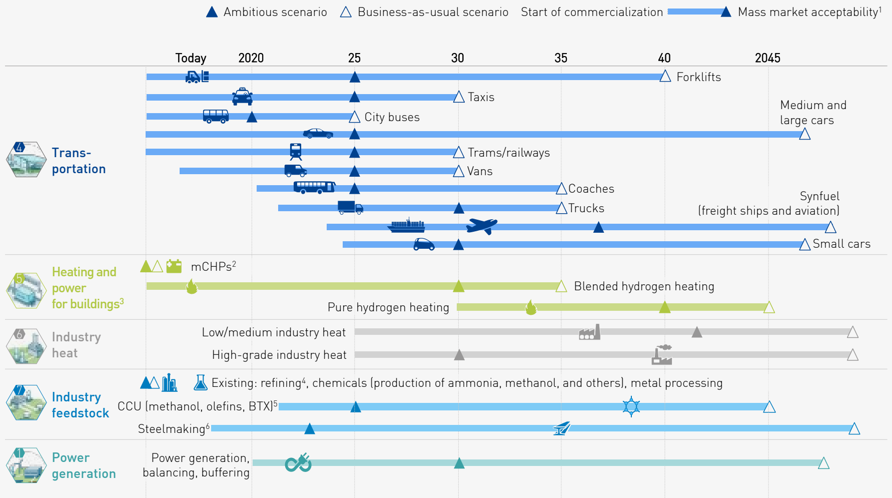
According to scientific projections, the total hydrogen demand is expected to grow, although the growth potential depends on scenario assumptions. Generally speaking, the EU assumes a low baseline for current hydrogen demand (approx. 70 TWh) and projects 790-900 TWh (69 -77 Mtoe) of hydrogen demand in their 1.5LIFE and 1.5TECH scenarios, both aiming to reach the 1.5 ºC global warming target from the Paris agreement. In another scenario, in which hydrogen should play a major role in decarbonisation efforts, the overall demand would almost double to 1 700 TWh (146 Mtoe) (Figure 12). The Hydrogen Europe industry initiative (see *'Hydrogen Roadmap Europe'* box) expects a sevenfold increase from 325 TWh (28 Mtoe) in 2015 to 2 250 TWh (194 Mtoe) in 2050 in their ambitious scenario, where hydrogen will be largely applied in all aforementioned sectors. In contrast, demand would reach only about 780 TWh (67 Mtoe) in 2050 in the business-as-usual scenario. Material economics projects a 540 TWh potential demand unlockable in the near term and 1 200-1 400 TWh in the medium-term, as long as there will be sufficient cost decreases, investments, and policy support.

Looking at these numbers, the role of hydrogen in the future energy mix is not very clear today. As a result, businesses and regions are hesitant to make investment decisions. However, hydrogen will be an important element of a low-carbon economy, and developing the needed infrastructure has long lead times. It is necessary to address the issue expeditiously. To create more certainty, the EU and several member states have set up hydrogen strategies and political guidelines to accelerate decarbonisation efforts.

HYDROGEN ROADMAP EUROPE

For many applications, hydrogen technologies already exist today. However, they are often not yet competitive or their use is restricted to niches. The hydrogen Roadmap Europe gives an overview of the status quo and potentials of hydrogen technologies within different scenarios of transitions to a low-carbon energy system.

Read more



1 Defined as sales >1% within segment 2 mCHPs sales in EU independent of fuel type (NG or H_2) 3 Pure and blended H_2 refer to shares in total heating demand
4 Refining includes hydrocracking, hydrotreating, biorefinery 5 Market share refers to the amount of production that uses hydrogen and captured carbon to replace feedstock 6 CDA process and DRI with green H_2, iron reduction in blast furnaces, and other low-carbon steelmaking processes using H_2

FIGURE 14: HYDROGEN ROADMAP - FROM TECHNOLOGY AVAILABILITY TO MASS MARKET ACCEPTABILITY

Source: Hydrogen Europe

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The EU hydrogen strategy

The priority for the EU is to develop renewable hydrogen, produced using mainly wind and solar energy

In July 2020, the European Commission launched the 'Hydrogen strategy for a climate-neutral Europe'. The strategy stresses the urgency to act with a view on the long investment cycles in clean energy. According to the strategy, the EU plans to scale up hydrogen application in three phases.

In phase I (2020-2024), the strategy calls for 6 GW of renewable hydrogen electrolysers and the production of up to 1 million tonnes of renewable hydrogen to decarbonise existing hydrogen feedstock production (e.g. in the chemical sector). Additionally, new end-use applications in industrial processes and possibly in heavy-duty transport should be scaled up.

In phase II (2025-2030), the initial amount needs to be increased to 40 GW capacity and 10 million tonnes of renewable hydrogen in the EU by 2030. In this phase, it is expected that renewable hydrogen will gradually become cost-competitive and will be further applied for steel-making, trucks, rail, maritime, and other transport modes. Local hydrogen clusters and infrastructure will become more and more important.

In phase III (2030-2050), renewable hydrogen technologies should finally reach maturity and be deployed at a large scale to reach all hard-to-decarbonise sectors.

The EU hydrogen strategy is backed by various initiatives in cooperation with industry (e.g. the European Clean Hydrogen Alliance) as well as a multitude of funding options to support upscaling of hydrogen projects and infrastructure.

Initiatives on EU Level

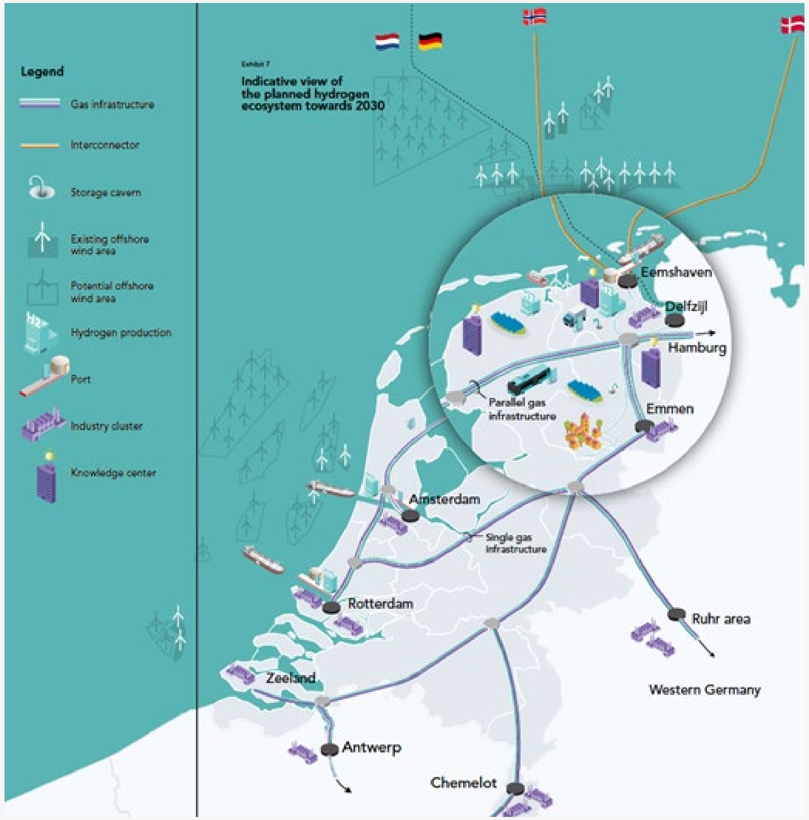
- European Clean Hydrogen Alliance (EC/ Hydrogen Europe)
- Hydrogen Europe (industry association)
- Fuel Cell and Hydrogen Joint Undertaking
- EGHAC - European Green Hydrogen Acceleration Centre (EIT/Breakthrough Energy)
- Renewable Hydrogen coalition (renewable energy industry initiative)

Hydrogen in coal regions

Hydrogen - an investment agenda

The transition to a climate-neutral hydrogen economy will bring massive investment needs. Figures vary depending on assumptions of future hydrogen scenarios. However, it is clear that multi-billion investments will be needed across Europe. The EU hydrogen strategy estimates that 'from now to 2030, investments in electrolysers could range between EUR 24-42 billion. (...) Also, investments of EUR 65 billion will be needed for hydrogen transport, distribution and storage, and hydrogen refueling stations.' Up to 2050 cumulative

REGIONAL HYDROGEN STRATEGY IN NORTHERN NETHERLANDS



The Province of Groningen in Northern Netherlands has developed a regional hydrogen strategy, which looks at the necessary investments into a future hydrogen economy as a great economic and job potential for the region. The strategy assesses both regional hydrogen demand and renewable energy supply options and integrates them into a consistent picture of energy import and hydrogen export with neighbouring regions and countries.

- Presentation at the Coal Regions Virtual week (November 2020)
- The Northern Netherlands Hydrogen Investment plan 2020 (PDF)

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investments between EUR 180-470 billion are expected. Furthermore, a larger amount of money will need to go into the energy supply infrastructure to produce the required amounts of hydrogen. In the EU's hydrogen strategy it is stated that up to 2030 'EUR 220-340 billion would be required to scale up and directly connect 80-120 GW of solar and wind energy production capacity to the electrolysers to provide the necessary electricity.'

For these reasons, many regions across Europe see the transition to a hydrogen economy as a good opportunity to bring sustainable economic activities and future-proof jobs to their region and are developing hydrogen strategies to reap the benefits of this transition.

Strategy Development

Every EU region must develop an energy transition strategy based on its regional capacities and development objectives, and needs to assess which role hydrogen should play in it. The EU coal regions are diverse: some are densely populated urban regions, while others are rural regions often facing challenges of shrinking population; some are heavily industrialised while others rely on agriculture or tourism. Consequently, the future role of hydrogen will vary strongly across coal regions.

Key questions are:

- what are potential future demands in the region (assuming a transition towards a climate-neutral economy)?
- what is the potential of the region to produce hydrogen?
- what are the infrastructure needs to transport hydrogen? How could existing infrastructures be used for hydrogen?

The answers to these questions vary from region to region, but they are fundamental to develop a suitable hydrogen strategy, stir long-term investments in the right direction, and align private and public actions and responsibilities.

What will be the hydrogen demand in your region?

Today, hydrogen is produced and used in many regions across Europe, mainly as a feedstock for the chemical industry. The short-term challenge will be to switch the production of this feedstock hydrogen to a low-carbon energy supply.

The longer-term future demand for hydrogen will depend on several factors.

1. Overall population and population density: especially for transport, the demand for hydrogen will directly depend on the number of inhabitants in the region.
2. Technological choices and developments: the use of hydrogen will not only depend on general technological developments (in the field of hydrogen and alternatives), but also on regional technology choices, such as whether a region invests more in overhead lines for e-trucks or extends hydrogen facilities.
3. The structure of the economy: specifically energy-intensive industries will have a large hydrogen demand in a carbon-neutral economy.

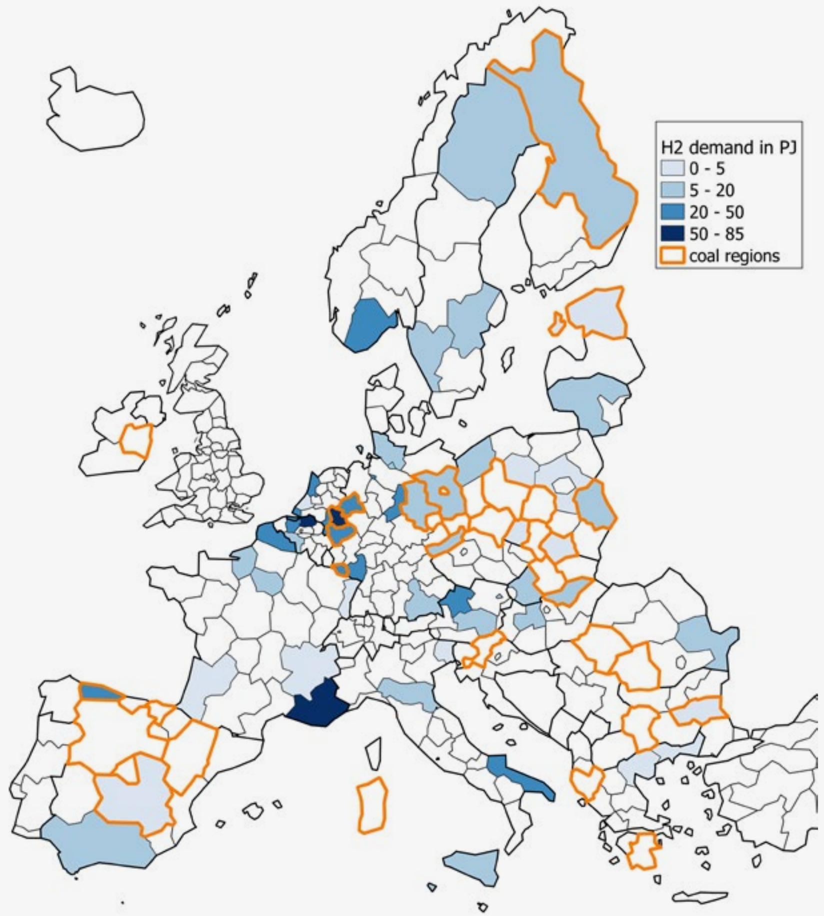

FIGURE 15: HYDROGEN DEMAND FOR DECARBONISED STEEL, CEMENT, AND CHEMICAL INDUSTRY IN 2050

The map shows the regional distribution of additional industrial hydrogen demand in 2050 (blue colour shading). Orange boundaries indicate NUTS2 regions with coal mining, peat and oil-shale production.

Source: Wuppertal Institute

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While the first two factors apply to all EU regions, energy-intensive industries are concentrated in clusters and distributed unevenly across Europe. Some coal regions show high-shares industries, which are likely to be consumers of large amounts of hydrogen, such as chemical industry and steel production. Figure 15 shows an estimate of the hydrogen demand for decarbonised steel, cement, and chemical industry in 2050 across the EU. It shows the differences between EU coal regions and indicates which regions will become high-demand regions. In any case, a rigid regional assessment of the future hydrogen demand needs to be undertaken on a national and regional level.

What is the potential to produce clean hydrogen in your region?

Another key question is, how much clean hydrogen can a region produce? Producing green electricity or green hydrogen has a great economic and job potential for those regions with high renewable potential (see also JRC study on Clean energy technologies in coal regions).

Regions with higher renewables potentials than what is needed within the region for electricity generation, could potentially become suppliers of hydrogen, to be used by customers in their own region or to be exported to other regions. Figure 16 gives an overview of the technical potential for green electricity in Europe per NUTS-2 region.

Examples

Hydrogen production at a former coal-fired power plant site in Hamburg, Germany

A consortia of Mitsubishi Heavy Industries, Shell, Vattenfall, and the local energy company Wärme Hamburg are planning to build a 100 MW green hydrogen production facility at the site of the coal-fired power plant Moorburg in Hamburg, which ceased operations in 2020. Due to its position in the port of Hamburg, closeby to energy-intensive industry companies, and with access to the existing gas network and electricity grid connection, the project is expected to be key for the decarbonisation efforts in Hamburg and aims to become a 'Green hydrogen hub' after completion in 2025.

Read more

Green hydrogen to decarbonise steel production in Mo i Rana, Norway

In collaboration with steel-producing company Celsa and Mo Industry park, the energy company Statkraft plans to set up a 40 MW alkaline electrolyser to decarbonise the steelmaking process of Celsa. The project is targeted for operation by the end of 2023. Additionally, within the industry park, further industrial opportunities for green hydrogen will be exploited.

Read more

REFHYNE project

The REFHYNE project, funded by the Fuel Cells and Hydrogen Joint Undertaking, aims to build and operate the world's largest PEM electrolyser at Shell's Rhineland refinery in Cologne. The 10 MW electrolyser is being built by ITM Power, and operation is scheduled to begin in 2021.

Read more

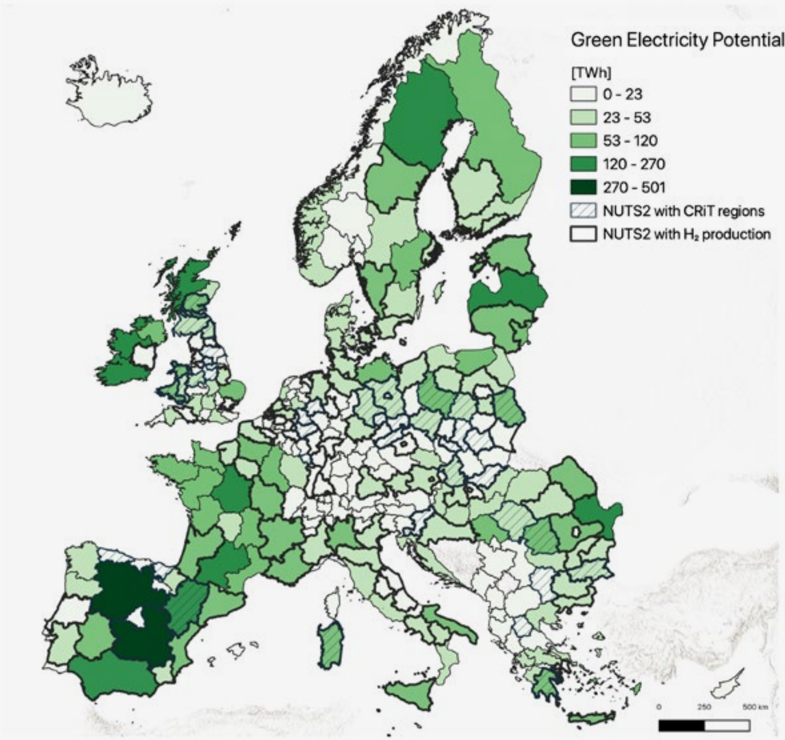

FIGURE 16: POTENTIAL FOR GREEN ELECTRICITY IN THE EU

Technical potential for green electricity per NUTS2 region, marked are CRIT coal regions (hatched) and regions in which today hydrogen is produced (bold boundaries).

Source: JRC 2020

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Hydrogen infrastructure

Hydrogen infrastructure needs to take into account:

- existing infrastructure (e.g. for natural gas) that could be converted for hydrogen use;
- geographical conditions (access to rivers, sea, etc.);
- hydrogen needs and supply options of neighbouring regions (national and cross-border);
- long-term time horizon and high investments for infrastructure development;
- public-private partnerships or at least cooperation to develop a hydrogen strategy.

Any commercial use of hydrogen requires the establishment of a suitable transport infrastructure. There are uncertainties about the magnitude of future demand as well as the future sources of green or blue hydrogen and their geographical distribution. The challenge is to gradually build an infrastructure that starts with robust small-scale elements and can be expanded over time.

There are two methods of hydrogen distribution in Europe that will become relevant in the regions: pipelines, trucks, and, to some extent, railway transportation. Pipelines can transport gaseous hydrogen and are comparably cheap as long as demand is large enough, which will mostly come from industrial centres with energy-intensive industries. The cost of new hydrogen distribution pipelines will require substantial investments, yet the conversion of existing natural gas distribution networks will be a feasible alternative in some regions. Trucks, on the other hand, are more beneficial when demand is low and will be needed to supply hydrogen filling stations and other smaller hydrogen consumers.

Considering the current status of technological development, the establishment and repurposing of infrastructure will most likely start in industrial centres, where pilot projects have been initiated (see examples). Parts of previous grey hydrogen production based on fossil feedstocks can be converted to CO_2-free hydrogen production. Existing natural gas pipelines (if available) can be transformed into pure hydrogen pipelines transporting hydrogen to the regional centres of consumption. A detailed map of all currently existing gas pipelines can be found here.

As technologies improve and demand increases, national-and cross border connections will be installed and shipping and import logistics are built up. A global market for hydrogen is emerging, which increasingly determines the price of hydrogen.

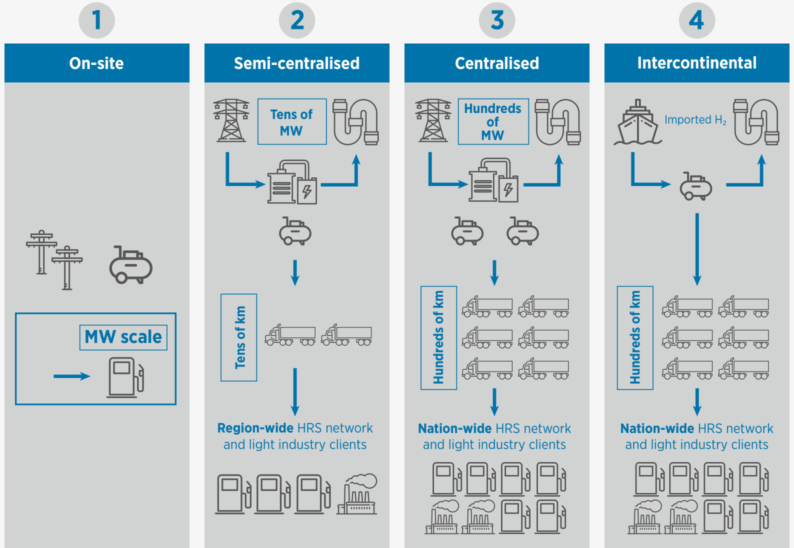

FIGURE 17: POTENTIAL FUTURE STEPS FOR SCALING UP HYDROGEN INFRASTRUCTURE

Source: IRENA

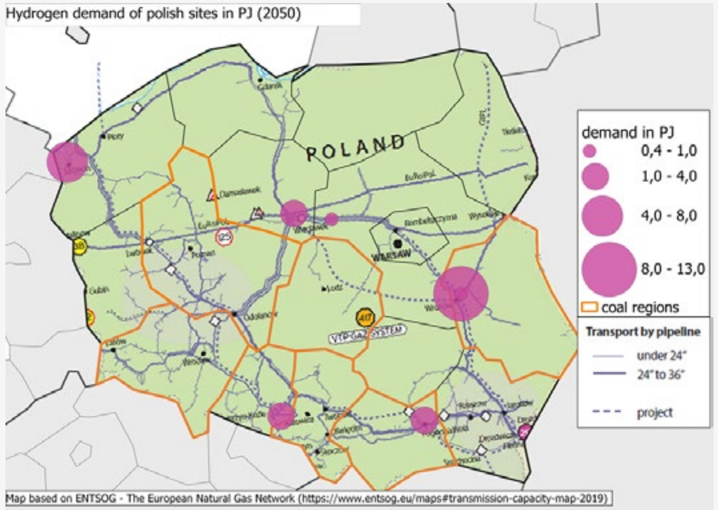

FIGURE 18 : HYDROGEN DEMAND AT SITES 2050 AND TODAY'S NATURAL GAS GRID IN POLAND

Source: Wuppertal Institute

In the above map, the underlying assumption was that Silesia would largely turn to CCS to decarbonise their steel industry. In a workshop with Silesian stakeholders, we found out that this is not the most likely strategy. We would recalculate H2 demand for Poland without CCS and could include such an updated map as an example.

Options for non-energy uses of coal

Future prospects of coal products

Until today, coal has been used predominantly to generate electrical power and as a valuable part of steel and cement industries, leading to the annual consumption of over 5 billion tonnes of coal a year. However, coal can also be used for non-energetic purposes.

One of the most promising alternatives is the application of lignite as a fertilizer. Based on the mineral Leonardite, coal fertilizers have been used to enhance soil qualities since the 19th century and may become an alternative to nitrogenous fertilisers, which are being criticised due to nitrate contamination and ammonia emissions. Compared to chemical fertilisers, lignite additives have characteristics close to those of existing soils, which can not only be beneficial for functioning farmland, but also help to rebuild the soil structure of over-used land and the restoration of carbon sinks, which could make the application of lignite agrochemicals a tool to absorb carbon dioxide. Currently, there are different approaches on lignite humate products tested with promising results so far. However, the EU's Farm to Fork Strategy, which aims at reducing the use of fertilizers, might lower its economic potential.

Despite uses for agriculture, most other technologies currently available are considered not market-ready, not scalable and/or not future-proof due to high emission production routes. The latter counts especially for the coal-to-chemicals industry, which is currently the fourth largest consumer of coal. Through the conversion of by-products of coal coking, the industry produces a broad range of common chemicals, pharmaceuticals, dyes, and preservatives and produces polymers through coal gasification (mainly in China). Due to the high emissions of these production routes, coal-to-chemicals cannot be recommended as an alternative for development.

The production of montan waxes is an established process for coal refinement and it is one of the alternatives for coal that is currently applied. Its specific natural characteristics make raw montan wax suitable for many applications, including polishes, lubricants, asphalt, and the foundry industry. However, montan wax production requires a certain type of lignite that is only available in a few coal regions. Therefore, it can only be considered as a niche technology.

Activated carbon has a well-established market and is commonly used in the purification of water and organic solvents. There is an increased need for activated carbon due to water scarcity and recycling. Activated carbon can be made also from biomass carbonaceous materials such as coconut shells, wood, and peat, so scalability is limited and cannot be considered as a long-term option.

Other technologies may have a more promising future, but are at the development stage and might only cater to niche markets. These technologies range from rare earth element extraction (e.g. for battery production), chemical synthesis for nanomaterials, and new ways to use coal as feedstock for the production of lightweight carbon fibre materials, electrodes, and graphene products.

Whether or not the development of these technologies in the near future or medium-to-long term can economically justify the continuation of extractive coal mining needs to be carefully elaborated. This is especially true under the foreseeable developments on the EU-level regarding a circular economy (see *'Less waste, more value: Building a circular economy is the other element of future production'* box).

LESS WASTE, MORE VALUE: BUILDING A CIRCULAR ECONOMY IS THE OTHER ELEMENT OF FUTURE PRODUCTION

The technological options in this toolkit highlight the challenges and opportunities on the pathways towards a climate-neutral economy. Even though the application of new technologies in the value chain is crucial, those technologies are only one element of the transition. In a climate-neutral future, economies need to transform into circular economies that keep resources in the production cycle as much as possible. Reducing raw material consumption and increasing material efficiency and recirculation (e.g. in steel production and the construction sector) is expected to have a significant effect on emission reduction. Furthermore, because EU manufacturing companies spend about 40% on materials, closed-loop models can also increase individual companies' profitability, while sheltering them from resource price fluctuations.

Generally speaking, circular economy principles could increase EU GDP by an additional 0.5% by 2030 and create around 700 000 new jobs. Therefore, regional development should not only focus on applying new technologies but also taking up circular economy approaches as currently developed under the EU Circular Economy Action Plan.

Regional authorities can include circular economy considerations (e.g. in public procurement) by including sustainability criteria related to maintenance, recycling, and sustainable sourcing of raw materials. More generally, decision-makers should integrate their commitments to a circular economy into regional or local strategies setting out priorities and measures. Creating a dedicated entity can also help to support circular economy projects especially in the early phases of the transition, for example in the form of a competence centre for circular building construction as it has been started in the Rhenish coal region in Germany with the ReBau-project.

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Annex I: helpful tools and handbooks

Technology options

IEA Energy Technology Perspectives 2020

This IEA flagship report assesses an extensive range of technology options that play a role to reach net-zero emissions by 2050. The analysis addresses the challenges and opportunities associated with a rapid, clean energy transition. The report covers all areas of the energy system, from fuel transformation and power generation to aviation and steel production.

Read more

ETP Clean Energy Technology Guide

The ETP Clean Energy Technology Guide is an interactive website that contains information from over 400 individual technology designs and components across the whole energy system that contribute to achieving the goal of net-zero emissions. For each technology, it includes information on the level of maturity and a compilation of development and deployment plans, cost and performance improvement targets and current developers of these technologies.

Read more

Knowledge platform and network

Re4Industry

The Re4Industry project aims to facilitate a smooth and more secure transition to the adoption of renewable energies for the energy-intensive industry sector and both offer knowledge resources on industry transition and a platform for stakeholder exchange (under development).

Read more

Smart specialisation

ONLINE-S3

The EU research and innovation strategy for Smart Specialisation (RIS3) is a policy concept developed by the European Union. It has been adopted as part of the EU cohesion policy and has become a precondition for receiving funding from the European Regional Development Fund (ERDF). In brief, 'smart specialisation' is about identifying a region's key activities, areas, or technological domains that give them a competitive advantage, and help focus transformative efforts based on those.

In that context, ONLINE-S3 has been developed as an e-policy platform, augmented with a toolbox of applications and online services, able to assist national and regional authorities in the EU to elaborate their smart specialisation agenda. It contains a guidebook to accompany the smart specialisation process as well as a toolkit.

Read more

Annex II: further reading

- Agora Energiewende & Wuppertal Institute (2019). Climate-neutral industry.
- Climate Strategies (2020). Investments in climate-friendly materials to strengthen the recovery package.
- DIW (2020). Fossil Natural Gas Exit – A New Narrative for the European Energy Transformation towards Decarbonization.
- E3G (2019). Insights from the UK coal phase out experience.
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- GEM (2020). Gas at a Crossroads: Why The EU Should Not Continue To Expand Its Gas Infrastructure.
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- JRC (2018). EU coal regions: opportunities and challenges ahead.
- JRC (2020). Decarbonisation of industrial heat: The iron and steel sector.
- JRC (2021). The use of woody biomass for energy production in the EU.
- Material Economics (2019). Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry.
- Sandbag (2020). Playing With Fire: An assessment of company plans to burn biomass in EU coal power stations.
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Initiative for coal regions in transition

Led by the European Commission, the Initiative for coal regions in transition assists EU countries and coal regions tackling challenges related to the transition to a low-carbon economy.

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