INDUSTRY

REDUCING CARBON INTENSITY OF INDUSTRY TO ENSURE SUSTAINABLE GROWTH IN EUROPE

Current situation and challenges

Industry is responsible for 30% (1,201 $MtCO_2e$) of EU27 greenhouse gas emissions, either from:

- **Energy use**: burning fossil fuels to obtain high-grade or low-grade heat, using non-renewable electricity.
- **Direct emissions from process**: for instance, the chemical reaction involved with cement production generates CO_2 as a by-product.

Achieving a low carbon industry is of paramount importance, not only to reach the 2050 carbon neutrality target, but also to allow economic growth for EU companies and workers.

The more challenging issues lie in core highly emissive chemical processes such as the production of cement or the reduction of iron ore, where substitutes, hydrogen or electrowinning can provide solutions.

The second technology challenge remains sustainable high-grade heat generation. High-grade heat requires high temperatures (above 300°C) that cannot be achieved simply with electrical resistors; and without profitable sustainable heat, the industry may turn toward fossil fuels. Hydrogen, a renewable and carbon-free fuel, can be a mainstream source for high-grade heat, once it becomes more affordable.

Regarding electric efficiency, low grade heat and cooling, the technology challenge relies mostly in the penetration rate of the best already available technologies and in the circular economy.

> **"We should lever the full potential of hydrogen across the value chain – let's learn from the Chinese approach on PV, as they now dominate the market," Diederik SAMSOM**, Head of Cabinet of Executive Vice-President of the European Commission Frans Timmermans

Solutions, projects and scale-up

Steel and cement industries are responsible for at least 30% of the industry emissions[1]. Therefore, several of the proposed solutions focus on these two industries. Carbon capture, for storage (CCS) or usage (CCU), is also a candidate to reduce carbon emissions while keeping businesses thriving.

As of today, heat generation is carbon-intensive, due to the heavy use of fossil fuels. Therefore, several solutions arise to tackle this; some of which can also be applied to cement and steel production.

Most of the proposed solutions follow the logic below:

- Step 1, in the short term: launch tenders financed by green transition funds to kick start innovation, by allowing several pilot sites to be profitable while using breakthrough technologies.
- Step 2, 2020-2030 horizon: the construction and operation of pilot sites to foster cost reductions in breakthrough technologies, through learning experience, as well as scale-up.
- Step 3, 2030-2050: affordability of the breakthrough technologies enables sector-wide use. Carbon pricing also helps to bridge the economic gaps.

Major energy efficiency programs could also be launched, with the objective to accelerate penetration of best available technologies, practices and processes regarding:

- Electric motors that are widely used in equipment, fans, compressed air, conveyors, etc.
- Low-grade heat, with reuse from high-grade heat waste, high temperature heat pumps, industrial heat networks, waste, biomass and geothermal energy.
- Best cooling technologies, best use of refrigerants.

Finally, plastics industry could also both curb its emissions impact and its waste impact through innovative biomaterials and chemistry pathways.

Impacts

- **€216 billion total market (turnover + investments) per year in 2030.**
- **3.8 million permanent jobs in 2030.**
- **269 $MtCO_2$ avoided per year in 2030.**

Regional approach

The regions surrounding Antwerp (Belgium), Düsseldorf (Germany) and Rotterdam (Netherlands) display several noteworthy synergies. These industrial areas gather major CO_2 emitters (cement industries, steel industries, refineries), while also being located near underground CO_2 storage sites (mostly, North Sea oil and gas wells), and chemical industries that may use CO_2 as an input. Furthermore, the nearby offshore wind turbines of the North Sea could supply green electricity for the hydrogen creation process, as well as other industrial processes.

List of projects - INDUSTRY

Core processes for cement, steel and chemical industries

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Electrifying iron ore reduction enables to shift iron ore usage from high-GHG emissive BF/BOF integrated steel plants to low-GHG EAF plants

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Recycle and reuse process gases in the blast furnace and basic oxygenated furnace with CC

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Heat supply

#22 - SWITCH TO LOW-CO_2 FUELS FOR HIGH-GRADE HEAT INDUSTRY PROCESSES
Co-processing of waste and biomass in furnaces (from 300° to over 1000°C)

#23 - SWITCH TO LOW-CO_2 SOLUTIONS FOR LOW-GRADE HEAT INDUSTRY NEEDS
Recovery from high-grade heat waste, high-temperature heat pumps, bioenergy, geothermal energy, symbiosis heat networks

Electric efficiency

#24 - IMPLEMENT MASSIVE ELECTRIC EFFICIENCY PROGRAM FOR ALL EUROPEAN INDUSTRIAL PLANTS
High-efficiency motors, equipment and services along with digital and Industry 4.0

Other industrial products

#25 - REDUCE GHG IMPACT OF REFRIGERANTS
Mainstream the use of low-GHG refrigerants in all sectors

#26 - REDUCE GHG IMPACT OF PLASTIC THROUGH REUSE AND RECYCLING
Develop technology solutions to increase circularity of plastics

[1]EEA, 2018 data.

REDUCE THE NEED FOR CONCRETE THANKS TO BETTER DESIGN AND ALTERNATIVE CONCRETE FOR EQUIVALENT USAGES

New concrete and better use in construction

INDUSTRY | Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** Cement production accounts for 2%[1] of global CO_2 emissions; low-GHG alternatives exist but have not sufficiently penetrated the market yet
- **Solution:** Boost the use of biobased concrete, starting with 10,000 tons in 2030
- **Key impacts:** 2.0 $MtCO_2e$ avoided, €2.8 billion total market, 42,000 jobs in 2030

Innovation bet | Acceleration and scale-up | Drive to market scale

Project opportunity and ambition

- Incentivize and allow architects to reduce use of concrete: more efficient design of buildings and use of hollow structures.
- Launch technical studies to assess areas and sectors in which biobased concrete can be rapidly and effectively deployed.
- Update the European and national building standards to drive the adoption of biobased concrete and favor use of hollow-shaped concrete:
  - ◊ Concrete standards should be performance-based rather than composition-based.
  - ◊ Standards for calculating mechanical stress in buildings may have to be adapted to facilitate adaptation of shaped, hollow, and concrete blocks.
- Work with local authorities to encourage and reward the use of low-carbon building materials in public tenders.
- The success of the target described later is dependent on the collaboration between a range of stakeholders from the construction value chain. These include: the cement and concrete producers, the architects and contractors as well as local authorities.

Projects that inspired this analysis: Green-cast, Isobio and Novhisol.

Why this technology and project are needed to reach net-zero

- Concrete uses cement, the production of which is responsible for 2%[2] of total European CO_2 emissions.
- As global construction activities gear up, there is an urgent need for sustainable concrete no longer based on Portland cement, the basis of the construction industry for the past 200 years
- Most CO_2 emissions from Portland cement production are so-called process emissions. They are linked to the decomposition of limestone (calcium carbonate) into calcium oxide. And, CO_2 is the byproduct of the production process.
- Various alternatives of concrete are identified, they can be based on hemp and lime, non-heated clay, and fly ash, which is waste from thermal plants. For example: the 'green' concrete developed by the Drexel engineers, is based on old Egyptian technology, a form of alkali-activated cement that utilizes slag, an industrial byproduct, and limestone which does not require heating to produce.
- The target is to reach a market penetration rate of 30% by 2050, which is equivalent to 84 million tons[3] of concrete.

Impacts

	2030	2050
CLIMATE IMPACT	**2.0 $MtCO_2e$ avoided**	**5.9 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€2.8 billion total market** €3 billion turnover	**€8.4 billion total market** €8.4 billion turnover
JOBS	**42,000 jobs**	**126,000 jobs**

#14 [1]*From EPFL data (0.6 tCO_2e/ton of cement, https://www.research-collection.ethz.ch/handle/20.500.11850/301843), EC (163 Mt of cement produced in 2016, and 4.59 $GtCO_2e$ emissions in 2015)*
[2]*From EPFL data (0.6 tCO_2e/ton of cement, https://www.research-collection.ethz.ch/handle/20.500.11850/301843), EC (163 Mt of cement produced in 2016, and 4.59 $GtCO_2e$ emissions in 2015)*
[3]*See calculation for market size of concrete*

REPLACE THE USE OF CONCRETE WITH CARBON SINK MATERIALS IN NEW BUILD

Lower the climate impact of buildings with wood and alternative concrete

INDUSTRY

Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** New building construction is an emission-intensive process, with carbon-intense materials and high energy needs for transportation and equipment operation
- **Solution:** Upscale alternative comprehensive construction materials and approaches, using electric equipment (machines and vehicles), geothermal energy, and green areas
- **Key impacts:** 28.5 $MtCO_2e$, €131.7 billion total market, 2.5 million jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Build 500 buildings in each European country by 2025 using low GHG-intensity materials and construction methods, with construction materials split between wood and low-GHG emitting cement.

Project type 1: Wood buildings

Build 250 buildings from wood in each European country by 2025, sourcing 100% of the materials from Europe and using cross-laminated timber (CLT, sourced wherever possible from a local wood supply) in each country before 2025. These will be built in 10 European regions, corresponding to 10 different types of buildings: including offices, detached houses and apartment blocks.

- Building regulations will have to be adjusted accordingly.
- Use of electric machines and equipment, like in the city of Oslo, where the goal was not only to build a structure from low-GHG-emitting materials, will reduce emissions from construction activities, creating a 'net-zero construction site' using low emissions and locally sourced materials, where possible.
- Include other low-carbon technologies for a comprehensive approach (geothermal heating, heating pumps, and other eco-materials such as hemp, earth, etc.).
- Document key learnings from the project in terms of supply, market, regional constraints and difficulties in order to provide strong recommendations for scale-up.

Projects and stakeholders that inspired our analysis: National Wood Processing Cluster (Czech Republic), Lithuanian Prefabricated Wooden House Cluster, Altiflex (Danish building support supplier)

Project type 2: Low-GHG emitting cement buildings

Build 250 low-GHG cement-based buildings in each European country by 2025, sourcing 100% of the materials from Europe and using various techniques (see Industry part for more details on low-GHG cement). These will be built in 10 regions of Europe and include 10 different types of buildings, some detached houses, others apartment blocks, etc.

As for project type 1, electric machines and equipment as well as other low-carbon technologies will be used, and the key learnings will be documented.

Why this technology and project are needed to reach net-zero

- The construction industry accounts for 11% of global emissions, mainly because it uses a lot of concrete. This is especially the case in Southern Europe, where many buildings are made from cement (the production of which accounts for 2% of total European emissions). The choice of materials plays an important role in reducing energy demand and GHG emissions in the lifecycle of buildings. Alternatives to concrete, such as wood and low-carbon cement, produce less emissions, are carbon-neutral or even carbon-negative, and recyclable. Timber houses can have a negative carbon footprint, with $1m^3$ of spruce able to store 0.8 $MtCO_2$.
- Scandinavia is a European leader and 40% of Norway is covered in forests: its wood is exported for manufacturing into glulam and CLT in Austria and Germany, before being reimported into Norway for building construction.
- Construction activities are energy-intensive and use heavy machinery, equipment, and vehicles. The use of electric construction equipment reduces GHG emissions and projects combining both new materials and electric equipment considerably reduce emissions.

Impacts

	2030	2050
CLIMATE IMPACT	**28.5 $MtCO_2e$ avoided**	**42.8 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€131.7 billion total market** €131.7 billion turnover in 2030	**€197.6 billion total market** €197.6 billion turnover in 2050
JOBS	**2,502,000 jobs**	**3,753,000 jobs**

#16

REDUCE SHARE OF PORTLAND CLINKER IN CEMENT AND DEVELOP NEW ALTERNATIVE CLINKERS

Low-GHG and new cements

INDUSTRY

Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** Cement production accounts for 2%[4] of EU CO_2 emissions, and processes (excluding energy emissions) from clinker production alone generate 66% of those emissions
- **Solution:** Replacing clinker with substitutes (less clinker per unit of cement) can cut emissions by 18%[6]. Also, use of alternative clinkers (to replace the classic Portland clinker) achieves a 17%[7] cut in CO_2 emissions
- **Key impacts:** 6.8 $MtCO_2e$ avoided, €5.2 billion total market, 78,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Project type 1: Lower the share of clinker and adapt construction standards accordingly

Launch technical studies to determine which construction types are the most compatible with lower clinker-factor cement.

- In Europe, cement contains on average 73%[8] of ordinary Portland clinker.
- Introduce a lower clinker-factor cement: 60%.
- By 2030, the use of a lower clinker-factor cement on tenders for public construction work (bridges, buildings, etc.) helps ensure market uptake.

This would need to be paired with a supportive regulatory framework to ensure longevity.

Project type 2: Develop alternative clinkers on four pilot sites by 2025 hosted in cement production facilities to cut cement CO_2 emissions

- Launch feasibility study to select best-suited alternative clinker composition using existing research over six months.
- Launch industrial trials of alternative cements based on selected alternative clinkers for a year and a half on four real-size facilities producing 450 kilotons of cement across Europe (Poland, France, Italy, Germany) with different cement producers.
- Involve stakeholders across the construction value chain, including: the four cement production facilities that host the pilots, architects and contractors hired to test alternative cements on a construction site, and local authorities to commission construction work using new cement.
- Support market uptake of alternative cement through green public procurement programs and regulations.
- Revise EU and national standards to support the adoption of the new alternative cements on construction sites.

Why this technology and project are needed to reach net-zero

About 66%[9] of emissions from the cement manufacturing process come from the transformation of limestone at high temperature (decarbonation process) to produce clinker, which is traditionally composed of 75% limestone and 25% clay.

CEM I (ordinary Portland cement) contains 95% clinker. European standards EN197-1 allow other cement types with a clinker to cement ratio varying from 5% to 95%. Today in Europe, the average clinker to cement ratio (also called clinker factor) over all cement types is equal to 0.73. The most sold cement type is CEM II-A, where clinker is substituted with limestone up to a maximum substitution of 20%.

Introducing alternative decarbonized raw material into clinker composition such as recycled cement paste from demolition waste, air-cooled slag, and waste lime help lower emissions of the decarbonization phase of about 30% compared to ordinary Portland cement clinker. This technology is applicable to 100% of all building works by 2050 and 25% by 2030, and a lower clinker ratio in cement is applicable to the whole construction market.

Projects and existing pilots that inspired this analysis are:

- The AETHER project, which focused on a new type of clinker that can be used within existing industrial installations. This alternative clinker delivers a 25% to 30% cut in CO_2 emissions compared with conventional Portland cement as well as a 15% decrease in energy consumption due to a lower temperature needed for heat for raw materials transformation (1,225-1,300°C vs. 1,400-1,500°C for Portland's cement). Other types of low-CO_2 footprint clinkers are Sulpho-Aluminate Clinker (SAC), Ferro-Aluminate Clinker (FAC) or Calcium Aluminate Clinker.
- The Futurecem project 'Green Concrete II' reduces the clinker rate in cement by replacing it with 40% fillers, namely calcined clay and limestone. This low-clinker cement has the same performance as Portland cement and is being used to build two bridges in Denmark.

Impacts

	2030	2050
CLIMATE IMPACT	**Project type 1 (lower clinker ratio): 4.3 $MtCO_2e$** **Project type 2 (alternative to Portland clinker): 2.5 $MtCO_2e$**	**Project type 1 (lower clinker ratio): 17.4 $MtCO_2e$** **Project type 2 (alternative to Portland clinker): 5.8 $MtCO_2e$**
ECONOMIC IMPACT	**Project type 1 (lower clinker ratio): €3.3 billion total market** €3.3 billion turnover in 2030 **Project type 2 (alternative to Portland clinker): €2.0 billion total market** €2 billion turnover in 2025	**Project type 1 (lower clinker ratio): €13 billion total market** €13 billion turnover in 2050 **Project type 2 (alternative to Portland clinker): €4.6 billion total market** €4.6 billion turnover in 2050
JOBS	**Project type 1 (lower clinker ratio): 49,000 jobs** **Project type 2 (alternative to Portland clinker): 29,000 jobs**	**Project type 1 (lower clinker ratio): 196,000 jobs** **Project type 2 (alternative to Portland clinker): 69,000 jobs**

#16 [4]From CEPFL data (0.6 tCO_2e/ton of cement), EC (163 Mt of cement produced in 2016, and 4.59 $GtCO_2e$ emissions in 2015)
[5]From CEPFL data: 0.28 tCO_2e/ton of clinker for energy part, 0.54 tCO_2e/ton of clinker for process part. www.research-collection.ethz.ch/handle/20.500.11850/301843
[6]See calculations
[7]See calculations
[8]https://www.research-collection.ethz.ch/handle/20.500.11850/301843
[9]From EPFL data: 0.28 tCO_2e/ton of clinker for energy part, 0.54 tCO_2e/ton of clinker for process part.

#17

INDUSTRIALIZE THE USE OF CARBON CAPTURE AND USAGE TO DELIVER ULTRA-LOW CARBON CEMENT PRODUCTION

CCU solutions for cement industry

INDUSTRY | Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** The calcination phase in the cement industry is responsible for 66%[10] of cement emissions
- **Solution:** Capture unavoidable process emissions and reuse the CO_2 in industries such as concrete or petrochemicals
- **Key impacts:** 14.9 $MtCO_2e$ avoided, €1.1 billion total market, 16,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

The project goal is to scale up and industrialize carbon capture at cement kilns and CO_2 usage in the cement and concrete industry to capture 14% of cement production emissions by 2030 and 56% by 2050[11].

Project 1: Carbon capture by direct separation

Launch pilot projects of carbon capture by direct separation in 10% of all cement kilns with the ambition to capture a total of 7.8 $MtCO_2$ each per year by 2030.

- Direct separation consists of heating up the raw materials of clinker without getting the materials in direct contact with the fumes (see LEILAC project). The CO_2 emitted from the raw material decarbonation can then be channeled, with a high concentration.
- Assess candidate locations for direct separation projects at industrial scale (based on the existence of a market or outputs for captured CO_2).
- Incentivize the retrofitting of cement kilns as cement plants have a lifetime of 30 to 50 years.
- Push for quick standardization of 'green' cement products on the market to ensure market uptake and economic viability, as carbon capture amounts to more than 50%[12] of cement production cost.
- Key stakeholders include cement producers, contractors and architects, and law-makers.
- Set up support mechanisms such as carbon border adjustment.

Projects that inspired this analysis: LEILAC project in Lixhe, Belgium.

Project 2: Oxyfuel combustion in cement kilns

Launch pilot projects of oxyfuel combustion to retrofit 10% of all cement kilns and capture 8.2 $MtCO_2$[13] per year by 2030.

- Oxyfuel is the process of using pure oxygen instead of air to burn a fossil fuel. Therefore, the fumes can be cycled several times (thanks to the oxygen content), and the exhaust is rich in CO_2.
- Launch a feasibility assessment of oxyfuel combustion in cement kilns, using studies carried out on oxyfuel combustion in boilers.
- Identify industrial sites and launch industrial scale pilot projects creating synergies between cement plants producing CO_2 and neighboring chemical or petrochemical plants for CO_2 usage on eight big production sites, one in each of the following countries: Poland, Slovakia, Czech Republic, Romania, Germany, France, Italy and Spain.
- Key stakeholders to involve are cement producers, the SINTEF (Norwegian cluster with expertise in the subject), the European Cement Research Association, gas grid operators to transport CO_2, national and European authorities to push for public acceptance.

Projects that inspired this analysis: Norway through the SINTEF, Germany, Italy, France (industrial clusters).

Why this technology and project are needed to reach net-zero

Improvement of energy use in cement industry (switching fuels) can only cut emissions up to 34%[14]. Without carbon capture, use and storage, the emissions from the process would remain, and prevent reaching net-zero cement.

- Direct separation has been demonstrated by Leilac 2, capturing 80%[15] of CO_2 from the process (excluding CO_2 from energy combustion).
- Oxyfuel combustion (process of using pure oxygen instead of air to burn a fossil fuel) can cut up to 90% of post-combustion emissions: the Westküste100 project led by LafargeHolcim in Germany is expected for instance to capture 1 $MtCO_2$ per year by 2030 and use it or part of it to produce jet fuel.
- Captured CO_2 can also be reused in recycled concrete granulates to increase material strength. Active clusters on this topic are France (Fastcarb project and Solidia tests), Germany (targeted as a market by startup CarbonCure) and Sweden (targeted as a market by startup CarbonCure).

Impacts

	2030	2050
CLIMATE IMPACT	**Project type 1 (direct CO_2 separation): 7.8 $MtCO_2e$ avoided** **Project type 2 (oxyfuel): 7.1 $MtCO_2e$ avoided**	**Project type 1 (direct CO_2 separation): 31.3 $MtCO_2e$ avoided** **Project type 2 (oxyfuel): 32.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**Project type 1 (direct CO_2 separation): €680 million total market** €3 billion cumulated investment by 2030, €340 million yearly average (2020-2030), €340 million turnover in 2030 **Project type 2 (oxyfuel): €400 million total market** €1.9 billion cumulated investment by 2025, €200 million yearly average (2020-2030), €200 million turnover in 2030	**Project type 1 (direct CO_2 separation): €1.8 billion total market** €14 billion cumulated investment by 2050, €460 million yearly average (2020-2050), €1.4 billion turnover in 2050 **Project type 2 (oxyfuel): €0.8 billion total market** €5.8 billion cumulated investment by 2025, €200 million yearly average (2020-2050), €600 million turnover in 2050
JOBS	**Project type 1 (direct CO_2 separation): 10,000 total jobs** 5,000 construction jobs from investment 5,000 operation jobs from turnover **Project type 2 (oxyfuel): 6,000 total jobs** 3,000 construction jobs from investment 3,000 operation jobs from turnover	**Project type 1 (direct CO_2 separation): 27,000 total jobs** 6,800 construction jobs from investment 20,500 operation jobs from turnover **Project type 2 (oxyfuel): 12,000 total jobs** 3,000 construction jobs from investment 9,000 operation jobs from turnover

#17 [10]From EPFL data: 0.28 tCO_2e/ton of clinker for energy part, 0.54 tCO_2e/ton of clinker for process part. www.research-collection.ethz.ch/handle/20.500.11850/301843
[11]See calculation
[12]https://www.globalccsinstitute.com/archive/hub/publications/201688/global-ccs-cost-updatev4.pdf
[13]See calculation
[14]The complementary percentage of 66%, which was given earlier for the emissions from calcination process.
[15]https://www.project-leilac.eu/leilac-pilot-plant

HYDROGEN REDUCTION OF IRON ORE FOR BASIC OXYGENATED FURNACES AND ELECTRIC ARC FURNACES

Use green hydrogen from renewables and electrolysis to decarbonize steel industry

INDUSTRY

Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** Steel production accounts for 35%[16] of EU's total industrial emissions, mostly due to iron reduction with coke derived from coal
- **Solution:** Green hydrogen based on direct reduction of iron ore (DRI) could cut emissions of the sector by 15% in 2050
- **Key impacts:** 13.7 $MtCO_2e$ avoided, €6.1 billion total market, 9,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Reach 6% of the total steel market by 2030 using hydrogen-based iron ore reduction

- Draft a sector roadmap that assesses the key steps for upgrading switching existing plants, i.e. retrofitting or replacing the blast furnaces (which transforms iron ore into pig iron) with green hydrogen DRI facility and a shaft furnace (which transforms iron ore into direct reduced iron, or DRI). DRI can then be charged into an electric arc furnace, skipping altogether the basic oxygenated furnace step that usually follows the blast furnace.
- Having a shaft furnace on-site, which currently may use natural gas instead of hydrogen, will help reduce the length of the retrofit process. Furthermore, the sites must have a supply of green hydrogen (either from the market or produced on-site with electrolyzers).
- Stakeholders include steel plants operating the selected pilot sites, a green hydrogen supplier, the national authority to coordinate finance schemes, the 'Green Steel for Europe' project consortium and its partners (including ESTEP, EUROFER, BFI, CEPS, IMZ, and CSM) for know-how and industry uptake.
- To secure the market uptake, it needs to be ensured that green steel remains competitive compared to regular steel with a financial support scheme (such as carbon border adjustment, carbon price, and feed-in tarriffs) and guaranteed outputs through green public procurement programs to counterbalance high prices.
- Location: Steel producing regions that have sites equipped with BF/BOF in Northern Spain, the Ruhr region, North of France, Sweden, Poland and the Czech Republic.

Projects that inspired this analysis: HYBRIT project in Sweden, which will consume 2633 kWh of green hydrogen and emit 25 kg of CO_2 per ton of steel compared to the Swedish average of 1.6 t of CO_2 per ton of steel, for a production cost 30% higher than average.

Why this technology and project are needed to reach net-zero

- 60% of steel is produced through the primary route, which consists of melting iron ore pellets and coke in a blast furnace (BF) to produce pig iron. It then goes through a basic oxygenated furnace (BOF) to produce liquid steel[19] This process emits 1.88 tCO_2 per ton of steel[19] due to the use of coal to reduce iron ore into pig iron. The secondary route consists of melting scrap in an electric arc furnace (EAF) to obtain liquid steel. The emissions from the secondary route depend on the electricity used to power the EAF, and amount on average to 0.5 tCO_2 per ton of steel produced.[20]
- The direct reduction technology reduces iron ore in a shaft furnace with green hydrogen and reduces iron ore into DRI which can be fed in an electric arc furnace to produce liquid steel. Therefore, effectively by-passing the carbon-intensive primary route mentioned above.
- As such, to reduce GHG emissions on a large scale in Europe, emphasis should be on the replacement or retrofitting of existing BF/BOF brownfield plants. Those plants are spread across Europe but are mainly located in Slovakia, Poland, Czech Republic, Austria, Northern Spain and the Ruhr region.
- The aim is to roll out this technology on 33% of BF/BOF (or 20% of the total steel market) in Europe by 2050.
- Ramping up the green hydrogen direct reduction will require new skills and create new jobs as well as provide flexibility to the steel industry. However, it will also add pressure on the demand for green hydrogen in Europe.
- Temporary support mechanisms must be put in place to offset the high prices of green hydrogen, as compared to coal and natural gas, and cover the cost differential between fossil-based steel and green steel.

Impacts

	2030	2050
CLIMATE IMPACT	**13.7 $MtCO_2e$ avoided**	**43.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€6.1 billion total market** €1.5 billion investment by 2030, €150 million yearly average (2020-2030) €5.9 billion turnover	**€19 billion total market** €3.6 billion investment between 2030 and 2050, €180 million yearly average (2030-2050) €18.8 billion turnover
JOBS	**91,000 total jobs** 2,000 construction jobs for investment 89,000 production jobs for turnover	**285,000 total jobs** 3,000 construction jobs for investment 282,000 production jobs for turnover

#18 [16]Wortler, et al., 2013: 1.88 tCO_2e/ton of steel. EUROFER: 160 Mt of steel production: https://www.eurofer.eu/assets/Uploads/European-Steel-in-Figures-2020.pdf
In Depth Analysis EU, EC, (868 $MtCO_2e$ emitted by industry, figure 11): https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf
[17]Definition: https://www.metallics.org/pig-iron.html
[18]Definition: https://www.metallics.org/dri.html
[19]Wortler, et al., 2013
[20]http://www.carmeuse-steel.com/news/co2-impact-steel-making-industry

ELECTROWINNING OF IRON ORE FOR ELECTRIC ARC FURNACES

Electrifying iron ore reduction enables to shift iron ore usage from high-GHG emissive BF/BOF integrated steel plants to low-GHG EAF plants

INDUSTRY

Core processes for cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** Iron and steel production is based on coal and accounts for 35%[21] of EU's total industrial emissions. About 90% of these emissions come from iron and coke reduction
- **Solution:** Electrowinning of iron ore avoids the use of carbonated reductants and lifts the scrap availability constraint, which currently limits the use of electric arc furnaces
- **Key impacts:** 2.6 MtCO_2e avoided, €0.2 billion total market, 3,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

- The aim of this R&D program is to accelerate the scale-up of steel making based on electrowinning, from laboratory level to industrial trials.
- The project aims to launch pilots in plants equipped with an electric arc furnace (EAF), preferably located near an important source of renewables coupled with a storage solution to power the EAF without interruption.
- The objective is to further test the technology (TRL 8 validated) and monitor profitability.
- Stakeholders include steel producers operating the pilot plant, utility companies to supply green power, and a third party to supply the electrowinning electrolyzer.
- The program research will be in a region where green power is affordable and abundant, such as Sweden, the Netherlands or Germany, which have abundant offshore wind power production. Poland may also be a candidate as it plans to invest in 5 GW of offshore wind farms by 2030.
- The project provides momentum to the steel sector to cut 17%[22] of its emissions by 2050.

Projects that inspired this analysis: Siderwin project, which piloted the production of 25 tons of steel annually. The pilot achieved a CO_2 emissions reduction of 87%[23] as compared to BOF/BF steel production and reduced direct energy consumption by 31%.

Why this technology and project are needed to reach net-zero

- There are currently 500 steel plants in Europe, of which 30 are integrated steel plants equipped with blast furnaces and basic oxygenated furnaces for primary production of steel. The rest is produced by electric arc furnaces, through a secondary production route.
- Steel is produced at 60% through a primary route[24], which consists of melting iron ore pellets and coke in a blast furnace to produce pig iron. It then goes through a basic oxygenated furnace to produce liquid steel. This process emits 1.88 tCO_2 per ton of steel due to the use of coal to reduce iron ore into pig iron. The secondary route, based on scrap melting in an electric arc furnace (EAF), only emits on average 0.5 tCO_2 per ton of steel produced[25]. However, it only covers 40% of the European production due to limited steel scrap availability.
- The electrowinning technology overcomes the limited steel scrap availability issue by processing iron-ore into an EAF. It therefore has the potential to help increase the EAF production route compared to production from the BF/BOF route. It is energy efficient as the iron-ore conversion takes place at a low temperature (110°C) and there are no losses due to conversion (as opposed to direct reduction based on green hydrogen). However, this technology can only reach demonstration stage by 2030. It also needs to be combined with a storage solution to ensure a continuous supply of electricity to the EAF. The final target is to achieve 33%[26] of blast furnaces and basic oxygenated furnaces and switch their production to EAF via electrowinning by 2050.
- Carbon border adjustment measures must be put in place so that producers from Europe and outside Europe bear the same carbon cost. Alternatively, other temporary support mechanisms must be put in place to offset the high prices of green electricity compared to coal and natural gas.

Impacts

	2030	2050
CLIMATE IMPACT	**2.6 $MtCO_2e$ avoided**	**51.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€180 million total market** €500 million cumulated investment by 2030, €50 million yearly average (2020-2030) €130 million turnover in 2030	**€2.2 billion total market** €7.8 billion cumulated investment by 2030, €260 million yearly average (2020-2050) €2.0 billion turnover in 2050
JOBS	**3,000 total jobs** 1,000 construction jobs for investment 2,000 production jobs for turnover	**33,000 total jobs** 4,000 construction jobs for investment 29,000 production jobs for turnover

#19 [21]Wortler, et al., 2013: 1.88 tCO_2e/ton of steel. EUROFER: 160 Mt of steel production: https://www.eurofer.eu/assets/Uploads/Europe-an-Steel-in-Figures-2020.pdf)
In Depth Analysis EU, EC, (868 $MtCO_2e$ emitted by industry, figure 11): https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf
[22]See calculation
[23]Siderwin project, https://www.siderwin-spire.eu/content/home
[24]https://www.eurofer.eu/assets/Uploads/European-Steel-in-Figures-2020.pdf
[25]http://www.carmeuse-steel.com/news/CO_2-impact-steel-making-industry
[26]See penetration, in respect to current share of BF/BOF (primary route)

REUSE PROCESS GASES AND CAPTURE CO_2 TO LOWER EMISSIONS OF STEEL INTEGRATED PLANTS

Recycle and reuse process gases in the blast furnace and basic oxygenated furnace with CC

INDUSTRY | Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** In Europe, 90%[27] of GHG emissions from steel production come from iron reduction from coke, which occurs in the blast furnace
- **Solution:** Recycling process gases (CO and H_2) from the blast furnace back into the process limits emissions and the need for coke as a reductant
- **Key impacts:** 16.8 $MtCO_2e$ avoided, €1.8 billion total market, 27,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

- The aim of the project is to replicate and scale up the existing technology of recycling top gases from blast furnaces.
- The first step is to carry out an assessment and mapping of existing top gases blast furnaces recycling projects and the required steps to retrofit blast furnaces with the recycling equipment to recover CO_2.
- Launch pilot plants equipped with blast furnaces, producing a significant quantity of steel (above three million tons yearly) and preferably located near a chemical park to ensure outputs for captured CO_2 will be selected. The technology is already available hence scale up can be carried out rapidly.
- The project starts with one full-scale integrated pilot plant, producing 3.3 million tons of steel per annum. The aim is to have finished the retrofit by 2025. The technology will then be replicated on 6% of the European steel production.
- Stakeholders include steel producers, chemical platforms, local authorities to discuss potential CO_2 storage and experts such as the EUROFER Sustainability for Steel Construction Products Committee, the European Steel Technology Platform and the Green Steel for Europe Consortium for knowledge sharing.
- Key geographical clusters which have recycling projects are the Ruhr region, Poland, Slovakia, Czech Republic, Austria, and Northern Spain as they possess integrated steel making plants with blast furnaces.

Projects that inspired this analysis: Steelanol project (carbon capture and usage in Ghent); LKAB project in Lulea (Sweden).

Why this technology and project are needed to reach net-zero

- Most European steel (about 60%[28]) is made via the primary route, which consists of melting iron ore pellets and coke in a blast furnace to produce pig iron. It then goes through a basic oxygenated furnace to produce liquid steel. BF and BOF installations have an average lifetime of 15 to 20 years and are used across Europe to produce steel but are predominant in Eastern Europe.
- To decrease the amount of CO_2 emitted while keeping the current infrastructures in place, steel plants can invest in technologies that capture CO_2, H_2, and CO from the top gases leaving the blast furnace and reinject them into the furnace after preheating.
- This has a double benefit: reinjected gases act as reducing agents, decreasing the quantity of coke and coal needed to reduce iron ore, and less CO_2 is emitted from the top gases.
- To maximize the technology potential, the carbon captured in excess that cannot be reinjected into the furnaces can be sold to other industrial plants to produce biofuels. This is the case with the Steelanol project located in Ghent, Belgium, which uses CO_2 captured from a steel plant furnace to produce bioethanol.

Impacts

	2030	2050
CLIMATE IMPACT	**16.8 $MtCO_2e$ avoided**	**53 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€1.8 billion total market** €11.4 billion cumulated investment by 2030, €1.1 billion yearly average (2020-2030) €650 million turnover in 2030	**€3.3 billion total market** €36.2 billion cumulated investment by 2050, €1.2 billion yearly average (2020-2050) €2 billion turnover in 2050
JOBS	**27,000 total jobs** 17,000 construction jobs for investment 10,000 production jobs for turnover	**49,000 total jobs** 18,000 construction jobs for investment 31,000 production jobs for turnover

#20 [27]*Roland Berger, The future of steelmaking, May 2020*
[28]*https://www.eurofer.eu/assets/Uploads/European-Steel-in-Figures-2020.pdf*

#21

SCALE ON-SITE GREEN HYDROGEN PRODUCTION IN REFINERIES

Shift from fossil-based H_2 to decarbonized H_2 for feedstock usage

INDUSTRY

Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** The industrial sector consumes 90% of European hydrogen, however most of this hydrogen is produced using fossil fuels
- **Solution:** Create new industrial clusters and a steering European entity to reach 12% green hydrogen in refineries' consumption by 2030
- **Key impacts:** 2.1 $MtCO_2e$ avoided, €1 billion total market, 15,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

- This project aims to accelerate the shift from grey hydrogen to green hydrogen production, which is based on the electrolysis from renewable sources. It will start by launching a call for participation to select refineries that are interested in investing in large scale green hydrogen installations on-site or in purchasing green hydrogen.
- The target is to start with five real-size electrolyzer pilot projects of 175 MW each by 2025. Green hydrogen will avoid 75% of GHG emissions compared to the current carbon footprint of grey hydrogen. By 2030, the objective is to scale up to 3.7 GW electrolyzer projects installed to supply 12% of the refinery demand of H_2.
- On average, a refinery consumes 30,000 tons of hydrogen yearly, of which 25% comes from on-site processes (not replaceable) and 75% is sourced externally. Green hydrogen can replace this external sourcing.
- Hydrogen can be used to store renewable energy before being consumed, and excess hydrogen can be sold to neighboring industrial chemical or steel plants.
- Stakeholders: oil and gas players operating refineries in Europe, chemical and steel companies, specialized organizations such as Hydrogen Europe, and the Fuel Cells and Hydrogen Joint Undertaking.
- Geographical clusters: Benelux and the Rhine region, Southern France, Northern Italy, Portugal, as well as secondary clusters in Ireland, Finland, Lithuania, North East Spain and Romania. Also, involve big chemical companies, oil and gas companies, and experts' societies such as FuelsEurope and Concawe.

Projects that inspired this analysis: the REFHYNE initiative in Germany, the MULTIPLHY initiative in Rotterdam, HySynergy in Denmark, and Delfzijl in the Netherlands (see details in following section).

Why this technology and project are needed to reach net-zero

- Industry consumes 90% of European hydrogen which is mostly grey hydrogen produced from fossil fuels. In the refining sector, 6% of emissions are associated with the production of hydrogen consumed. As refineries account for 23% of industrial emissions (23% of 868 $MtCO_2e$[29], thus 199 $MtCO_2e$), this yields to 12 $MtCO_2$ emitted yearly for hydrogen used in refineries.
- This consumption pattern is expected to slightly drop or remain stable up to 2050, of which 66% should be used for biofuels and 33% for traditional refined products.
- Producing green hydrogen on-site using electrolyzers will considerably lower these emissions. Starting with a 12%[30] market penetration by 2030 to help set the pace to reach 30% by 2050.
- This project will contribute to achieving the 2030 proposition set by Hydrogen Europe of 2×40 GW electrolyzer capacity for the EU and its neighbors (such as North Africa and Ukraine) alike[31]. The roadmap estimates that Europe's 40 GW can be split into a 6 GW captive market (hydrogen production at the demand location) and a 34 GW hydrogen market (hydrogen is transported), demonstrating the need of industrial cooperation in clusters.
- Several projects based on this technology have already been launched, such as:
  - ◊ REFHYNE: 10 MW Polymer Electrolyte Membrane electrolyzer at the Wesseling site in the Rheinland Refinery Complex, expected to start operating in 2020.
  - ◊ MULTIPLHY: High-Temperature Electrolyzer system supported by a consortium involving the CEA, Neste (the world's leading provider of renewable diesel and renewable jet fuel), plant builder Paul Wurth, and cleantech company Sunfire in Rotterdam.
  - ◊ HySynergy: supported by Shell and Everfuel in Fredericia, Denmark, for a 20 MW electrolyzer from 2022-2023 for €20 million, and it could be scaled up to 1 GW.

Impacts

	2030	2050
CLIMATE IMPACT	**2.1 $MtCO_2e$ avoided**	**5.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€990 million total market** €920 million investment by 2030, €92 million yearly average (2020-2030) €900 million turnover in 2030	**€2.3 billion total market** €1.8 billion investment between 2030 and 2050, €90 million yearly average (2030-2050) €2.3 billion turnover in 2050
JOBS	**15,000 total jobs** 1,000 construction jobs for investment 14,000 production jobs for turnover	**35,000 total jobs** 1,000 construction jobs for investment 35,000 production jobs for turnover

#21 [29]*In Depth Analysis EU, EC, figure 11: https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf*
[30]*See calculation*
[31]*https://www.hydrogen4climateaction.eu/2x40gw-initiative*

SWITCH TO LOW-CO_2 FUELS FOR HIGH-GRADE HEAT INDUSTRY PROCESSES

Co-processing of waste and biomass in furnaces (from 300° to over 1000°C)

INDUSTRY | Heat supply

IN A NUTSHELL...

- **Issue:** Heat in industry for high-temperature processes is produced mostly from fossil fuels. About 61%[32] of industry CO_2 emissions come from the supply of high-grade heat created by fossil fuel combustion
- **Solution:** Generalize the use of biomass or waste as feedstock for high-temperature production processes in the cement, steel and food industries
- **Key impacts:** 26.7 $MtCO_2e$ avoided, €7.4 billion total market, 110,000 jobs in 2030

Innovation bet | Acceleration and scale-up | **Drive to market scale**

Project opportunity and ambition

- This project will increase the substitution rate of low CO_2 fuels in high-grade heat processes for all industries. This enables a 20% reduction in CO_2 emissions by 2050.
- This can be achieved by using multiple sources, i.e. biomass, end-of-life tires, industrial commercial and municipal solid waste, construction and demolition waste, plastics, textiles, paper residues, biomass waste, waste oils and solvents. However, a focus on non-hazardous domestic waste is planned specifically for this project at a European scale.
- Initial investment required targets light retrofitting in the form of storage facilities for waste, sorting capacities including magnetic separation, and fine shredding. There is little environmental impact resulting from the combustion of waste as the cement kiln temperature is around 1,400°C as compared to 950°C in regular municipal incinerators. As such, there is only a negligible quantity of residues.
- The targeted roll-out requires the development of regional clusters involving all stakeholders: industries, local authorities and waste providers.

Projects that inspired this analysis are substitution projects in the industry, which include the Allmendingen cement plant in Germany and the Retznei plant in Austria. Both plants run on 100% alternative fuels. Additionally, there is the Brevik plant in Norway, which uses 72% of alternative fuels.

Why this technology and project are needed to reach net-zero

- Biomass and waste represent only 10% of supply for process heating[33]. Waste valorization is best suited to treating district waste or plastic waste, as the very high temperatures remove residues and toxic emissions.
- The cement industry has already developed the substitution of fossil fuel sources to produce high-grade heat, currently reaching an average thermal substitution rate of 40%[34] in Europe. Other industries, especially the steel industry and the food industry, must follow suit to cut down emissions from the combustion process while using non-upgraded waste.
- Inspiring projects in the cement industry are the following:
    - ◊ The Allmendingen plant in Germany operated by Schwenk Cement uses 100% alternative fuels. The cement plant recycles exhaust gases to dry municipal sludge and produce heat for the cement kiln.
    - ◊ The Retznei plant in Austria operated by LafargeHolcim uses 35% construction and demolition waste for its processes.
- The main obstacle to this technology is the identification of alternative waste and biomass sources while also ensuring a stable supply.

Impacts

	2030	2050
CLIMATE IMPACT	**26.7 $MtCO_2e$ avoided**	**106.9 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€7.4 billion total market** €7.4 billion turnover in 2030	**€29.4 billion total market** €29.4 billion turnover in 2050
JOBS	**110,000 jobs**	**441,000 jobs**

#22 [32]Capgemini analysis, based on Eurostat (534 $MtCO_2e$ for high-grade industrial heat) and In Depth Analysis EU, EC, figure 11 (868 $MtCO_2e$ for industrial emissions): https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf
[33]https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118592/towards_net-zero_emissions_in_the_eu_energy_system_-_insights_from_scenarios_in_line_with_2030_and_2050_ambitions_of_the_european_green_deal_on.pdf (page 37)
[34]https://cembureau.eu/media/1892/cembureau-what-is-coprocessing.pdf

SWITCH TO LOW-CO_2 SOLUTIONS FOR LOW-GRADE HEAT INDUSTRY NEEDS

Recovery from high-grade heat waste, high-temperature heat pumps, bioenergy, geothermal energy, symbiosis heat networks

INDUSTRY | Heat supply

IN A NUTSHELL...

- **Issue:** Low-grade heat accounts for 840 TWh[35], which could partly be covered by wasted heat generated from high-temperature processes, cooling, or even geothermal
- **Solution:** Develop renewable energies (such as biomass, geothermal, and heating pumps), symbiosis and circular reuse of wasted high-grade heat, heat networks within large industrial clusters and ports
- **Key impacts:** 50.8 $MtCO_2e$ avoided, €7.2 billion total market, 107,000 jobs in 2030

Innovation bet | Acceleration and scale-up | **Drive to market scale**

Project opportunity and ambition

Project type 1: Power generation and low-grade heat reuse from lost high-grade heat, by 2030 covering 10% of the low-grade heat demand in industry, and avoiding 27 $MtCO_2e$

- Launch tenders for power generation from high-grade and low-grade heat reuse (organic Rankine cycles for Combined Heat Power, TFC Trilateral Flash Cycle, etc.) in the industrial context.
- Typically, high-grade heat users in the steel, cement, and glass industries, in addition to their internal efficiency set-ups (such as regeneration, pre-heating, and others), could provide low-grade heat (taken from their waste heat), to nearby consumers.
- Projects are expected to deliver new technologies before 2025, to be scaled up in Europe by 2030.

Projects that inspired this analysis: H-REII project, Tasio project

Project type 2: Heat recovery, reuse and industrial heating network in industry clusters, by 2030 covering 3% of the low-grade heat demand in industry, and avoiding 8 $MtCO_2e$

- In large multi-industry or port clusters with both high-grade waste (such as metals, minerals, and chemistry) and low-grade needs.
- Build 600 MW of heat recovery installations and network grids if the infrastructure is not readily available.

Project type 3: Direct use of deep geothermal energy in industry, by 2030 covering 5% of the low-grade heat demand in industry, and avoiding 12 $MtCO_2e$

- Support 40 exploratory studies by 2022 and 30 drillings by 2025.
- 20 industrial plants successfully switch from fossils (in priority coal) to geothermal energy.
- Set up a georisk guarantee fund to limit risk exposure related to not finding appropriate geothermal resources, in order to foster private funding and lower financial cost.
- Priority to countries with largest potentials, i.e. Eastern Europe, Germany, France, Italy, and the Netherlands.

Projects that inspired this analysis: Rittershoffen geothermal plant of Roquette Group, Tuscan brewery 'Vapori di Birra' in Italy

Project type 4: Heat-cooling symbiosis high-temperature heating pumps in agro-industry, by 2030 covering 1% of the low-grade heat demand in industry, and avoiding 3 $MtCO_2e$

- Build 600 MW recovery capacity from high-temperature heat pumps.
- 1 kW of electrical power will typically generate at the same time 3 kW of cold and 4 kW of heat. If used alone for cold, 4,000 W of heat will be wasted. If used alone for heat, 3 kW of cold will be lost.
- When the cold and low-grade heat are simultaneously needed, high-temperature heating pumps (thermo-refrigerated pumps) can be used for agro-industry and other industries.
- When a plant does not simultaneously use heat and cold, the project can still ensure recovery with a heat exchanger, and distribution to the consumer through a heat or cold network.

Why this technology and project are needed to reach net-zero

Low-grade heat is a significant part of emissions in specific industrial sectors. These emissions could be reduced through renewables (such as biomass, heat-pumps, and geothermal energy), or by setting up a circular, industrial symbiosis approach, under which excess high-grade heat in one company could be used as low-grade heat in another.

- The industrial sector in EU consumes 2,800 TWh and is responsible for 862 $MtCO_2$ annually.
- High-grade heat (from 300°C to over 1,000°C) accounts for 70% of industrial heat and 62% of its CO_2 emissions, i.e. 1,960 TWh and 534 $MtCO_2$, mostly in metal, mineral, glass, and chemical industries.
- Low-grade heat (from 60°C to 300°C) accounts for 30% of heat, i.e. 840 TWh and 327 $MtCO_2$, mostly in food, paper, textile and partly in the above-mentioned sectors.
- Most of this heat is generated by fossil energies (gas, coal and partly liquids). This fossil-based heat could be replaced by renewable energies such as deep geothermal energy, potentially available on 25% of the European surface, high-temperature (above 100°) industrial heating pumps, biomass and biogas.
- Symbiosis is a way to ensure the excess high-grade heat is in one industrial facility is used in another facility.
    - ◊ A technical potential of 400 TWh waste heat from high-grade heat could be recovered to generate power and feed low-grade heat needs. The heat can be used in the same industrial plant, or between neighboring plants within similar industrial clusters (typically a metal or chemical plant close to a paper or food plant).
    - ◊ Another symbiosis to be looked after is between heat and cold needs. In the agro-industry, a high-temperature heating pump can produce cold and push the heat to feed low-grade needs, rather than losing it to the air.
    - ◊ Having a heat network within the industrial cluster is key to transporting the waste heat from high-grade industries or cold industries to neighboring industries, and if applicable to nearby city district heating (longer network).

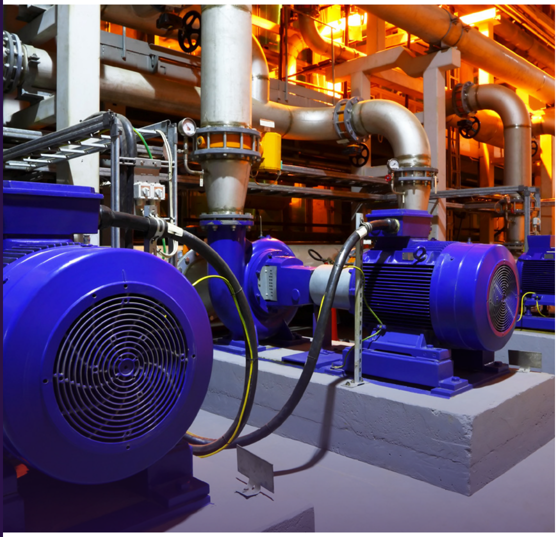
Impacts

	2030	2050
CLIMATE IMPACT	**Project type 1 (reuse and CHP): 26.7 $MtCO_2e$** **Project type 2 (reuse in heat networks): 8.4 $MtCO_2e$** **Project type 3 (deep geothermal energy): 12.4 $MtCO_2e$** **Project type 4 (cold-heat symbiosis): 3.3 $MtCO_2e$**	**Project type 1 (reuse and CHP): 80.1 $MtCO_2e$** **Project type 2 (reuse in heat networks): 25.1 $MtCO_2e$** **Project type 3 (deep geothermal energy): 37.3 $MtCO_2e$** **Project type 4 (cold-heat symbiosis): 9.8 $MtCO_2e$**
ECONOMIC IMPACT	**Project type 1 (reuse and CHP): €5.4 billion total market** €5.4 billion turnover in 2030 **Project type 2 (reuse in heat networks): €700 million total market** €700 million turnover in 2030 **Project type 3 (deep geothermal energy): €900 million total market** €900 million turnover in 2030 **Project type 4 (cold-heat symbiosis): €230 million total market** €610 million investment by 2030, €61 million yearly average (2020-2030), €170 million turnover in 2030	**Project type 1 (reuse and CHP): €16.1 billion total market** €16.1 billion turnover in 2030 **Project type 2 (reuse in heat networks): €2.0 billion total market** €2.0 billion turnover in 2030 **Project type 3 (deep geothermal energy): €2.8 billion total market** €2.8 billion turnover in 2030 **Project type 4 (cold-heat symbiosis): €600 million total market** €1.8 billion investment by 2050, €60 million yearly average (2020-2050), €500 million turnover in 2050
JOBS	**Project type 1 (reuse and CHP): 80,000 jobs** **Project type 2 (reuse in heat networks): 10,000 jobs** **Project type 3 (deep geothermal energy): 14,000 jobs** **Project type 4 (cold-heat symbiosis): 3,000 jobs**	**Project type 1 (reuse and CHP): 241,000 jobs** **Project type 2 (reuse in heat networks): 29,000 jobs** **Project type 3 (deep geothermal energy): 42,000 jobs** **Project type 4 (cold-heat symbiosis): 8,000 jobs**

IMPLEMENT MASSIVE ELECTRIC EFFICIENCY PROGRAM FOR ALL EUROPEAN INDUSTRIAL PLANTS

High-efficiency motors, equipment and services along with digital and Industry 4.0

INDUSTRY | Electric efficiency



IN A NUTSHELL...

- **Issue:** EU industry consumes 400 TWh of electricity via mechanical motors, pumps, fans, air compressors, cooling and conveyors, which are often inefficient
- **Solution:** By 2030, conduct an energy efficiency audit in all industrial facilities in Europe and drive implementation of 80% of the recommended measures, including replacement of least performing equipment with best available technologies
- **Key impacts:** 19.9 $MtCO_2e$ avoided, €280 billion cumulated investment, 420,000 jobs in 2030

Innovation bet | Acceleration and scale-up | **Drive to market scale**

Project opportunity and ambition

Launch massive electric efficiency audit and replacement program.

- Process Scope (equipment using electric motors): mechanical equipment, pumps, fans, air compressors, cooling and conveyors.
- Technical scope: motors and equipment, end-to-end efficiency, performance monitoring systems, sensors, optimized maintenance and management (Industry 4.0).
- Between 2020 and 2022, launch pilot projects targeting 100 industrial sites from every sector across Europe (10 sectors x 10 company audit test sites to find upscaling improvement efficiency).
- Each sector pilot attributed via tender.
- Pilots' objective is to elaborate and validate the technical, financial and delivery approaches.
- Additional pilots' objective is to prepare upscaling to serve 100% of European industries by 2030. This is done by replacing 40% of the least efficient equipment with high-performance electric motors and best Industry 4.0 practices.
- Approach and financing scope: address change inside a multisite company and provide financial solutions.
- Public support design: may include public tenders for large scale equipment change, providing subsidies such as Contract for Difference against base (TCO) total cost of ownership.
- Platforming: support the launch of motor procurement platforms to increase volumes supplied by European producers and lower costs of European funding.
- Scale up audits and implementation at European scale.

Key stakeholders:

- Labelled operation and maintenance service providers, OEM service branches, energy performance consultancies.
- ESCOs, financial services, public authorities to finance investments needed and lower the risk of operation funding through guaranteed funds.

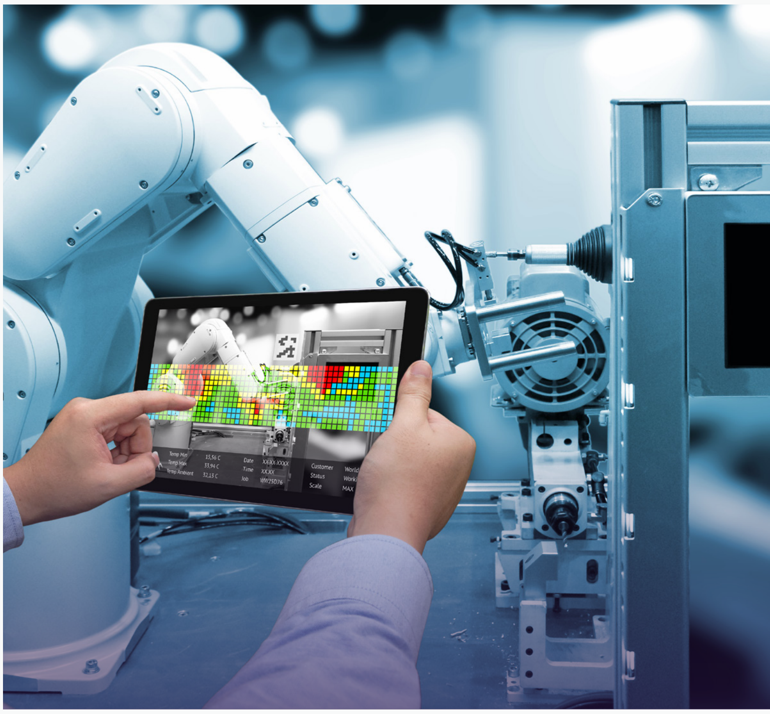
Projects that inspired this analysis: Task Energy Audits for Motor Systems of the Electric Motor Systems Annex (EMSA) of the IEA Technology Collaboration Program on Energy Efficient End-Use Equipment (4E) (framework), Motorbox (company offer), WienerBerger - Plant Improvement Program, Viktovice - performant machineries, Metron, Energisme (companies' offers).

Why this technology and project are needed to reach net-zero

Electric motors are key components of core industrial processes in industries (e.g. presses or rolls) as well as auxiliary systems (such as compressed air, ventilation or water pumping). According to the IEA, 40% of industrial electricity consumption comes from motor use. However, over 50% of this energy use is not optimized.

Therefore, there is a need to identify electricity losses and sort out efficiency measures which have a 30% potential electricity saving via the improvement and replacement of motors.

Identify these potential savings in an efficient manner by using digital solutions. In the long term, data collection from sensors on motors (installed after the audit) extends efficiency measures with predictive maintenance.



Impacts

	2030	2050
CLIMATE IMPACT	**19.9 $MtCO_2e$ avoided**	**24.6 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€28 billion total market** €280 billion cumulated investment by 2030, €28 billion yearly average (2020-2030)	**€3.3 billion total market** €66.5 billion cumulated investment between 2050 and 2030, €3.3 billion yearly average (2030-2050)
JOBS	**420,000 jobs**	**50,000 jobs**

REDUCE GHG IMPACT OF REFRIGERANTS

Mainstream the use of low-GHG refrigerants in all sectors

INDUSTRY | Other industrial products

IN A NUTSHELL...

- **Issue:** To achieve the phase-out of EU HFC (hexafluorocarbons) by 2030 requires further support, especially in the development of alternative refrigerants
- **Solution :** Program to support industries to use new low-GHG refrigerants
- **Key impacts :** 70.4 $MtCO_2e$ avoided, €3.5 billion total market, 53,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

- Support the development of alternative refrigerants to ensure HFC (hexafluorocarbons) phase-out in 2030.
- Ensure distribution of these new alternative low-GHG products to all final sectors (including industry, buildings, and automotive).
- Technical scope: small/medium/large DX; pumped/flooded; Process Chillers.
- Technical solutions: ammonia, CO_2 (R744), Water (R718), R-455A, R-32, natural alternatives.

Main stakeholders:

- Product distributors, resellers, labelled operation and maintenance service providers, OEM service branches.
- ESCOs, financial services, public authorities to finance the investments needed and lower the risk of operation funding through guarantee funds.

Projects that inspired this analysis: Danfoss DIRcalc™ (software to design the use of CO_2 alternatives to refrigerant use).

Why this technology and project are needed to reach net-zero

Adopted in 1987, the Montreal Protocol aims at reducing emissions of chlorofluorocarbons (CFCs) responsible for the hole in the ozone layer by replacing them with the hexafluorocarbons (HFCs) which today equip most refrigeration appliances. Currently, 97% of CFCs have been eliminated and the ozone layer is being restored. However, HFCs are powerful GHG: their global warming power is 2,000 times greater than that of CO_2 and their lifetime in the atmosphere exceeds 13 years. Moreover, driven by higher demand for cold, HFC emissions due to refrigerants have been increasing since 1990 by 10 to 15% annually.

In 2015, the EU agreed to phase out HFCs in 2030 for all refrigerants use. The achievement of this target is monitored by the European Partnership for Energy and the Environment (EPEE). This regulation states that it will be forbidden to refill equipment with fluids having a global warming potential (GWP) of greater than 150. In addition to the phase-out target, the long-term objective for 2030 is to reduce global greenhouse gas emissions from refrigerants by a factor of 5. Given the emissions in 2015 (183 $MtCO_2e$), the final GHG emission target is 38 $MtCO_2e$.

This phase-out is making progress. Virgin R-404A and refrigerants with a GWP above 2,500 have been banned since 2020, and ultra-low GHG solutions are available on the market. However, some small industries, like the food sector, may require additional support to identify the best technologies to use. In some cases, innovative processes need to be developed to better adapt alternative solutions to a specific process (e.g. meat in food industry).

Impacts

	2030	2050
CLIMATE IMPACT	**70.4 $MtCO_2e$ avoided**	**87.1 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€3.5 billion total market** €3.5 billion turnover in 2030	**€3.5 billion total market** €3.5 billion turnover in 2050
JOBS	**53,000 jobs**	**53,000 jobs**

REDUCE GHG IMPACT OF PLASTIC THROUGH REUSE AND RECYCLING

Develop technology solutions to increase circularity of plastics

INDUSTRY | Other industrial products

IN A NUTSHELL...

- **Issue:** Europe produced 62 Mt of plastics in 2018 mainly from fossil sources while 70% of total plastic waste is sent to landfills or is burned
- **Solution :** Develop chemical plastic recycling alternatives to reach the target of having 50% of European plastic waste recycled in 2030
- **Key impacts :** 13.5 $MtCO_2e$ avoided, €19.7 billion total market, 296,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Project type 1: Inventory of existing recycling processes and scale at European level

- Assess all existing innovative processes enabling the use of plastic waste as substitutes to fossil resources in chemical production (e.g. pyrolysis, catalytic hydrogasification with plasma and others).
- Undertake technical-economic studies and assess regulatory frameworks to confirm Europe scale-up opportunities.
- Develop best technologies to reach 20% of plastic waste (not already recycled by other processes) from chemical recycling in 2030.
- A European consortium involving key chemical industry stakeholders and circular plastic initiatives must be created to deploy the best available technologies at an industrial scale.
- Initial projects will be deployed in Germany and Spain, where technologies already exist. The technologies will then be deployed in all European countries.

Projects that inspired this analysis: PolyCE (European project).

Project type 2: Create new chemical recycling processes

To fully achieve scale, new processes need to be found, specifically in the field of chemical recycling.

- Support laboratories and corporate R&D to fund specialized laboratory or industrial pilots for new plastic recycling processes. For instance, via processes of gasification, pyrolysis, solvolysis, and depolymerization.
- This project type targets 30 new R&D initiatives to be launched in 2021, with expected results in 2025.

This research will be done and applied at pilot scale. Promising technologies will be integrated into the existing pool of the European consortium created in project type 1. These will be tested at industrial scale.

Projects that inspired this analysis: for pilots, Chemcycling (BASF process), Ecomethylal (European project).

Why this technology and project are needed to reach net-zero

The European plastic industry produces around 60 million tons of plastic[36] annually, generating 160 $MtCO_2e$[37] per annum. Future scenarios predict that a 56% reduction in total plastic life cycle emissions is possible through demand reduction, substitution and recycling (mechanical and chemical)[38]. In parallel, the European Commission aims to recycle at least 50% of plastic waste in 2030.

Today, 30% of plastics are recycled, mostly through mechanical processes. However, this method has high sorting requirements and decreases material quality in each cycle. This recycling rate can only be improved by using chemical processes to break down the chemical structure of plastics from polymer to monomers. These new products will then be used as a raw material in chemical industries.

Several chemical recycling projects already exist. These include Chemcycling[39] and Ecomethylal[40]. The first one is an industrial project launched in 2018 by BASF in partnership with Quantafuel. It uses pyrolysis to reduce plastic waste into pyrolysis oil before feeding it in a steam cracker. The Ecomethylal project addresses the plastics which are usually put in landfills, i.e. non-recyclable plastic waste (NRPW), and aims at removing 3.6 tons of plastic waste during the project period.

Such projects must now be tested and deployed in Europe. General barriers to industrial deployment of such technologies are market uptake and acceptance from regulators.

Impacts

	2030	2050
CLIMATE IMPACT	**13.5 $MtCO_2e$ avoided**	**46.2 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€19.7 billion total market** €15.9 billion investment by 2030, €1.6 billion yearly average (2020-2030) €18.1 billion turnover in 2030	**€66.2 billion total market** €56.7 billion investment by 2050, €1.9 billion yearly average (2020-2050) €64.3 billion turnover in 2050
JOBS	**296,000 total jobs** 24,000 construction jobs for investment 272,000 production jobs for turnover	**992,000 total jobs** 28,000 construction jobs for investment 964,000 production jobs for turnover

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