RE4Industry Brochure

RE4INDUSTRY
Renewable energies for industries

Towards 100% Decarbonisation of Energy Intensive Industries with Renewable Energy Integration

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.952936.

RE4INDUSTRY
Renewable energies for industries

Authors: Olgu Birgi, Rainer Janssen

Editors: Alessandro Carmona, Patrick Reumerman, Manolis Karampinis, Andreas Ziogos

Contributors: Asier Rueda, Aimilia Lympeti, Manolis Karampinis, Alessandro Carmona, Alejandro Fresneda, Irene Bolea, Clara Jarauta Córdoba, Georgios Zisopoulos, Myrto Zeneli, Panagiotis Grammelis, Olgu Birgi, Rainer Janssen, Asier Zubero, Martijn Vis, Bas Davidis, Patrick Reumerman, Maria Proenca, Suzanne Verhoef, Katia Paglé, Ioannis Karnachoritis, Marina Papageorgiou, Cosette Khawaja, Martijn Vis, Emmanouil Karampinis, Ana Sofia Praxedes

ISBN: 3-936338-87-6

Published: © 2023 by WIP Renewable Energies, Munich, Germany

Contact: WIP Renewable Energies
Sylvensteinstr. 2, 81369 Munich, Germany
olgu.birgi@wip-munich.de, Tel: +49 89 72012765
www.wip-munich.de

Website: https://re4industry.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.952936.

RE4INDUSTRY
Renewable energies for industries

About RE4Industry

The EU has started a progressive decarbonisation with the ambitious aim to become carbon neutral by 2050. In addition, the Russian invasion of Ukraine and the COVID-19 crisis have further emphasized the immediate need to be independent of fossil fuels and the importance of energy security. Renewable energy solutions will play a significant role in diminishing GHG emissions and ensuring energy security through the production of clean and non-depletable energy locally.

Energy Intensive Industries (EIIs) are expected to play an important role in this transition as they represent 24% of the final energy consumption, but a clear long-term vision and strategy is required in order to remain competitive while contributing to the decarbonisation targets of EU.

In line with this purpose, the project is aiming to facilitate for the energy intensive industry (EII) sector in Europe a smooth and more secure transition to the adoption of Renewable Energies (RE) in their production processes and facilities. The project will guide the EIIs and their organisations in their path for a total decarbonisation towards 2050 by providing vision and guidance to establish their long-term strategy for a coherent and more secure retrofitting and integration of current and future RE solutions in their facilities and processes.

Aim of the Brochure

This brochure aims to synthesize the work carried out in the framework of the RE4Industry project and guide the industry players on the successful decarbonisation of their sectors.

The brochure starts with an overview of Energy Intensive Industries (EIIs) and their sector status in the EU scope. In the second chapter, cases of flagship organisations successfully adopting renewable energy solutions are given place. Lessons learned from the three industrial case studies of Corbion, Sinedor, and Mytilineos are presented in chapter three. Lastly, chapter four highlights various renewable energy technologies that can be used for heat and electricity generation for EIIs.

Finally, RE4Industy project partners are briefly introduced at the end of the handbook.

Table of Content

Figures

Tables

1- EII Sector Status in EU

This chapter aims to give an overview of the current status of Energy Intensive Industry sectors in Europe, namely:

- Non-Ferrous metals
- Cement
- Lime
- Chemicals
- Steel
- Glass

General information on European scope and EIIs´ energy and greenhouse gas (GHG) emissions profile regarding the selected EIIs sectors can be found within the chapter. Furthermore, decarbonisation pathways and different alternatives for the decarbonisation of the sectors are presented.

Energy-intensive industries are significant economic sectors in Europe. An estimated 3.2 million people are employed in the new EU27 in the industries of iron and steel, minerals, refineries, and chemicals. This accounts for about 11% of all industrial employment. In the EU27, these four industries account for 15% of the total value added in manufacturing.[1]

Energy-intensive industries are operating in a dynamic policy landscape as climate policies are rapidly evolving. In light of the Paris Agreement, the European Commission, European Parliament, and Member States have implemented ambitious policies to align greenhouse gas (GHG) emissions with policy goals. Currently, GHG emissions from these industries are mainly regulated through the European Emission Trading Scheme (EU ETS), a pan-European policy instrument that oversees emissions from over 12,000 installations. Participants in the EU ETS are required to monitor and report their carbon dioxide (CO_2) and other GHG emissions and obtain permits for these emissions. In line with the EU emission reduction goals, Figure 1 shows that emissions from energy-intensive industries participating in the EU ETS decreased from 2008 to 2012 but have plateaued since 2013.

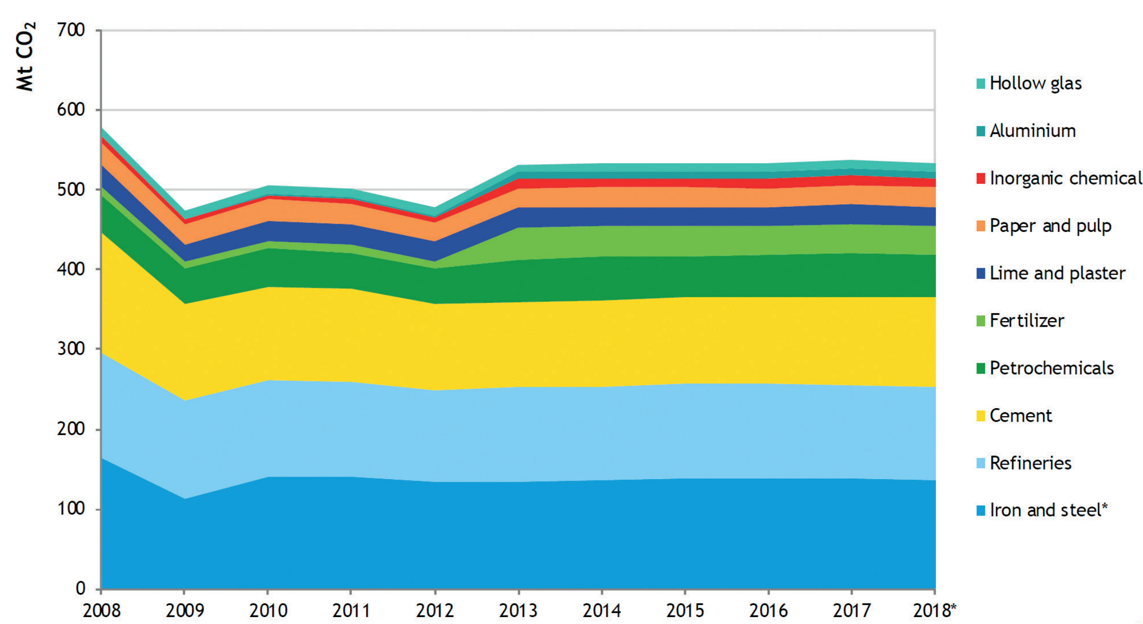


Figure 1: CO_2 emissions in the EU ETS from the energy-intensive industries, EU27, 2008-2018
*Source: EUTL data, CE Delft calculations. * Preliminary data BTA*

[1] EU Parliament, 2020, Energy-intensive Industries: Challenges and opportunities in energy transition

In EU Parliament´s Energy-intensive industries report the following examples for every technology route in the EIIs are given. It's important to acknowledge that several technologies, particularly in the fields of electrification, CCU (Carbon Capture and Utilization), and hydrogen, rely on the availability of abundant renewable electricity sources. These technologies are therefore closely linked to the progress of the electricity sector. Conversely, measures related to energy efficiency, circular economy, process innovation, and CCS (Carbon Capture and Storage) can directly reduce CO_2 emissions. However, until the electricity sector achieves carbon neutrality, an increase in electricity demand may delay the closure of fossil fuel-based electricity generation and hinder the overall progress towards climate neutrality in the economy.

Table 1: Overview of the examples of available technologies for the energy-intensive industries

Sector	Iron and steel	Cement and Lime	Chemicals, polymers and fertilizers	Refineries
Circular economy	More scrap recycling, replace by wood in construction	Concrete recycling	Higher quality plastics recycling, naphtha from waste plastic, reduce fertilizer use	Recycled Carbon Fuels, reduction of demand by electric vehicles
Electrification	Electric Arc Furnace, Electrolysis of Iron Ore		Cracker of the Future, Electric boiler	Heat pumps, electric boiler
Carbon capture, utilisation and storage (CCUS)	Capture ready: ULCOS, HIsarna, Steel2chemicals, Steelanol.	CCUS on clinker oven, LEILAC, mineralisation	CCUS on SMR, Oxy-fuel + CCUS	Synfuels, capture/CCUS on SMR
Hydrogen (H_2)	H_2-Direct Reduced Iron: HYBRIT, SALCOS, H_2Future, etc.	HT heat	H_2 from electrolyser, HT heat	HT heat
Biomass	Blast furnace on biocokes	Biofillers, biogas fired kiln	Biobased feed: MeOH, EtOH, bioBTX, H_2 from biogas	Biofuels, biocrude as input
Other process innovation	HIsarna	Low-carbon cement, CO_2 curing	Catalytic ethylene cracker, novel separation technologies	Novel separation technologies

Non-Ferrous metals

Non-ferrous metals are the metals - including alloys – that do not contain iron (ferrite) in abundant amounts. Non-ferrous alloys generally have iron compositions of less than 1% as measured by weight.

Non-ferrous metals are generally categorized into four main groups, including **base metals, precious metals, specialty metals** and **rare metals**.[2]

Overview of the European non-ferrous metal sector

- Worth **€120 billion**,
- Employing around **500,000 people** directly
- Employing more than **2 million people** indirectly [3]

There is a lack of reserves in Europe; consequently, metal ores and concentrates imports from other continents are heavily relied on.

Energy consumption and GHG emissions

The non-ferrous metals industry is the most electrified of all energy-intensive industries, with a **58% share of electricity use** in its overall energy consumption. As a result, the non-ferrous metals industry is **highly sensitive to increased electricity prices** than other manufacturing industries.[4]

On the other hand, the EU non-ferrous metal industry has already achieved to reduce its absolute (direct and indirect) emissions by **61% since 1990**, the highest reduction achieved worldwide and retaining the potential of reducing GHG emissions by **more than 90% until 2050**, a date that marks the EU climate neutrality target.[5]

Energy efficiency & decarbonisation innovations

Table 2 demonstrates the commonly used non-ferrous metals, energy consumption and GHG emissions stemming from these metals, as well as energy efficiency and decarbonisation innovation that would aid the decarbonisation of these sectors.

Efficiency (especially in the electrolysis processes), using alternative fuels, electrification, heat recovery, and CCUS are the main pathways for the decarbonisation of the non-ferrous metals sector.

Table 2: Non-ferrous metals energy consumption, GHG emission and decarbonisation innovations[5]

	Energy consumption	GHG	Energy efficiency & decarbonisation innovations
Al	14-16 MWh/t electricity Al (primary production)	Total 17.4 Mt CO_2 eq. (in 2015)	Efficiency in electrolisis process, CCS
Cu	Approximately 1.5 MWh electricity, total energy 3.3 MWh/t of copper	Total 4.439 Mt CO_2 eq (in 2015)	Efficiency in electrolisis process, alternative fuels (hydrogen, syntetic fuels), waste heat recovery
Ni	Refining: 5-5.5 MWh/t, flash furnace: 2.6-2.8 MWh/t nickel	348.46 kt CO_2 eq (in 2015)	Electrification of various processes e.g electric heating and gas production Efficiency in heat recovery, CCS
Zn	Electricity usage per t Zinc 3.8 MWh/t	3.394 Mt CO_2 eq (in 2015)	CCU e.g. algea Project (Finnfjord AS, the Arctic University of Norway), CCS
Silicon & Ferro alloys	Electicity input: Silicon 12.4, Ferrosilicon 8.9, Ferromangan 3 MWh /ton	Silicon 8.4, Ferrosilicon 6.3, Ferromangan 1.5 Mt CO_2-eq	CCU e.g. algea Project (Finnfjord AS, the Arctic University of Norway), CCS

Eurometaux (www.eurometaux.eu) is an association that represents the interests of the non-ferrous metals industry in Europe. Its members include producers, transformers, and recyclers of non-ferrous metals, as well as European and national metals associations. In October 2019, Eurometaux released a report titled „Metals for a Climate-Neutral Europe: A 2050 Blueprint," which examines the potential and challenges that the European non-ferrous metals industry faces in achieving a climate-neutrality goal by 2050. To achieve these targets, the Eurometaux roadmap proposes several measures, including increasing energy efficiency in production processes, using renewable energy sources, promoting the circular economy by recycling and reusing materials, and developing new low-carbon production technologies.

[2] RE4Industry Project Deliverable (2022): D3.1: Non-ferrous metals sector status in Europe

[3] T. Wyns and G. Khandekar, "Metals for a Climate Neutral Europe - A 2050 Blueprint," 2020. [Online]. Available: https://www.eurometaux.eu/metals-blue-print-2050/

[4] Energy balance sheets 2016 DATA 2018 edition. 2018.

[5] T. Wyns and G. Khandekar, "Metals for a Climate Neutral Europe - A 2050 Blueprint," 2020. [Online]. Available: https://www.eurometaux.eu/metals-blue-print-2050/

Cement

Cement is the main ingredient in making concrete, and concrete is the most-used manufactured substance in terms of volume. Concrete is affordable, robust, durable and resilient to fire, floods and pests. It has the flexibility to produce complex and massive structures. The demand for concrete, therefore for cement, is expected to grow 12-23% by 2050 with the growing population and economy.[6]

Overview of the European cement sector

According to Eurostat data, the cement manufacturing industry in the EU characterized as follows

- **€15.2 billion** turnover and **€4.8 billion** in value added.
- Employing around **47,000 persons** in Europe in 2019[7]
- Distributed over around **350 enterprises**

Energy consumption and GHG emissions

Cement production accounts for **8% of the total CO_2 emissions globally**. Cement production is highly energy intensive, 50-60% of the production costs are linked to the energy costs. The typical electrical energy consumption of a modern cement plant is about **110–120 kWh per ton of cement** and **requires 60 to 130 kg of fuel oil or its equivalent**, depending on the cement type.[8]

Cement production is one of the largest sources of carbon dioxide emissions in the world. These emissions come from two main sources: energy-related emissions and process-related emissions.

Energy-related emissions in cement production come from the burning of fossil fuels to provide the high temperatures needed to produce clinker, which is the main component of cement. Fossil fuels such as coal, oil, and natural gas are commonly used for this purpose. The emissions from burning these fuels include carbon dioxide (CO_2), as well as other greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O).

In addition to energy-related emissions, cement industry is known to emit large amounts of greenhouse gases, primarily carbon dioxide (CO_2), during their production processes. These emissions are known as „process emissions," which are released during the chemical reaction that occurs when limestone is heated to produce clinker, a key ingredient in cement. This type of emission represents a large portion of the emissions from industry, and it is hard to avoid since it occurs during the production process.

[6] RE4Industry Project Deliverable (2022): D3.1 Cement & Lime sector status in Europe

[7] Cembureau, "Activity report 2020." [Online]. Available: www.cembureau.eu

[8] N. A. Madlool, R. Saidur, M. S. Hossain, and N. A. Rahim, "A critical review on energy use and savings in the cement industries," Renewable and Sustainable Energy Reviews, vol. 15, no. 4. pp. 2042–2060, May 2011. doi: 10.1016/j.rser.2011.01.005.

Energy efficiency & decarbonisation innovations

While efforts to reduce CO_2 emissions have primarily focused on cement production, additional reductions can be achieved by considering the entire value chain from cement production to its use in construction materials like mortars and concrete. CEMBUREAU, the European Cement Association, is an organization that represents the interests of cement manufacturers and promotes a sustainable and competitive cement industry in Europe. They have developed a decarbonisation roadmap that outlines the industry's strategy for reducing carbon emissions and achieving climate neutrality. The roadmap prioritizes innovation, investment, and cooperation, and provides a vision for the cement industry's transition towards a low-carbon future. CEMBUREAU's decarbonisation roadmap includes a **"5C approach"** that promotes a collaborative approach along the **clinker, cement, concrete, construction, carbonation** value chain involving all actors to help turn the low carbon vision into reality. The below chart (Figure 2) of CEMBUREAU summarizes the technical pathways to achieve net zero emissions compared to the 1990 CO_2 emissions of the sector. While the improvements and decarbonisation in the cement value chain (5C) still seems crucial for the decarbonisation pathway, a total of 783 kg CO_2/ t cement should be removed to reach net 0 emissions in the sector.

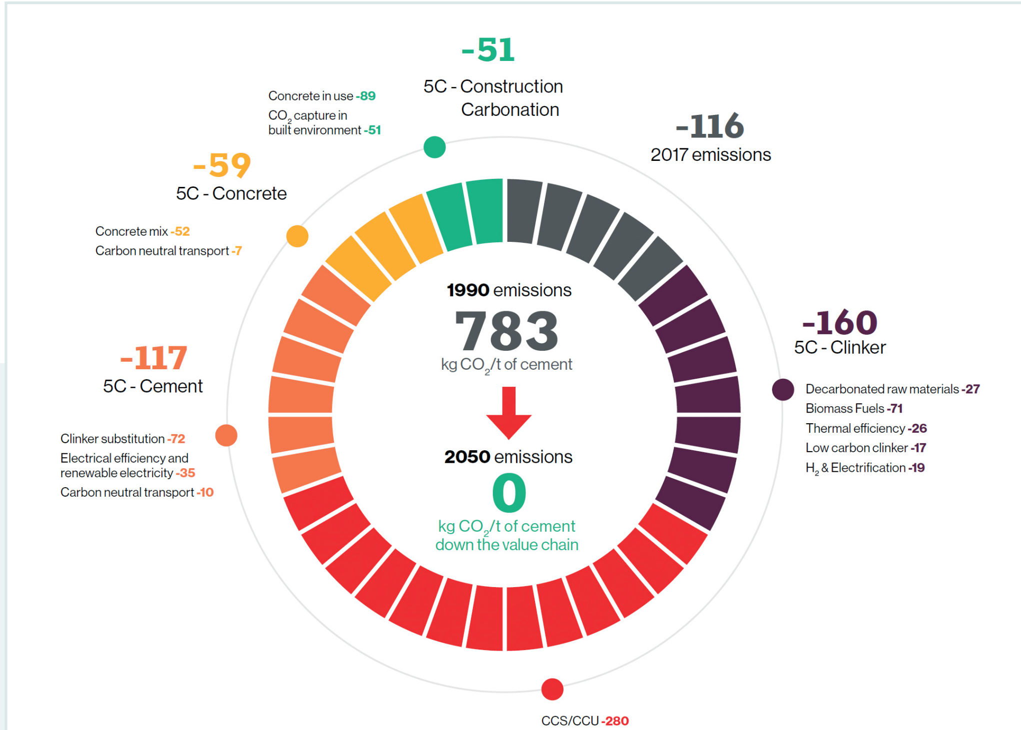


Figure 2: CEMBUREAU Roadmap CO_2 reductions along the cement value chain (5Cs: clinker, cement, concrete, construction, re-carbonation)

Even though the whole value chain has to be improved to achieve the net zero target, some steps are more carbon-intensive than others. The most energy intensive phase of the value chain is at the cement plant, where two critical materials are produced: **clinker** and **cement**.

Some potential measures to reduce emissions linked with **clinker production** are use of **alternative decarbonated raw materials** (waste and by-products from other industries) to replace some of the limestone, **fuel substitution** (alternative fuel, biomass, hydrogen), increased **thermal efficiency** (in kilns), use of **new types of cement clinkers** that are chemically different and emitting less CO_2 and **CCUS**.

In order to reduce emissions linked with cement production, electricity used for mixing, grinding and transportation should come from renewable sources. **Using low-ratio clinker cement** or **alternatives to clinker** is another way to decrease emissions related to cement production.

Lime

Lime, also known as quicklime or burnt lime, is a white or grayish-white alkaline chemical compound. Lime is used in various applications in different sectors such as environmental, metallurgical, construction, chemical/industrial, and more. In addition, lime is highly reactive and can be dangerous if not handled properly.[6]

Overview of the European lime sector

Lime products are used in a wide variety of applications in Europe, and worldwide and it is irreplaceable for many industrial sectors, from steel manufacturing to construction materials, chemical industries and paper pulp.

- **€4.2 billion** turnover and **€1.4 billion** value added
- **15.000** direct employment and
- **30.000** indirect employment

Source: sublime-etn.eu

It´s high importance and diverse substance is due to its alkalinity, ability to purify and neutralise. The average EU citizen indirectly uses around 150 g/day of lime products.

Energy consumption and GHG emissions

Lime forms through a calcination process. A thermal decomposition process takes place where limestone (CaCo3) or dolomite CaMg(CO3)2 releases CO_2 and converts into lime (CaO) and dolime ($CaMgO_2$) under the influence of high temperatures. Lime production leads to emissions of greenhouse gases, due to the process itself likewise cement (process emissions) but also due to energy requirements.

The calcination process is responsible for the most part of energy use and the CO_2 emissions, since the production of lime requires temperatures around 1200oC and maintaining these temperatures requires a significant amount of heat. Simultaneously, **68% of total emissions are an inevitable by-product of the calcination process**.

Table 3 reveals that the majority of emissions stem from the process itself, with a notable increase in CO_2 emissions resulting from the utilization of dolime as a raw material.

Table 3: Average CO_2 emissions for lime products (EuLA, 2012)

Emissions	Process (tCO_2/ tlime product)	Combustion (tCO_2 / tlime product)	Electricity (tCO_2 / tlime product)	Total (tCO_2/ t lime product)
Lime	0.751	0.322	0.475	1.092
Dolime	0.807	0.475		1.301

Measures for reduction of CO_2 emissions

EuLA is a non-profit organization located in Brussels, Belgium that advocates for the interests of the lime industry in Europe. Its members come from various countries within the European Union. In 2020, EuLA released a decarbonisation roadmap for the lime industry. The roadmap presents the industry's plan to decrease its greenhouse gas emissions, consistent with the goals of the Paris Agreement on climate change.

The potential measures for CO_2 reductions mentioned in EuLA´s decarbonisation roadmap are fourfold:

- **Energy efficiency by fuel savings:** Improving energy efficiency mainly during the calcination step is an important option to reduce energy related emissions.
- **Low carbon sources by fuel switch:** The fuels that are used for the production of the required heat usually are natural gas and fuel oil. Switching to low carbon sources is key for CO_2 reduction.
- **CCUS:** Almost 70% of the total CO_2 emission of the lime industry are process emissions, therefore the only solution to reach carbon neutrality is the CCS & CCU which considered as end of pipe solution.
- **Carbonation:** Carbonation is the natural effect associated with the use of lime and it can be described as the reverse reaction of lime production. During the lifetime of products that contain lime, CO_2 from the atmosphere is captured forming limestone and by this way the cycle of lime is closing.

Chemicals

The chemical sector is a diverse industry that produces a wide range of chemical products, including plastics, pharmaceuticals, fertilizers, and other chemicals used in various industries. The products of the EU chemical sector can be categorized into three main categories[9]:

- **Base chemicals** are also known as commodity chemicals, represented 60.4% of total EU chemical sales in 2018 and cover petrochemicals and their derivatives (polymers) along with basic inorganics.
- **Specialty chemicals** represented 27.2% of total EU chemical sales in 2018, cover areas such as paints and inks, crop protection, dyes and pigments, and auxiliaries for industry (other chemicals such as glues, essential oils and gelatin).
- **Consumer chemicals** are sold to final consumers, such as soaps and detergents as well as perfumes and cosmetics. They represented 12.4% of total EU chemical sales in 2018.[10]

Overview of the European chemicals sector

The EU's chemical sector plays a significant role in the European economy and is one of the largest chemical industries globally. It encompasses various industries, such as petrochemicals, plastics, pharmaceuticals, agrochemicals, and specialty chemicals. In 2018, the EU generated €565 billion in revenue from the chemical sector, with Germany and France being the two most extensive chemical producers in Europe, followed by Italy and the Netherlands.

[9] RE4Industry Project Deliverable (2022): D3.1 –Chemical & Fertilizers Sector

[10] Cefic, "2020 FACTS & FIGURES of the European chemical industry".

- Chemical manufacturing is the fourth largest industry in the EU.
- The sector accounts for 7.6% of EU manufacturing turnover
- Consists of **30,000 companies**
- Directly employing approximately **1.2 million**, indirectly and **3.6 million people**[10]

Energy consumption and GHG emissions

The chemicals sector covers a wide range of diverse processes, ranging from complex continuous processes to smaller-scale batch processes.

The combustion of fossil fuels, indirect emissions from electricity consumption, and process emissions (resulting from processes that create CO_2 as a by-product of chemical reactions) make up the chemicals sector´s carbon footprint.

In 2017, the fuel and power consumption of the EU chemical industry, including pharmaceuticals, amounted to 52.7 million tons of oil equivalent and gas, with electricity accounting for nearly two-thirds of total energy consumption.[10]

According to the European Environmental Agency (EEA), the EU chemical industry, including pharmaceuticals, emitted 135.2 million tons of CO_2 equivalent in 2017.

The most important pollutant, CO_2, was partially restricted; however, much of the decline is linked to the abatement of nitrous oxide (N_2O), which is the second most important pollutant. The steady decline of chlorofluorocarbons can be seen in Figure 3.

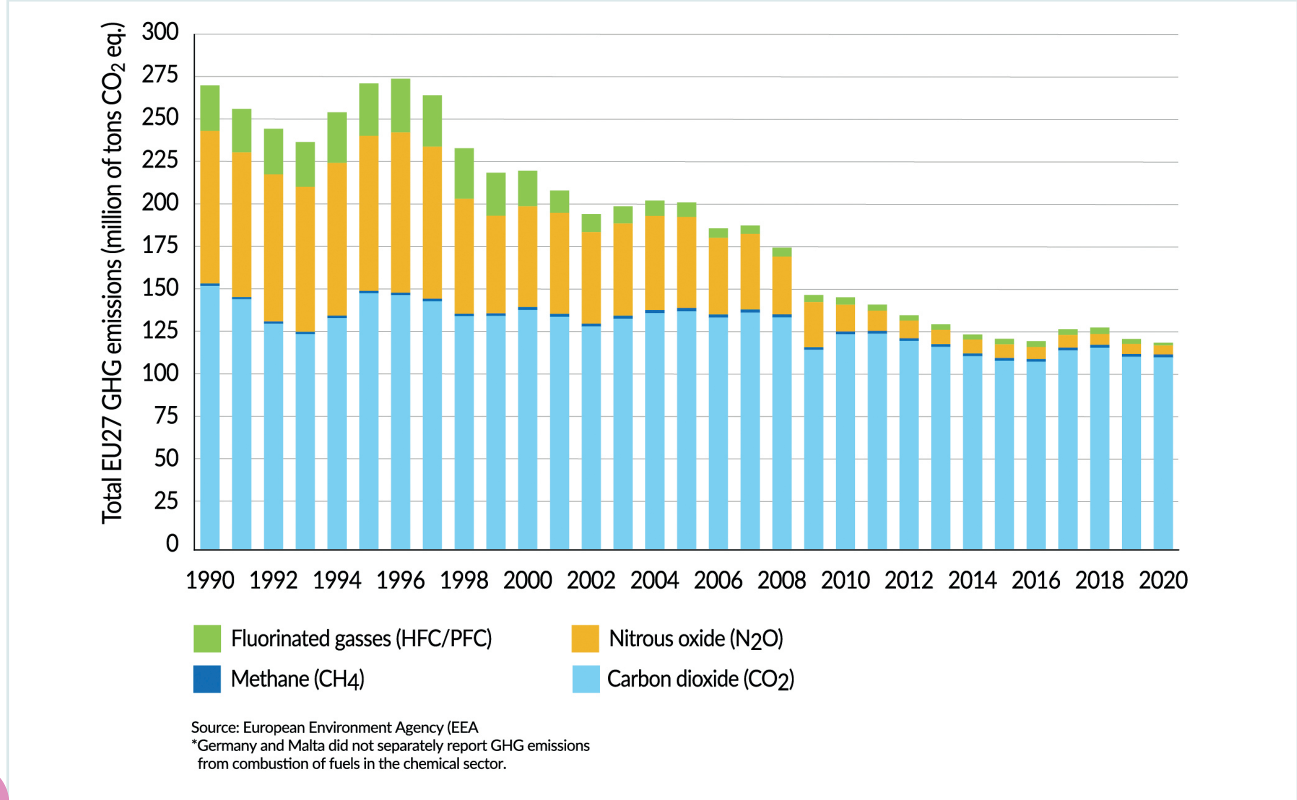


Figure 3: GHG emissions in the EU chemical sector, millions of tons (CO_2 equivalent)

Methanol, Ethylene, Chlorine, and Ammonia are the most important chemicals based on their large production volumes but also their energy and carbon intensity. These chemicals are responsible for most CO_2 emissions in the sector.

Energy efficiency & decarbonisation innovations

CEFIC, which stands for the European Chemical Industry Council, is a trade association based in Brussels that advocates for the interests of the chemical industry in Europe. Its membership is made up of more than 29,000 companies, ranging from large multinational corporations to small and medium-sized enterprises. CEFIC is committed to reducing the industry's greenhouse gas emissions and achieving net-zero emissions by 2050.

A range of current and future technologies can sustain Europe's track record of energy and improve energy efficiency. Some are mentioned below:

- **Final energy demand** can be maintained at a **constant level**,
- Emissions could be virtually eliminated with **energy efficiency** (33% of the total emissions reductions),
- **CO_2 capture and utilization and storage** (CCUS) (25%),
- **Renewable electricity** (20%)
- **Fuel switching** and **measures to reduce nitrous oxide emission**s (22%)[11]

In addition to the technologies mentioned, **improvements in feedstock**, which is usually fossil fuel based, is another way to reduce GHG emissions. It can be done by efficiently utilizing existing feedstock, increasing the amount of renewable feedstock like biomass, alternative feedstock, and recycling.

[11] M. ; de B. J. ; L. N. ; den O. B. Stork, "Roadmap for the Dutch Chemical Industry towards 2050," 2018

Steel

The sector of conventional steel production in Europe is one of the most significant sources of CO_2 emissions. The sector contributes to **approximately 4% of total European CO_2 emissions**. Regarding the industrial sector, steel making process in Europe contributes 22% of CO_2 emissions. [12, 13]

At around 1.9 billion tons of production per year worldwide and **139 million tons in the EU**, steel is the third most abundant man-made bulk material, after cement and timber.[14]

Overview of the European steel sector

- The EU industry creates roughly **€132 billion** of gross value added.
- In 2020, the steel sector in Europe reported that the industry supports over **2.6 million** total full-time equivalent Jobs[14]

[12] R. Berger, "The future of steelmaking–How the European steel industry can achieve carbon neutrality," Rol. Berger GMBH, 2020.

[13] RE4Industry Project Deliverable (2022): D3.1 Steel sector status in Europe

[14] EUROFER, "European Steel in Figures," 2021.

[15] J. Kim et al., "Decarbonizing the iron and steel industry: A systematic review of sociotechnical systems, technological innovations, and policy options," Energy Res. Soc. Sci., vol. 89, p. 102565, 2022. [Online] https://doi.org/10.1016/j.erss.2022.102565.

Energy Consumption and GHG Emissions

Table 4 shows the final energy use in iron and steel making. Negative energy use represents recovered energy in the iron and steel-making processes.

The primary sources of CO_2 emissions in the iron and steel-making processes are **raw materials**, and **fuel combustion**.

In the processes from the sintering to the final steel product manufacturing, CO_2 is emitted through ovens, boilers, stoves, furnaces, and other miscellaneous equipment.

Among 1.8 t CO_2 emissions per ton of rolled coil in a typical integrated steel plant, 1.7 t CO_2 is associated with coal use, and the remaining 0.1 t CO_2 is responsible for lime use.

Most of the carbon footprints in the iron and steel industry are energy-related emissions.

Table 4: Final energy use in iron and steel making in 2015[15]

Process	Energy use (EJ year)	Share (%)
Coking coal and coke	24.1	70.0
Other coal	6.1	17.6
Blast furnace gas and coke oven gas	-3.3	-9.6
Natural gas	2.3	6.7
Oil	0.4	1.2
Biomass	0.1	0.4
Electricity	4.0	11.8
Heat	0.6	1.9
Total	34.4	100.0

Energy efficiency & decarbonisation innovations

EUROFER, which is the European Steel Association, is a trade association based in Brussels that advocates for the interests of the European steel industry. Its membership comprises over 500 companies, including large multinational corporations and small and medium-sized enterprises. Europe is known globally for its highly developed steel industry, which presently leads the world in terms of environmental and climate performance. To steer the industry towards a low-carbon future, EUROFER released a decarbonisation roadmap named „Low Carbon Roadmap- Pathways to Achieving a Carbon-Neutral European Steel Industry" in 2019. This shift to a carbon-neutral future requires significant investments in new technological advancements, energy infrastructure, and changes in energy consumption and sources, with access to high-quality materials such as iron ore and scrap being a critical factor.

To ensure that Europe fulfills its obligations under the Paris Climate Accords and also make European steel compatible with a clean, low-carbon future, EUROFER has set forth a clear set of pathway scenarios that will drive this necessary transformation in the sector.

In addition to the measures names by EUROFER, a circular economy benefits the steel industry in various ways such as raw materials conservation, innovation, durable products, jobs, efficiency, and CO_2 emissions. The recycling ratio of steel is very high in the industry, close to 95%, making steel the most recycled material. While the high recycling ratio is mainly for economic reasons, it provides other environmental benefits, including less energy use and lower carbon emissions.

Besides the mentioned options, other ways to reduce the emissions in the sector are given below:

- **Using biomass in steel making** (torrefied waste wood, charcoal, biochar etc.)
- **Using carbon as a reductant** (CCUS) could potentially be applied to all major point sources in the steel sector)
- **Using electrical energy through an electrolysis-based process**
- **Plasma direct steel production**
- **Suspension ironmaking**
- **Substituting H2 for carbon as a reductant** (Hydrogen could also be used directly as a reducing agent in the steel making process and therefore has excellent potential for CO_2 reduction.)

The decarbonisation of the iron and steel industry via hydrogen must be supported by hydrogen produced from a low-carbon route.

Glass

Glass still represents one of the most used materials in manufacturing, building and consuming processes, significantly enabling light-weighting products and superior quality glazing.[16]

Main products of the glass sector are **container glass, flat glass, fiberglass, domestic,** and **special glass products** (See Table 5).

Table 5: Main products of the glass sector

Main glass products	Share in EU glass industry	Usage
Container glass	The largest glass sector in EU with 62% of EU production.	Packaging products as bottles and jars
Flat glass	Second largest glass sector, and it accounts for nearly 29% of total EU production.	Residential, automotive, and commercial construction, and innovative applications.
Fibre glass	Continuous filament glass fibre (CFCG) production contributes with the smallest share of 2% in terms of tons in sector.	Mainly used as composites in different sectors.
Domestic	The sector accounts for about 4% of the total European production.	Manufacturing of glass tableware, cookware and ornamental material etc.
Special glass products	They represent a small share in total global glass production for high added-value products	Lighting glass, laboratory glassware, optical or and extra thin for electronic industries etc.

Overview of the European glass sector

Even though normal operations of most glass sectors were disrupted since 2020 because of the COVID-19 crisis, 2021 showed a slow recovery.

- In 2021, **39.1 million tons** of glass were produced in the EU.
- The EU is one of the largest glass producers in the world, with China and North America.
- In 2021, the EU-27 glass industry employed about **181,000 people**.

[16] RE4Industry Project Deliverable (2022): D3.1 Glass sector status in Europe

Energy consumption and GHG emissions

Glass is an energy-intensive sector and extremely high temperatures are needed for glass making; hence, energy represents one of the largest operational costs in glassmaking. Burning natural gas with air has been the traditional way of glass production, which is an energy-intensive and polluting process. As a result, glass production causes 22 million tons of CO_2 each year in Europe.[17]

Energy efficiency & decarbonisation innovations

Today, most glass sector emissions result from using fossil fuels to melt raw materials. A switch to a carbon-neutral source of energy is an important reduction potential.

Glass Alliance Europe (GAE) is a European association that advocates for the interests of the glass manufacturing industry. Its goal is to promote policies and regulations that foster the industry's growth and competitiveness at the European level. Glass Alliance Europe recognizes the significance of the European Green Deal, which aims to achieve climate neutrality for Europe's economy and society by 2050. In this context, having a competitive industrial foundation within the EU that leads in low-carbon solutions becomes crucial for the transition of all economic sectors across Europe.

Glass plays a pivotal role as a key enabling material in sectors with significant potential for emissions reduction, namely energy, building, and transportation. As such, it becomes an essential product for a carbon-neutral Europe. Additionally, glass contributes substantially to the establishment of a genuine circular economy by being infinitely recyclable and reusable in container applications. This characteristic helps conserve resources and reduce carbon emissions.

In addition, recommendations inside the glass sector aiming for emissions reduction and addressing decarbonisation technologies are common in the available literature (Table 6). However, their financial viability and technical feasibility need further research.

Table 6: Glass industry decarbonisation innovation technologies

Novel Technologies
Energy efficiency improvements in terms of fuel furnace consumptions
Waste heat recovery to pre-heat combustion air and raw materials, or electricity
Combustion Innovations
Oxyfuel combustions
Introduction of liquid biofuels (biodiesel and Hydrotreated vegetable oil)
Reduce Combustion Innovations
Electric Arc Furnaces (EAF) rather than gas fired furnaces
Hybrid furnaces running on multiple fuels and electricity
Study of the feasibility of hydrogen to run glass furnaces
Circularity
Increased cullet uses to produce new glass (waste to material)
Calcined raw materials as CaO to substitute carbonates reducing CO_2 emissions
CCUS identify as the most potential short-term carbon neutral technology

[17] How LIFE is reducing emissions from glass production (europa.eu)

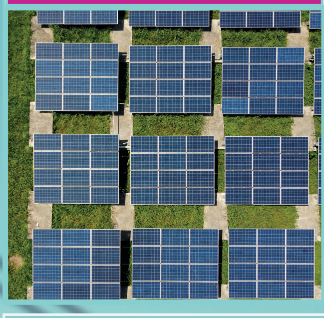
2- Renewable energy solutions

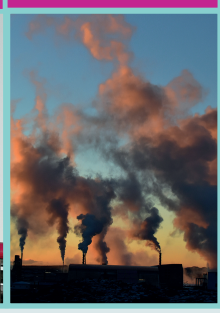
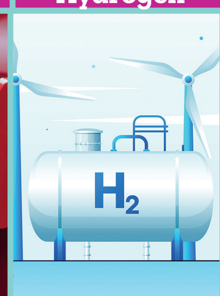
This chapter gives an overview of the relevant renewable energy (RE) technologies currently available (regarding the 2030 scope) and to be available in the transition towards 2050 for the decarbonisation of Energy Intensive Industries (EIIs).

RE solutions have been classified into technologies based on the use of renewable electricity and those to be used to produce heat for multiple industrial processes. Electrification will be key thanks to the gradual decrease of renewable power prices and the conversion of natural-gas-dependent processes. Industrial processes that are not readily eligible for electrification will still need a form of renewable heat.

Renewable Energy technologies within the scope of 2030 are shown in the table below.[18]

Table 7:Renewable electricity and heat solutions

Renewable Electricity Sources			
Photovoltaics	Wind	Hydraulic	Renewable PPAs Power Purchase Agreements
			

Renewable Heat Sources					
Solar Thermal	Heat Pumps	Geothermal	Biomass	Biofuels	Green Hydrogen
					

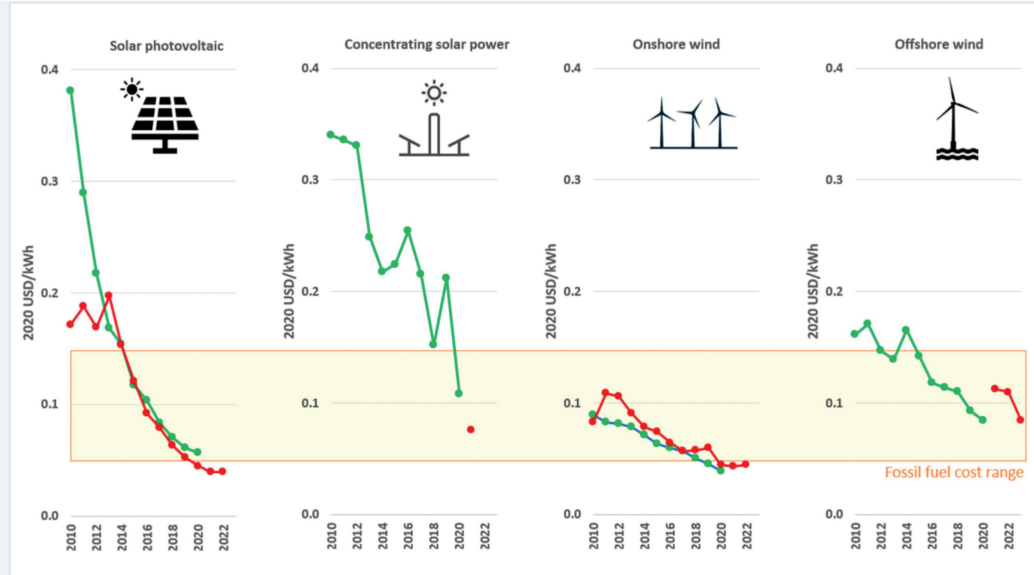
[18] Carmona-Martínez AA, Fresneda-Cruz A, Rueda A, Birgi O, Khawaja C, Janssen R, Davidis B, Reumerman P, Vis M, Karampinis E, Grammelis P, Jarauta-Córdoba C. Renewable Power and Heat for the Decarbonisation of Energy-Intensive Industries. Processes. 2023; 11(1):18. https://doi.org/10.3390/pr11010018

Renewable Electricity

Renewable power can be obtained from different sources: **solar photovoltaic**, **concentrating solar power** and **on-/off-shore wind**. These technologies have seen an improvement in power production in the last decade. In comparison, fossil-based energy sources, such as coal-fired power plants have had operating costs higher than their renewable counterparts.

Figure 4 also indicates that the shown renewable technology prices have had a considerable decline since 2010. This shows that the competitiveness of renewable power generation and that similar technologies based on renewable resources required in the decarbonisation of energy-intensive industries might have a similar cost-declining trend.

Figure 4: Global weighted-average levelized cost of energy (green) and power purchase agreements auction (red) prices for solar photovoltaic, on-/off-shore wind and concentrating solar power between 2010-2023. Source: IRENA



Furthermore, the current worldwide photovoltaic energy capacity is expected to grow from 200 GW (EU share of 25%) installed to 3000 GW (EU share of 5%) by 2050, according to the Roadmap by the IEA.

The main advantage of renewable power is its flexibility in terms of its implementation. Grid connected installations harvest electricity for self-consumption and the surplus can be given to the network. On the other side, off-grid facilities operate in isolation. These are placed in remote locations to meet electricity demands. Off-grid facilities require the installation of batteries to store surplus electricity.

There are two main pathways for the implementation of renewable electricity produced either from solar photovoltaic, concentrating solar power and on-/off-shore wind. The most straightforward pathway is the **direct substitution of fossil-based electricity in current industrial processes**. The second pathway involves **the electrification of current processes based on a heat supply obtained from the use of non-renewable fuels like natural gas, coal, among others.**[19] In addition, electrically powered technologies cover the broad temperature spectrum required by the industry[20] and applications that require low and medium temperature such as electric boilers and heat pumps to supply heating and cooling are not sector-specific and can thus be implemented transversally.[18]

[19] Lechtenböhmer S, Nilsson LJ, Åhman M, Schneider C. Decarbonising the energy intensive basic materials industry through electrification – Implications for future EU electricity demand. Energy. 2016;115:1623-1631. doi:https://doi.org/10.1016/j.energy.2016.07.110

[20] Madeddu S, Ueckerdt F, Pehl M, et al. The CO_2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat). Environ Res Lett. 2020;15(12):124004. doi:10.1088/1748-9326/abbd02

Renewable Heat

Renewable heat can be produced from diverse renewable energy sources such as solar thermal, heat pumps, geothermal, biomass, biofuels and green hydrogen.

Solar Thermal

Solar thermal collectors are devices used for producing energy by harnessing solar energy into usable heat. They absorb the incoming solar radiation, convert it into heat, and transfer this heat to a medium (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either to be used directly or to be stored in a thermal energy storage tank.[21]

Table 8: Common types of collectors and the temperature range they can deliver

Motion	Collector type	Absorber type	Temperature °C
Non-concentrating	Flat plate collector (FPC)	Flat	30-80[22]
	Evacuated tube collector (ETC)	Flat	50-200[22]
Concentrating (single-axis tracking)	Parabolic trough collector (PTC)	Tubular	60-375[23]
	Linear fresnel collector (LFC)	Tubular	60-400[24]
Concentrating (two-axis tracking)	Parabolic dish collector (PDC)	Point	750-1000[25]
	Power tower receiver	Point	500-1500[26]

There are two types of solar collectors: non-concentrating/ stationary and concentrating collectors. Concentrating collectors reach a higher temperature level in comparison to their non-concentrating counterparts. Non-concentrating collectors are suitable for the applications that require low (<150°C) to medium (150°C – 400°C) temperature. Whereas concentrated collectors are required for higher temperatures (>400°C). Table 8 shows the common types of collectors and their temperature range.

Almost all industrial processes with a heat demand require temperatures that can be provided by a solar thermal system. Among EIIs, the chemical sector has a high share of low- and medium-temperature heat demand in its production processes (>50%) and it is the most suitable industrial sector (among EII) where solar thermal heat could be fruitfully used.

The selection of an appropriate solar collector depends on multiple factors: operating temperatures, thermal efficiency, energy yield, cost, the space occupied, among others.

[21] Anastasovski A, Raskovic P, Guzovi'c Z, Sedić A. A Systematisation of Methods for Heat Integration of Solar Thermal Energy in Production Processes: A Review. 2020;8:410-437. doi:10.13044/j.sdewes.d7.0310

[22] Wang R, Ge T. Advances in Solar Heating and Cooling. Woodhead Publishing; 2016.

[23] Belessiotis V, Kalogirou S, Delyannis E. Thermal Solar Desalination: Methods and Systems. Elsevier; 2016.

[24] GmbH IS. Fresnel Collector LF-11 Datasheet.; 2021.

[25] Berrada A, El Mrabet R. Hybrid Energy System Models. Academic Press; 2020.

[26] Qazi S. Standalone Photovoltaic (PV) Systems for Disaster Relief and Remote Areas. Elsevier; 2016.

[27] Sornek K, Filipowicz M, Jasek J. The Use of Fresnel Lenses to Improve the Efficiency of Photovoltaic Modules for Building-integrated Concentrating Photovoltaic Systems. J Sustain Dev Energy, Water Environ Syst. 2018;6:415-426. doi:10.13044/j.sdewes.d6.0204

Heat Pump

A heat pump is a device that transforms heat from the air, ground, and water to useful heat. It has a broad usage and could be applied for residential, commercial, and industrial scopes. Heating, cooling and hot water can be provided by a heat pump. This transformation is done through a refrigerant cycle.

The refrigerant is a special fluid that circulates in a closed circuit in the four main devices of a heat pump which are evaporator, compressor, condenser, and expansion valve. Heat pumps are devices that utilize mechanical work to convert energy into heat. The underlying thermodynamic principle of heat pumps is based on the fact that compressing fluids into a smaller volume results in an increase in their temperature. See Figure 5.

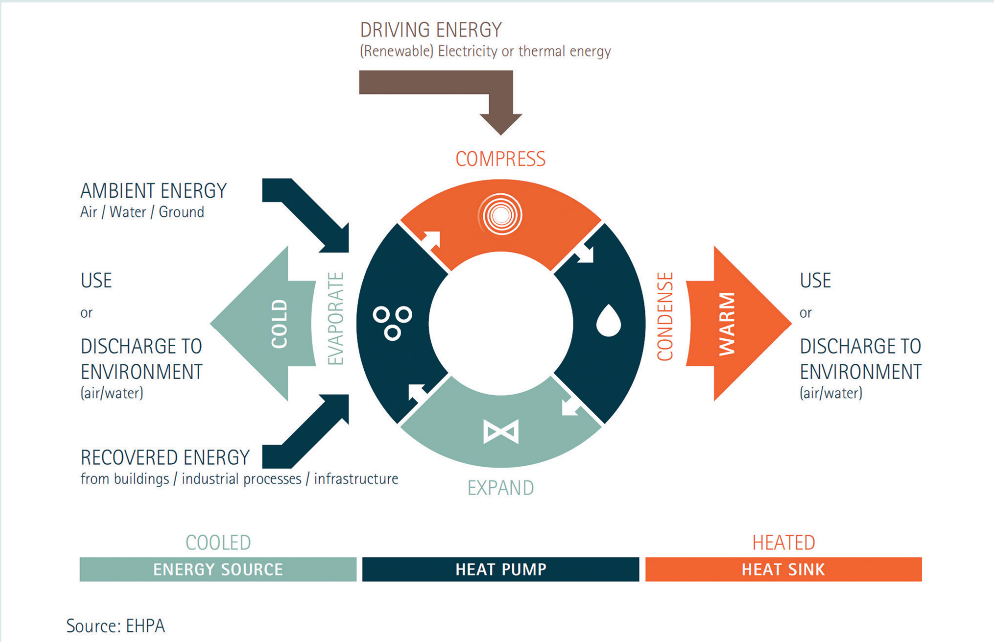


Figure 5: Vapor compression cycle providing heating and cooling simultaneously

Different types of heat pumps are available for different needs and environmental conditions. **Underwater heat pumps** use a water source as the heat exchange medium and they are considered to be highly efficient due to the excellent temperature characteristics of water as an energy carrier. This feature makes this type of heat pump especially interesting for locations with extreme weather conditions. Whereas **air source pumps** are installed above ground and use heat from the surrounding ambient air as their primary energy source. **Exhaust heat pump** is another type of air heat pump that uses exhaust heat from manufacturing processes. Since exhaust heat is warmer than the surrounding air, evaporation to condensation process is more effective with this kind of heat pump. Therefore, these types of heat pumps are immensely implementable in the industrial sector.

The implementation of heat pumps at EIIs is limited for multiple reasons. There are not enough manufactures of equipment based on the concept of heat pumps. The available equipment is not able to deliver the broad range of process temperatures typically required by industry. Even though EIIs have a large heat demand up to 200°C degrees, most of the commercial manufactures provide equipment able to supply heat up to 90°C degrees. Only a few providers offer equipment that can deliver heat within the 120-165°C degrees range. Moreover, a number of ongoing projects have demonstrated to be able to deliver heat within the 160-200°C degrees range[28].

[28] Zühlsdorf B, Bühler F, Bantle M, Elmegaard B. Analysis of technologies and potentials for heat pump-based process heat supply above 150 °C. Energy Convers Manag X. 2019;2:100011. doi:https://doi.org/10.1016/j.ecmx.2019.100011

Geothermal

Geothermal energy is seen as an energy source that will contribute to the decarbonisation of industry. The projections show that around 100 to 210 TWh/year will be available from geothermal energy resources by 2050.[32] Even though the main applications of geothermal energy have been in the residential and commercial sectors in the form of district heating, applications in the agricultural and industrial sectors are also foreseen.[29, 30, 31]

All regions in Europe show an economical potential for geothermal energy applications depending on the depth except for Iceland, and a few other European regions with a clear volcanic activity. In these regions, the potential to produce electricity from geothermal energy is limited to reservoirs at depths below 2 km (See Figure 6). However, direct geothermal applications in agricultural greenhouses or industry can still be developed with such depths.[30]

Financing and development of new heat grid infrastructure is seen as a big challenge of geothermal based energy. Therefore, retrofitting could be an alternative for the implementation of geothermal energy within the sector of urban district heating, and also as an energy source for EIIs.

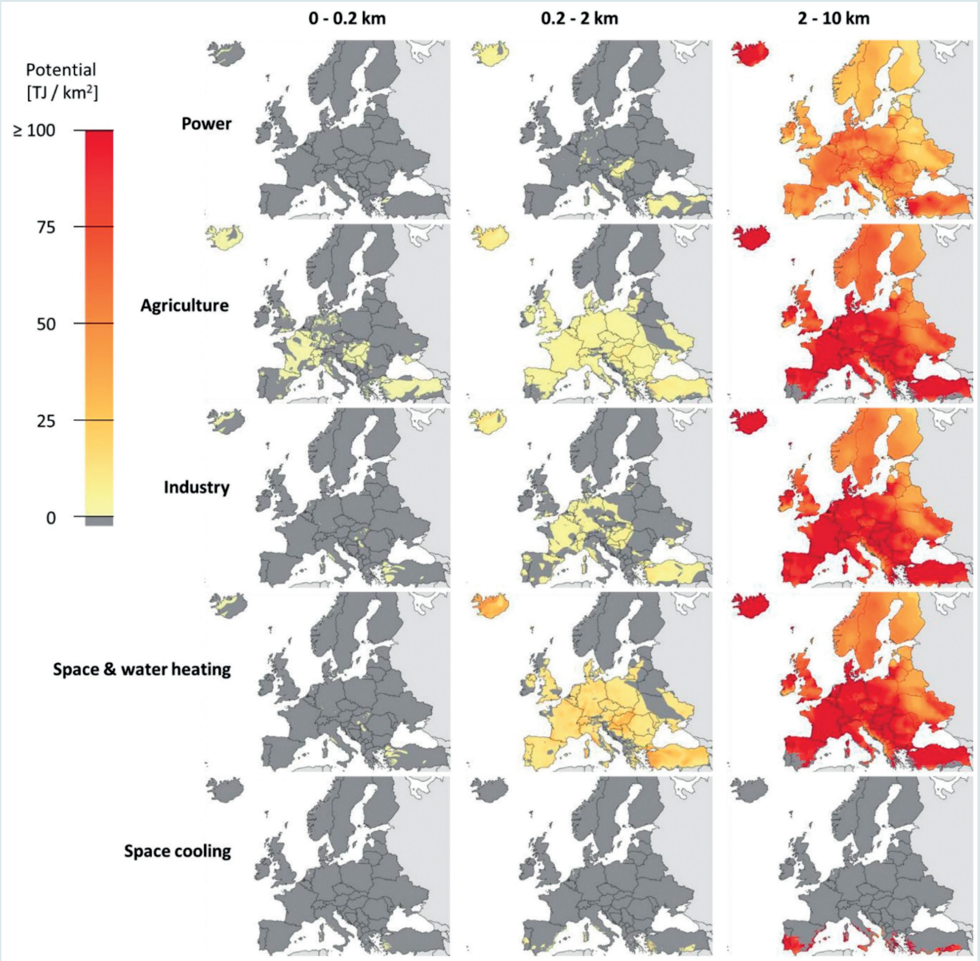


Figure 6: Long-term economic potentials for various geothermal applications in Europe at three different ranges[32]

[29] Urbancl D, Trop P, Goričanec D. Geothermal heat potential-the source for heating greenhouses in Southestern Europe. Therm Sci. 2016;20(4):1061-1071.

[30] Østergaard PA, Lund H. A renewable energy system in Frederikshavn using low-temperature geothermal energy for district heating. Appl Energy. 2011;88(2):479-487. doi: https://doi.org/10.1016/j.apenergy.2010.03.018

[31] Barkaoui A-E, Boldyryev S, Duic N, Krajacic G, Guzović Z. Appropriate integration of geothermal energy sources by Pinch approach: Case study of Croatia. Appl Energy. 2016;184:1343-1349. doi:https://doi.org/10.1016/j.apenergy.2016.04.112

[32] Dalla Longa F, Nogueira LP, Limberger J, Wees J-D van, van der Zwaan B. Scenarios for geothermal energy deployment in Europe. Energy. 2020;206:118060. doi:https://doi.org/10.1016/j.energy.2020.118060

Biomass

Solid biomass, which is by far the main feedstock (91%) for bioheat generation, has been identified as key fuel for the renewable energy transition. The conversion of the biomass to useful forms of energy could be achieved with three main conversion pathways that are **thermo-chemical, physical-chemical** and **bio-chemical** conversion processes.

Renewable heat can be produced via thermo-chemical conversion processes. Figure 7 showcases the main thermo-chemical conversion technologies that are able to produce renewable heat and power from solid biomass. All thermo-chemical conversion technologies are available on a commercial scale, depending on the feedstock in use, though it should be noted that combustion is more widely applied than all other technologies. The use of non-selective biomass is one of the main advantages of these technologies. Another advantage is that non-intermittent energy can be generated with biomass, which makes it possible to generate the required quantities of energy when needed.

In 2018, the pulp and paper sector, along with the wood and wood product industries, accounted for a combined 81% of the biomass utilized in energy consumption among EU industries. Following closely behind are the non-metallic mineral industries, such as glass, ceramics, and cement, which rank as the third largest users of biomass by volume. On the other hand, the chemical and petrochemical, iron and steel, and non-ferrous metal sectors only utilized 0.64%, 0.04%, and 0.03% of biomass, respectively, for their energy consumption needs.[33]

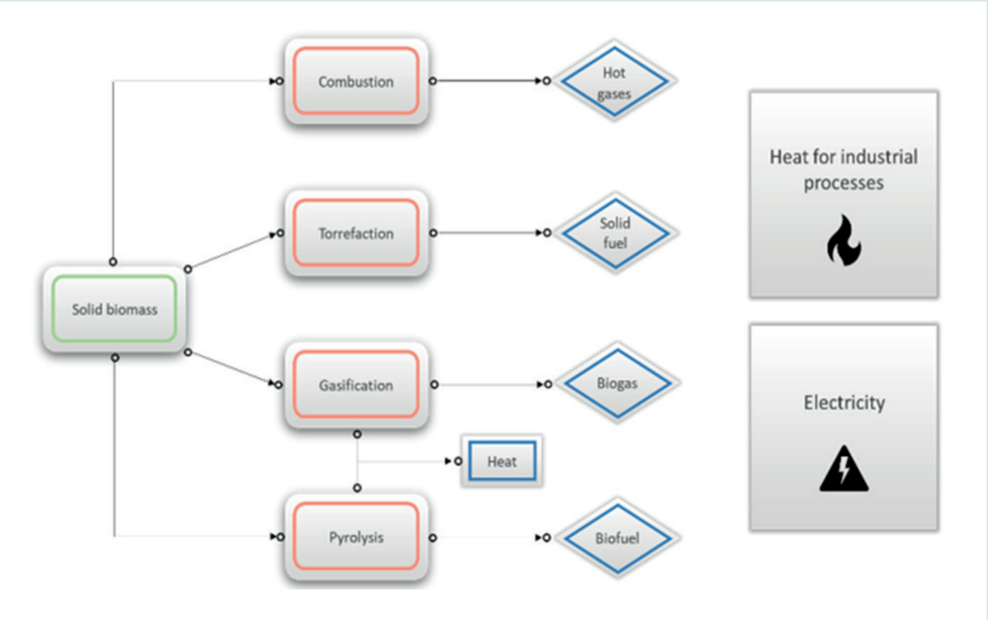


Figure 7: Main biomass thermochemical conversion technologies. Own design, based on information[34, 35, 36]

Biofuels

Biofuels are fuels obtained from the conversion of biomass either into a liquid (most common), solid or gaseous form of fuel.[37] The feedstock used for the production of biofuels play an important role in their classification as conventional (1st-Generation biofuels) and advanced biofuels (2nd-Generation biofuels).[38] While conventional biofuels are known to be produced from edible and land-consuming feedstocks, advanced biofuels make use of non-food and non-feed organic feedstocks.[39]

Although most of the commercialized biofuels like biodiesel and bioethanol are used in the transport sector[40], their use in energy-intensive industries within the cement, iron, ceramic, and chemical sectors, to name a few, is not extensive. These sectors still rely on using conventional fossil-based fuels, which could be substituted by renewable electricity and biomethane, for their processes like combustion-carbon-based electricity and natural gas for heat production. The similarities between the composition of natural gas and biomethane are very high; therefore, the combustion of natural gas could ideally be substituted with this renewable gas.[41] Biomethane is not only obtained via the anaerobic digestion of multiple renewable organic feedstocks, but also its use in the industry does not require any modification of current industrial processes. See Table 9.

Table 9: Comparison between natural gas, biogas and biomethane

Compound	Natural gas (%)[42]	Biogas (%)[43]	Biomethane (%)[44]
Methane	87,0-98,0	50-75	>90
Ethane	1,5-9,0	N.A.	N.A.
Butane	0,1-1,5	N.A.	N.A.
Pentane	<0,4	N.A.	N.A.
N2	5,5	0-10	N.A.
CO	0,05-1,0	25-50	N.A.
O2	<0,1	0-2	N.A.
H2	N.A.	0-1	<5

[33] Calderón C, Avagianos I, Jossart J-M. Bioheat Statistical Report.; 2020.

[34] McKendry P. Energy production from biomass (part 2): conversion technologies. Bioresour Technol. 2002;83(1):47-54. doi:https://doi.org/10.1016/S0960-8524(01)00119-5

[35] Islas J, Manzini F, Masera O, Vargas V. Chapter Four - Solid Biomass to Heat and Power. In: Lago C, Caldés N, Lechón YBT-TR of B in the B, eds. Academic Press; 2019:145-177. doi:https://doi.org/10.1016/B978-0-12-813056-8.00004-2

[36] Malico I, Nepomuceno Pereira R, Gonçalves AC, Sousa AMO. Current status and future perspectives for energy production from solid biomass in the European industry. Renew Sustain Energy Rev. 2019;112:960-977. doi: https://doi.org/10.1016/j.rser.2019.06.022

[37] Suurs RAA, Hekkert MP. Competition between first and second generation technologies: Lessons from the formation of a biofuels innovation system in the Netherlands. Energy. 2009;34(5):669-679. doi:https://doi.org/10.1016/j.energy.2008.09.002

[38] Heyne S, Harvey S. Assessment of the energy and economic performance of second generation biofuel production processes using energy market scenarios. Appl Energy. 2013;101:203-212. doi:https://doi.org/10.1016/j.apenergy.2012.03.034

[39] IRENA. Advanced Biofuels, What Holds Them Back?; 2019. https://www.irena.org/publications/2019/Nov/Advanced-biofuels-What-holds-them-back

[40] Ajanovic A, Haas R. On the future prospects and limits of biofuels in Brazil, the US and EU. Appl Energy. 2014;135:730-737. doi:https://doi.org/10.1016/j.apenergy.2014.07.001

Despite the technical feasibility of biomethane, one of its implementation challenges is deeply linked to its availability.[45] It is expected that biomethane will only replace around 8% of the total natural gas consumption of the EU by 2030.[46]

Green Hydrogen

Hydrogen is an energy carrier and can be produced from fossil fuels and biomass, from water, or from a mix of both. Its market is well established, most of which is consumed in the chemical sector. At present, roughly 95% of worldwide hydrogen production comes from fossil fuels.

Hydrogen may be produced through a variety of processes and a colour code nomenclature is becoming commonly used to facilitate discussion. See figure 8. Hydrogen is considered renewable or green when the full life-cycle greenhouse gas emissions of the production process are close to zero. The most common way of producing green hydrogen is through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources, but it can also be produced through other pathways. Figure 8 presents these different pathways based on the three feedstock that can be used to generate hydrogen: **Renewable electricity, biomass and biogas** and **sun irradiation**.

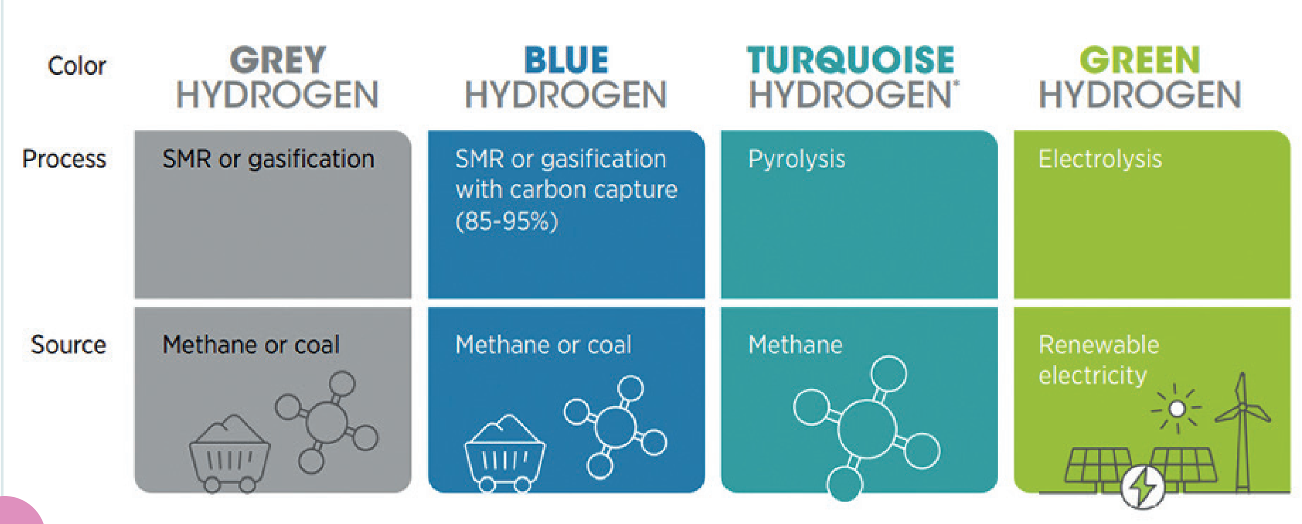


Figure 8: Selected shades of hydrogen source[47]

[41] Corbellini V, Kougias PG, Treu L, Bassani I, Malpei F, Angelidaki I. Hybrid biogas upgrading in a two-stage thermophilic reactor. Energy Convers Manag. 2018;168:1-10. doi:https://doi.org/10.1016/j.enconman.2018.04.074

[42] Arinelli L de O, Teixeira AM, de Medeiros JL, Araújo O de QF. Supersonic separator for cleaner offshore processing of natural gas with high carbon dioxide content: Environmental and economic assessments. J Clean Prod. 2019;233:510-521. doi:https://doi.org/10.1016/j.jclepro.2019.06.115

[43] Matuszewska A, Owczuk M, Zamojska-Jaroszewicz A, Jakubiak-Lasocka J, Lasocki J, Orliński P. Evaluation of the biological methane potential of various feedstock for the production of biogas to supply agricultural tractors. Energy Convers Manag. 2016;125:309-319. doi:https://doi.org/10.1016/j.enconman.2016.02.072

[44] Cavaignac RS, Ferreira NL, Guardani R. Techno-economic and environmental process evaluation of biogas upgrading via amine scrubbing. Renew Energy. 2021;171:868-880. doi:https://doi.org/10.1016/j.renene.2021.02.097

[45] Association EB. EBA Statistical Report 2020.; 2020.

[46] Eurogas. The Sustainable Credentials of Gas.; 2019.

[47] E. Bianco and H. Blanco, "Green hydrogen: a guide to policy making," 2020.

Steam reforming of biomethane/biogas with or without carbon capture and utilisation/storage is a mature and well-established technology besides electrolysis with ALK electrolysers. Less mature pathways are biomass gasification and pyrolysis, thermochemical water splitting, photocatalysis, supercritical water gasification of biomass, combined dark fermentation and anaerobic digestion.

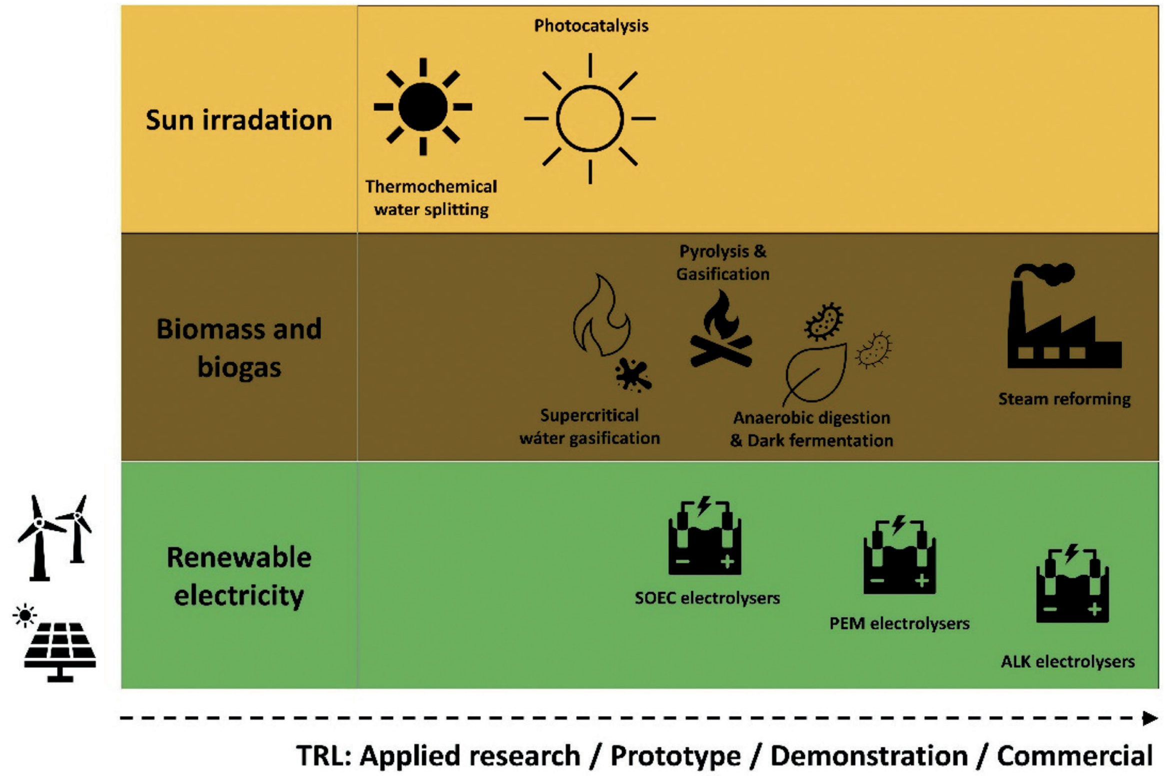


Figure 9: Renewable hydrogen pathways and current levels of maturity[48]

Currently, there is no significant hydrogen production from renewable sources, green hydrogen has been limited to demonstration projects[49], but is expected to develop in the coming years.

In the low- and medium-grade heat industrial segments, using renewable electricity is the primary way to decarbonize industrial processes according to FCH JU.[50] For industrial processes in the high-grade heat segment, hydrogen may offer benefits regarding its ability to generate high temperatures using process setups similar to today's. Besides its use for high-grade heat processes, EIIs can use green hydrogen for chemicals and synthetic fuels production and as a reduction agent (steel industries).[18]

[48] IRENA. Hydrogen from Renewable Power, Technology Outlook for the Energy Transition.; 2018. https://www.irena.org/-/media/files/irena/agency/publication/2018/sep/irena_hydrogen_from_renewable_power_2018.pdf

[49] IRENA. Hydrogen: A Renewable Energy Perspective.; 2019. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Hydrogen_2019.pdf

[50] FCHJU FC and HJU. Hydrogen Roadmap Europe – A Sustainable Pathway for the European Energy Transition.; 2019. https://www.fch.europa.eu/sites/default/files/Hydrogen Roadmap Europe_Report.pdf

3- Success Cases of Renewable Integration in EIIs

Successful cases of renewable energy integration in various EIIs exist. This chapter showcases five success cases of EIIs, that have adopted various decarbonisation measures from Spain, Greece, Belgium and Germany. The success case companies are performing in the steel (ArcelorMittal, Ebroacero), cement (Heracles, Heidelberg Materials) and glass sectors (Verallia) and serve as a good example for other players in the industry.

Table 10: Success Cases Key Information

Success case	Success cases key information	Decarbonisation efforts
ArcelorMittal	**Target:** Reduce CO_2 emission by 3.9 Mt/y by 2030	**Wind energy:** 12 wind turbines, rotor diameter 162 m, height 230m & capacity 6 MW/turbine. Energy production: 45 GWh/year. CO_2 emissions avoid.: 11,225 tons / year. **Solar energy:** more than 27,000 solar panels, since 201. It is the 3rd-largest park in Belgium of an area of 100,000 square meters. Energy production: 10 GWh/ year
Ebroacero	**Target:** Reduce CO_2 emissions. by 46,81 ton/year **Current emissions at Ebroacero:** 936,18 tCO_2eq	**Main action in 2021:** Agreement with **Solarfarm** for the **installation of PV solar cells. First project target:** establish 186,84Wp for renewable electricity self-consumption. **Power production:** ~207.254 kWh/year, 4-5% of overall power consumption **CO_2 emissions avoidance:** 46,81 tCO_2eq
HERACLES	Strategic goals of the company: Reduction of the total gross CO_2 emissions to 1,522 kt CO_2 (2030) from 2,103 kt of CO_2 (2019) Increase the substitution of fossil fuels by **alternative fuels** to **50 %** by 2023	The RE technology applied at the Milaki Cement Plant (**MCP**) is based on the co-processing concept of simultaneous recycling of mineral materials and recovery of energy within cement manufacturing; MCP is co-processing biomass, solid recovered fuel and dried sewage sludge;
Verallia	**Target:** Reduce CO_2 emiss. by 46% in 2030 (Scopes 1 & 2)	Verallia is investing to transform the technologies, resources and industrial equipment used on its sites, aiming to reduce their CO_2 emissions by 46% in 2030 (Scopes 1 and 2). In 2021, Verallia also decided to commit to a Scope 3 CO_2 emissions reduction target, to be achieved in collaboration with their suppliers.
Witnica Solar Park	**CO_2 emissions at Górazdze:** 2.73 Mton (2018) **Goradze Cement SA, Target:** Carbon-neutral concrete by 2050, and achieving to a reduction of specific net CO_2 emissions to below 525 kg per ton of cement-based material.	Installation of 159,856 PV panels leads to 63,000 t CO_2 emission reduction and production of 68 GWh electricity from RES annually which means around 2,500 homes could be powered with the green electricity from the solar park.

ArcelorMittal Ghent steel plant

ArcelorMittal Belgium has been selected as one of the success cases in the RE4Industry Project, owing to the industry's huge efforts to reduce CO_2 related emissions by utilizing Renewable Energy Sources (RES) in their basic production line and Carbon Capture and Utilisation (CCU) technologies.

Figure 10: Wind turbines and solar panels at ArcelorMittal's Ghent plant

To achieve their 2030 targets, a 2.5 million tons direct reduced iron (DRI) plant and electric arc furnace (EAF) facility at its Ghent site will operate alongside Ghent's state-of-the-art waste wood and plastic fired blast furnace (Horizon2020 Torero project).[51]

Moreover, the Carbalyst[52]/Steelanol[53] project promotes CCU by converting biologically waste gases captured from blast furnaces into bioethanol, which can be re-used as chemical feedstock or blended for use as liquid fuel. The two aforementioned projects are expected to be commissioned in 2022.

Three wind turbines will be put upright by the end of 2022 promoting the use of wind energy. Additionally, the installation of more than 27.000 solar panels on the roof of ArcelorMittal in Ghent has been completed, being the largest solar roof in Belgium. ArcelorMittal currently owns the fourth largest solar park in Belgium and the largest solar roof in Belgium.

Finally, ArcelorMittal Belgium and Dow Benelux have carried out trials with a new pilot plant on ArcelorMittal's premises in Gent that separates (CO_2) and carbon monoxide (CO) from the hot flue gases produced during steel production. In total, this will lead to a CO_2 emissions reduction of 3 million tons a year, compared with 2018 and enables the creation of synergies in ArcelorMittal Belgium's roadmap to reaching net zero carbon-emissions by 2050. The foreseen emission reductions will also make a big contribution to the company´s ambitious target to reduce carbon emissions by 3.9 million tons per year by 2030.[54]

[51] Torero - fueling a subtainable future
[52] Carbalyst®: Capturing and re-using our carbon-rich waste gases to make valuable chemical products | ArcelorMittal
[53] Home | Steelanol
[54] RE4Industry Project: D3.3 Success cases of RE integration Case study: ArcelorMittal Ghent steel plan

Electrical generation in-situ by means of photovoltaics in the steel industry – Ebroacero (Zaragoza, Spain)

The European steel sector is under pressure due to its CO_2 emissions produced by its high energy and resource-intensive processes. In 2018, the European Commission made public its long-term strategy on climate protection to make it a region by 2050 free of the emissions of green-house gases. The sector of conventional steel production in Europe is one of the biggest sources of CO_2 emissions.

In this respect, Ebroacero signed an agreement with Solarfarm for the installation of photovoltaic solar cell technology in its plant located in Zaragoza, in 2021.

This action has guaranteed Ebroacero an overall on-site production of electrical energy of around 4 to 5%. This amount is planned to be consumed entirely at its own facilities and no surplus will be sold to the grid.

Figure 11: Photovoltaics applications on site source: Ebroacero

The total investment amounts to around 150.000 € and aims to substitute the purchase of externally produced electricity.

In addition, results showed a total saving of 29.4 tons of natural gas, which translates into 86.33 tons of CO_2-eq avoided.

The installation of photovoltaics will aid in reducing emissions of Scope II. Current emissions at Ebroacero are around 936,18 tons of CO_2-eq. As mentioned above, the new photovoltaics installation may guarantee about 207.254 kWh/year produced by renewable sources, which represents 4-5% of overall power consumptions. This amount will aid in avoiding roughly 46,81 tons of CO_2-eq.[55]

[55] RE4Industry Project: D3.3 Success cases of RE integration Case study: Electrical generation in-situ by means of photovoltaics in the steel industry – Ebroacero (Zaragoza, Spain)

Biomass co-processing in the cement industry / The Milaki Cement Plant of HERACLES-Holcim

Cement manufacturing is an energy intensive process due to the need for heating the raw materials to a high temperature (around 1450oC). In Europe, where the cement industry is modernized and already implements state-of-the-art technology, around 3,300 MJ of thermal energy is needed to produce one ton of clinker [h]. Therefore, the fuel cost for producing this thermal energy is a significant cost factor in cement production.

In 2020, HERACLES – a member of the Holcim Group and one of the main cement manufacturers in Greece – designed and implemented an innovative project for the co-processing of biomass for cement production at its facilities in the Milaki Cement Plant, on the island of Evia.

A major component of HERACLES' strategy for climate change is the substitution of fossil fuels with alternative fuels, which decrease the company's environmental footprint, while increasing Biomass co-processing in the cement industry The Milaki Cement Plant of HERACLES-Holcim competitiveness of its products. In particular, the strategic goals of the company regarding energy and climate include:

- Reduction of the total gross CO_2 emissions (Scope 1) to 1,522 kt CO_2 by 2030. For comparison, 2,103 kt of CO_2 were emitted in 2019.
- Increase the substitution of fossil fuels by alternative fuels to 50 % by 2023. The introduction of alternative fuels at the cement production plants of HERACLES has been a gradual process. The licensing procedures for the use of alternative fuels started in 2009, while their gradual introduction in the production process started in 2013. In 2020, HERACLES used 130,000 tons of alternative fuels for thermal energy production, corresponding to 27.7% of the total fuel energy input, saving about 85,000 tons of CO_2 emissions and reducing the company's total CO_2 emissions by 7%.

To achieve the mentioned goals, the company made a total investment of 2 million EUR, aiming to substitute solid fossil fuels (e.g. petcoke) used in cement production with alternative biomass fuels. This substitution is expected to cause a reduction of CO_2 emissions by 70,000 tons per year.

About 75,000 tons per year of biomass – mostly prunings and other agricultural residues – can be valorised through this investment, contributing to promotion of circular economy principles and reducing the volume of waste that is landfilled.

Figure 12: Biomass pile (left) & close-up of biomass particles (right)

[56] RE4Industry Project: D3.3 Success cases of RE integration Case study: Biomass co-processing in the cement industry The Milaki Cement Plant of HERACLES-Holcim

Biofuel co-firing implementation in furnaces of glass industry Verallia Spain S.A (Zaragoza)

The glass manufacturing industry is an energy-intensive one due to the need for heating the raw materials to high temperatures in order to melt, form, coat and anneal glass containers, fibers, or flat glass slides (around 1600 oC).

In 2020, Verallia Spain S.A, the Spanish subsidiary of the top glass manufacturing company, decided to implement innovation in its processes to enhance corporative decarbonisation strategies in their facilities located in Zaragoza.

Verallia has identified the use of biofuels as co-firing fuels for their furnaces as key for the substitution of non-renewable liquid fuels used in their furnaces. In this context, the plant located in Zaragoza (Spain) is already running one of their furnaces mixing the biofuel with natural gas (10 wt. % biofuel). Replacing natural gas with biofuels such as biomethane would likely make this combustion CO_2 neutral.

The Group intends to apply a policy that favours renewable energy solutions (biofuels in particular) as well as the implementation of alternative solutions to road transport, such as rail.

In line with their intentions, Verallia runs on rapeseed biofuel in the Champagne region, reducing CO_2 emissions from its transport in the Champagne region by 60%, thus reducing fine particles by 80% compared to the use of diesel.

Figure 13: Truck running on rapeseed biofuel in the Champagne region source: Verallia

Considering an average consumption of 2000 t/ month and a substitution percentage with biofuel of around 10%, this would lead to a CO_2 emission saving of 395.6 t CO_2/ month.[57]

Solar PV Usage (PPA) in the Witnica Solar Park (Poland)

BayWa r.e. - a leading global renewable energy developer, service provider, distributor, and energy solutions provider - and Heidelberg Materials' Polish subsidiary Górazdze Cement have signed a 10-year corporate Virtual Power Purchase Agreement (VPPA) for the Witnica solar park in Poland, which was completed in 2021. The signing of the contract of the project in Witnica is a significant step for the Górażdże towards carbon neutrality in Scope 2 emissions. The contracted capacity will serve around 10% of the yearly consumption of Heidelberg Materials.

Figure 14: Aerial Picture of Witnica Solar Park source: ceenergynews

The solar park is connected to the Polish electricity grid and will supply the company with green electricity until 2031.

Witnica is currently the largest solar park in Poland with a capacity of 64.6 MWp. At the same time, it is the first subsidy-free solar park whose electricity is marketed through a long-term VPPA. BayWa r.e., therefore, hopes that this cooperation will pave the way for further VPPAs in the region and emphasizes that this project will provide the most cost-effective green power in the entire country. In this regard, more than 63,000 tCO_2 emission reduction was achieved by the off-taker Heidelberg Materials, and 68 GWh of electricity is produced from renewable energy sources annually.

Moreover, the solar park, which will produce enough green electricity to power the equivalent of around 22,500 homes is by far the largest solar project in Poland.

In August 2021 the solar park was sold to Alternus Energy Group, as pan-European Independent Power Producer, BayWa r.e. will continue to provide operations and maintenance services at the Witnica site for Alternus Energy.[58]

[57] RE4Industry Project: D3.3 Success cases of RE integration Case study: Biofuel co-firing implementation in furnaces of glass industry Verallia Spain S.A (Zaragoza)

[58] RE4Industry Project: D3.3 Success cases of RE integration Case study: Solar PV Usage (PPA) in the Witnica Solar Park/ Poland

4- Case studies on renewable energy solutions in EIIs

This chapter reports the developed case studies of the three energy-intensive industries that are a part of the project consortium. The aim is to showcase specific solutions and market benefits in the framework of a long-term renewable energy integration and decarbonisation strategy.

A dialogue has been established between the Technical Partners in charge of the each of the case studies (CIRCE, BTG and CERTH) and the case study hosts (SIDENOR, CORBION and MYTILINEOS) from the very beginning in order to learn first their needs and expectations. After the renewable energy technologies suitable for every case are assessed, the final decision of which technology to integrate is discussed jointly. A first glance at the initial stage is given below.

Mytilineos

Corbion

Sidenor

Mytilineos

MYTILINEOS is a Greek company operating in the industrial and energy sector, both in Greece as well as globally. Originally established back in 1908 as a small, family-owned metallurgical industry in Piraeus, in 1990 the MYTILINEOS group is founded and in 2017 the company consolidates as a new, single business entity, with a turnover of 2.26 billion € and around 3,850 employees (direct and indirect).

Figure 15: Major blocks of the AoG Plant and natural gas fired CHP plant

This RE4Industry case study focuses on the Aluminium of Greece (AoG) plant, which is part the Metallurgy Business Unit of MYTILINEOS. AoG is the largest vertically integrated alumina and aluminium producer in the European Union, with an annual production capacity of 900 kt of alumina and 222 kt of aluminium products (192 kt primary aluminium + 30 kt recycled fractions).

CERTH has identified four potential solutions which are considered as mature enough for deployment by 2030 and thus considered for further analysis.

- The electrification of the aluminium holding furnaces has the potential to deliver an emission reduction up to 26,500 tCO_2.
- Biomethane from anaerobic digestion can provide a “virtual” substitute for the current natural gas (NG) consumption.
- Syngas from biomass gasification is considered as a potential substitute for the NG used in alumina calcination.
- Green hydrogen offers the most promising long-term option, however there is still a long way before reaching economic parity.[59]

[59] RE4Industry Project: D4.2 – Initial vision document of current and future energy needs and solutions

Corbion

Corbion is the global market leader in lactic acid and its derivatives, and a leading supplier of emulsifiers, functional enzyme blends, minerals, vitamins, and algae ingredients. Corbion markets its products through a worldwide network of sales offices and distributors and has a global supply chain with manufacturing facilities in the US, Thailand, Brazil, the Netherlands, and Spain. Within the RE4Industry case study, renewable energy integration at the site of Corbion in Gorinchem, the Netherland is investigated.

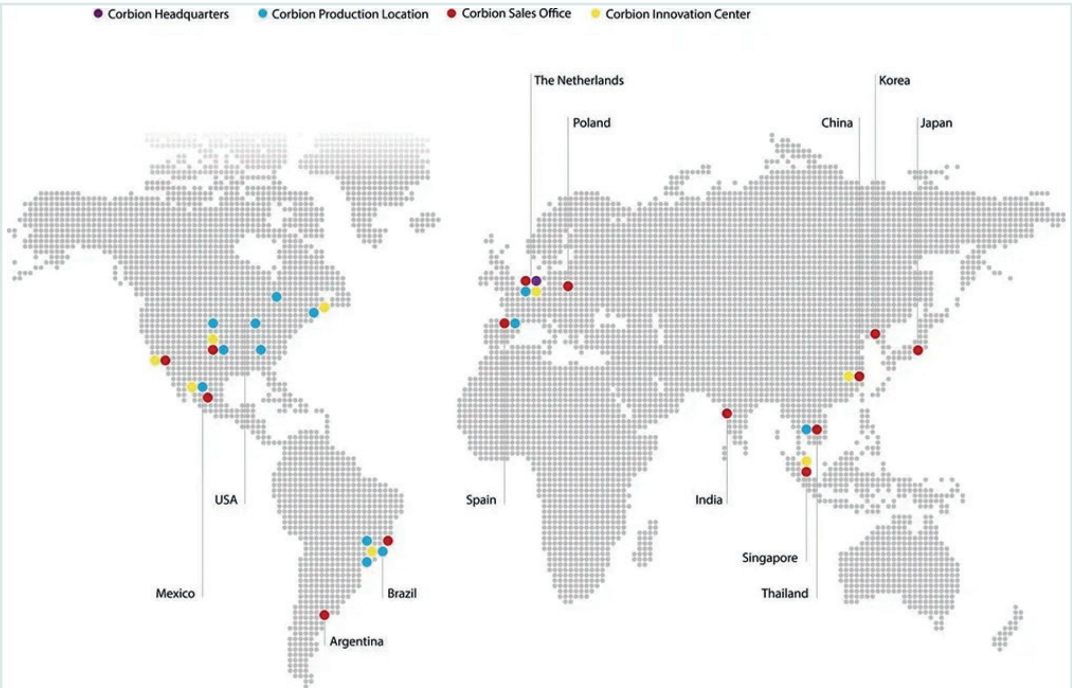


Figure 16: Location of Corbion headquarters, production locations, sales offices, and innovation centers

Given the long-term decarbonisation vision of the company and ongoing activities of Corbion to reduce its carbon footprint, and the need to make substantial steps to further reduce its scope I, II, and III GHG emissions by 33% in 2030, it was decided to focus the case study on replacing the natural gas fired central 15 MW steam boiler.

An initial assessment of the technical possibilities and financial feasibility was performed and discussed between BTG and Corbion. The proposed three relevant options included: **replacing natural gas with renewable electricity for steam production** (power to heat), **the use of hydrogen from renewable electricity** and **biomass for steam production**. The assessments resulted in the following observations:

- **The electric boiler has been selected for further analysis.** Drawbacks are its dependency on low electricity prices and high network connection costs and network fees.
- **Hydrogen combustion is a straightforward process.** Therefore, selected for further analysis.
- Main weak points are the current low/no availability of affordable renewable hydrogen and the absence of infrastructure to supply the hydrogen.
- Although technical and financially feasible, the bioenergy options are perceived by Corbion as high-risk technology regarding sustainability and social acceptance.
- Due to its high volumetric energy density, **pyrolysis oil is logistically the most attractive bioenergy solution**, and will be considered for further analysis.[59]

Sidenor

SIDENOR is a steel company, leader in the European steel industry for the production of special steel long products. It is also an important supplier of cold finished products in the European market. The company has production centers in Basque Country, Cantabria and Catalonia. The company has highly specialized facilities offering solutions for all industrial sectors requiring high quality steel services.

The focus of the study was SIDENOR's plant located at Basauri, in the Basque region, in northern Spain. This plant has been selected since it is a good representation of SIDENOR energy consumption not only in terms of quantity but also in terms of the types of energy consumed. The proposed renewable energy solutions include **the use of electricity** and **heat**.

Figure 17: SIDENOR´s production centers

Table 11: Comparison of renewable energy solutions for further selection as case study for SIDENOR

Option	Technical feasability	Financial feasability	Logistical implementable at Basauri's site	Full replacement of fossil options	Sustainability	Social acceptance	Selected as case study
PPAs *	+++	+++	---	+	+++	+++	No
Photovoltaics	+++	+++	+++	+	+++	+++	No
Green H_2	++	+/-	---	++	+++	++	Yes
Biomethane	+	+++	---	++	+++	+	Yes
Pyrolysis **	++	++	+/-	+/-	++	+/-	Yes
Heat Pumps	++	+	+++	++	+++	++	No

* Power Purchase Agreements / ** Of biomass for biochar production

- First, Power purchase agreements and the installation of Photovoltaics at SIDENOR's plants have been discussed.
- With respect to renewables solutions for heat, green hydrogen, biomethane, biochar from pyrolyzed biomass and heat pumps have been analysed.
- According to an analysis including several factors such as the technical and economic feasibility of the solutions, their logistical implementation, share of replacement of current fossil energies, sustainability, and social acceptance, **it has been decided to select green hydrogen, biomethane and biochar for further analysis.**[59]

Meet the Partners

Technological and Social Experts

Fundación CIRCE - Centro de Investigación de Recursos y Consumos Energéticos (project coordinator)

Apart from its role as coordinator, CIRCE is the main responsible for the assessment of the existing and upcoming technologies in the area of industrial decarbonisation as well as in the analysis of the industry needs, based on its wide experience in industrial retrofitting projects and renewable energy promotion activities.

BTG - Biomass Technology Group

BTG is in charge of developing RE4Industry baseline methodology for the development of Actions Plans in the EII. Its inter-disciplinary team has a long-standing expertise in analyzing industrial and service innovations and has already been working in the uptake of bio-based technologies and carriers by the EU industry in EU projects like BIOFIT or MUSIC.

CERTH HELLAS - Centre for Research and Technology

As one of Greece's leading research centres, CERTH has long experience in both technology development and knowledge transfer related to the energy sector. Within RE4Industry, CERTH is the primary responsible for analysing the current status of the EII sector and identifying success cases of renewable energy integration.

WIP Renewable Energies

As a private company active in the field of RE technologies, WIP leads RE4Industry replication strategy. Their expertise relies in the organisation of international RE events bridging the gap between research and implementation of RE systems. Moreover, they work hand in hand with the industry for the supervision and realisation of projects, which is crucial for maximising the impact of replication use cases.

White Research

As a social research SME specialized in market analysis, business strategy, innovation management and policy and user related issues, WR is in charge of designing RE4Industry engagement strategy and Collaborative Network in WP2 and provides the use cases with the required support to overcome legal, social and financial challenges that could hamper the uptake of renewable energies in the targeted industries.

Renewable Energy Oriented Associations

Bioenergy Europe

As the voice of European bioenergy for the development of a fair market for bioeconomy, BIOEU is in charge of organizing the main empowering, lobbying and advocacy activities of the project. They are conformed by more than 40 associations and 90 companies and R&D centres, which provides RE4Industry with a critical mass of stakeholders on bioenergy to achieve and replicate its objectives.

EEIP - Energy Efficiency in Industrial Processes

As a business and policy platform for energy transition that looks into new technical solutions and sound business models that accelerate the market growth, EEIP is in charge of leading the dissemination and communication activities of the project, taking advantage of the EEIP network users that covers the entire value chain (supply and demand side of the RE technologies explored within RE4Industry).

ESEIA - European Sustainable Energy Innovation Alliance

ESEIA is the European sustainable energy innovation alliance and counts on 27 leading research and innovation organisations in the field of sustainable energy systems from 13 different European countries. They are responsible for the entire network aware of RE4Industry results in order to become the market seed of the project.

Energy Intensive Industries

SIDENOR

SIDENOR is the largest manufacturer in Spain of special steels, forgings and castings, as well as one of the main manufacturers of drop forging pieces and is the main use case for the validation of RE4Industry methodology validation in Spain. Moreover, they have several production sites in Germany, France, Italy and the U.K., which enables the in-house transfer of results across the EU.

MYTILINEOS

MYTILINEOS is Europe's largest vertical integrated primary aluminum producer, owning bauxite mines, alumina refinery, and aluminum smelter plants. They are the main use case for Greece and continue its activities related to optimising energy efficiency and reducing GHG emissions. Their production facilities inside and outside Europe also enable the replication of the results in a wide number of countries.

PURAC (CORBION)

CORBION is the global market leader in lactic acid and lactic acid derivatives, and a leading company in emulsifiers, functional enzyme blends, minerals, vitamins, and algae ingredients. Corbion is thus a strong sustainable ingredient solutions company in biochemicals and food and is the main use case in the Netherlands.

RE4INDUSTRY

Renewable energies for industries

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.952936.

RE4INDUSTRY

Renewable energies for industries