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Master Thesis

Industrial uses for hydrogen

The case of the iron and steel sector in Europe

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Abstract

Decarbonising energy-intensive industries are essential for Europe's climate change mitigation goals. European countries have prioritised using hydrogen as a crucial element for the energy transition. The iron and steel sector must begin its transformation towards lower emission production. The interest in zero-emission steel has increased among private sectors and the government, and the scaling-up of hydrogen-based steelmaking is the solution that will become cost-competitive in those regions with cheap renewable electricity and will trigger an innovation boost that will reduce the costs of elements within the green hydrogen value chain.

The following work consists of a theoretical framework of hydrogen, starting from its production, storage and distribution toward the end-use applications. It is followed by a study on high-temperature thermal energy demand in the EU. The potential for decarbonising high-temperature process heat is presented, where the opportunity for using hydrogen in the iron and steel is identified.

An essential tool for this study is the georeferencing of the steelmaking plants across the EU, which helped identify advantageous locations with high industrial activity. The feasibility of hydrogen production in Europe is presented, with the available data for the design and necessary assumptions for scaling up.

The study's findings present the best locations for a medium-term deployment of fossil-free steelmaking and the necessary steps for better adaptability for transitioning towards a pure hydrogen-based process.

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Nomenclature

AC	Alternating current
ACC	Annual capital cost

BF	Blast furnace
BOF	Blast oxygen furnace
CAPEX	Capital expenditure
CCUS	carbon capture, utilisation, and storage
CDRI	Cold direct reduced iron
DRI	Direct reduced iron
EAF	Electric arc furnace
EI	Emission intensity
EII	Energy-intensive industries
EPSG	European Petroleum Survey Group
EU	European Union
GJ	Gigajoules
GW	Gigawatt
H_2-DR	Hydrogen-based direct reduction
HT	Hight-temperature
HBI	Hot briquetted iron
MAC	Marginal carbon abatement cost
NG	Natural gas
NUTS	Nomenclature of territorial units for statistics
OPEX	Operational expenditure
PJ	Petajoules
PEM	Proton exchange membrane
SOEC	Solid oxide electrolysis cell
SMR	Steam methane reforming
tcs	Tonnes crude steel
WAG	works-arising gases
WGS	World Geodetic System 1984

1. Introduction

The European Union aims to be climate-neutral by 2050, under the Paris Agreement's goal of limiting global warming to below 2°C and pursuing efforts to limit it to 1.5°C compared to preindustrial levels. (UNFCCC, 2015)

This objective is the core of the European Green Deal, ensuring no net emissions of greenhouse gases and providing energy security and economic growth. (European Commission, 2019)

The decarbonisation pathway requires an entire transformation of how we generate, distribute, consume and store energy. The transformation must occur in every adaptable sector through policy, regulation, research, innovation, infrastructure, and private and public investment.

Government strategies and academia affirm that prioritising hydrogen as a critical factor in the energy transition will aid in achieving these climate goals.

Hydrogen is a fossil-free energy carrier, feedstock, and fuel for industries like steel, cement, and chemicals. It can facilitate large-scale integration of renewables, balance the grid and facilitate seasonal storage. Approximately 90% of the hydrogen consumption in the European Union is for industrial uses; virtually all of this hydrogen is supplied by fossil fuels. The opportunity to scale up green hydrogen technologies is attractive to specific industries where low-cost renewable electricity is available and local regulations support it.

Key barriers must be overcome to realise the potential of hydrogen for energy transformation. The cost of producing and transporting green hydrogen is very high compared to fossil fuels, not to mention that some hydrogen technologies are not commercially ready. The hydrogen value chain is at risk of the lack of ready-to-use technologies and the lack of electrification of sectors that will require renewable electricity, which is the most significant cost component.

Hydrogen could become an internationally traded commodity. 85% of hydrogen is produced and consumed on-site rather than bought and sold in a broader market or across large distances. For instance, hydrogen can be produced where renewable electricity costs are low and transported through pipelines or ships (such as ammonia, liquid hydrogen, or liquid organic hydrogen carriers LOHCs). (IRENA, 2020)

The European Union's Hydrogen Strategy was published in 2020, and they estimate around

EUR 220-340 billion in investments for electricity production and EUR 24-42 billion for electrolysers in 2030. They target increasing electrolyser capacity to 6 GW by 2024 and 40 GW by 2030. (IRENA, 2020)

Energy-intensive industries (EIIs) make up more than half of the energy consumption in the European Union. These industries with the potential to quicken decarbonisation while keeping their markets competitive and transitioning to a hydrogen economy. Along with regulators, governments, and policymakers, these industries can lead the way for cost-effective pathways for climate change mitigation.

Steel and high-temperature heat production have great potential for low-emission hydrogen demand growth in the long term.

Steel production is responsible for 7% of the total GHG emissions globally, and high-temperature heat demand in the European Union generates approximately 1.1 $GtCO_2$/yr of direct emissions (excluding the chemical, iron, and steel sectors), around 3% of the global energy sector. (IEA, 2019)

Steelmaking is associated with high-temperature processes, and therefore they have a tremendous demand for high-temperature process heat.

Steel is the most used metal for construction and engineering. It is a fundamental element for development and innovation, and with increasing population and demand, the decarbonisation of the sector is crucial for climate change mitigation. Most of the crude steel produced in the EU is by the primary steelmaking route (blast furnace/blast oxygen furnace route), with 58% of total steel output, and the remaining is produced by the secondary route (electric arc furnace).

The iron and steel industry has already undergone methods for CO_2 mitigation, primarily relying on energy efficiency technologies.

However, the most popular innovation for a CO_2 avoidance pathway in steel is a hydrogen-based direct reduction of iron ore. Projects are underway to commercialise this process, some in early development but with increasing interest in steelmakers worldwide.

The decarbonisation of the steel sector with hydrogen would require 296 TWh of clean electricity per year, between 37 and 60 GW of electrolyser capacity, and more than €180 billion in investments (steel plants, electrolysers, and RES). (Correa Laguna, Duerinck, Meinke-Hubeny, & Valee, 2021)

The main challenge for scaling up hydrogen is the access to cheap low-carbon electricity. Currently, the share of energy from renewable sources in Europe is 22.1%. Despite the Covid-19 health crisis, the renewable capacity proved its resilience, despite lockdowns and an economic slowdown.

The Covid-19 health crisis impacted the world economy very hard, with slow recovery and a significant impact on the industry and its value chains, slowing the energy transition because of economic uncertainty.

Nevertheless, members of the EU have presented their recovery strategies, which emphasize the urge for climate change mitigation and the use of hydrogen as a decarbonisation tool in the following decades. Government support will incite innovation and development, accelerating investments and reducing costs for scaling up hydrogen technologies for all sectors across the continent.

1.1. Objective and scope

The thesis aims to study the current trends of hydrogen in energy-intensive industries based on their geographical distribution and the potential for decarbonising specific areas with hydrogen and considering the distribution of the hydrogen demand in the following decades. By analysing the trends of high-temperature heat demand in industries, the research emphasises the challenges needed to overcome for decarbonising the iron and steel industry. A feasibility assessment of a simplified hydrogen production plant coupled with a hydrogen-based direct reduction and an electric arc furnace is carried out, considering the necessary investments and policy support for future implementation. The adaptability of the transition to this steelmaking route is analysed alongside the existing policies and the trends for future hydrogen technology deployment in the EU.

The scope of the study is limited to the European Union and the United Kingdom.

1.2. Structure of the thesis

The thesis is organised as follows.

Chapter 1: The first chapter introduces the problem and subject of the thesis, delimiting the scope, setting the objective, and presenting the methodology throughout the study.

Chapter 2: The second chapter overviews hydrogen as an energy vector, how it can be produced, stored, and distributed, and its potential end-uses.

Chapter 3: In the third chapter, an analysis of the European heat consumption in industries is carried out, focusing on the high-temperature process heat. Following a similar model to (Naegler, Simon, Klein, & Gils, 2015), to identify the markets in which hydrogen can play a competitive role for high-temperature heat demand. The potential and forecast of hydrogen substituting fossil fuels in the energy-intensive industry are also analysed in this chapter.

Chapter 4: The fourth chapter describes the iron and steel industry: the processes, technologies, and activity in the European Union.

Chapter 5: The fifth chapter maps the iron and steel plants across Europe, integrated with their technologies, production capacity, and equivalent CO_2 emissions. The results of the high-temperature demand model are also mapped out for graphical analysis.

Chapter 6: The sixth chapter is dedicated to the potential use of hydrogen in the iron and steel sector. The analysis is carried out for hydrogen as fuel and high-purity feedstock to decarbonise the industry. Theroritecial values are analysed with the future trends for the next decades.

Chapter 7: The seventh chapter encapsulates the current policies supporting hydrogen as a decarbonising factor and presents the hydrogen strategies of the European Union and its members. Additionally, it presents the geopolitical opportunities and disadvantages for those countries with the highest industrial activity in the EU.

Chapter 9: The conclusions are presented in this chapter.

Appendices: The complete datasets for all calculations are available in this section.

1.3.Methodology

1.3.1. Research approach and process

The study's approach was a quantitative analysis of the industrial uses for hydrogen. This approach is location-based since some countries provide better conditions for adaptability.

The research has three main components: hydrogen, high-temperature heat demand and the iron and steel industry.

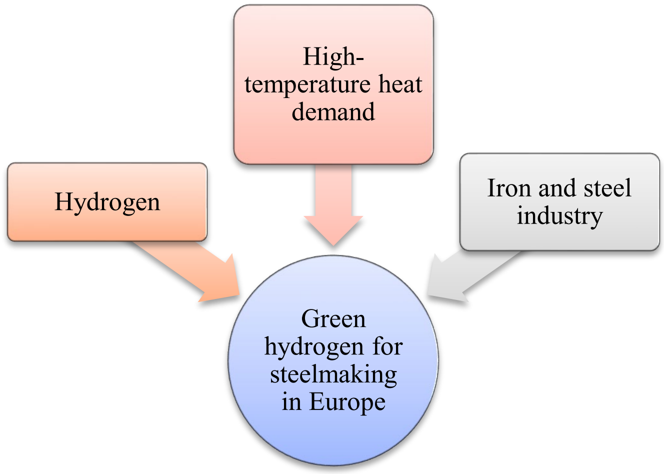


Figure 1 Relationship between chapters for the aim of the study.

The initial phase of the research process came with a theoretical study of hydrogen to better understand its uses in industrial applications today.

It was followed by a literature review that helped identify areas of opportunity for high-temperature demand in industrial applications. A similar approach was followed for estimating high-temperature thermal energy demand in Europe (Naegler, Simon, Klein, & Gils, 2015).

A quantification of high-temperature heat demand in Europe was calculated to identify those countries and industries with the highest potential for quicker decarbonisation with hydrogen. The European heat demand estimation was approached with three different data sets (DS1, DS2 and DS3). The data was updated to the latest available statistics. The full tables are available in Appendix A.

The data was calculated based on temperature ranges:

- *Low-temperature range*: Process heat under 100°C, space heating and water heating also fall into this temperature range.
- *Medium-temperature range*: All processes between the temperatures of 100°C – 500°C
- *High-temperature range*: Between 500°C and 1000°C, and above 1000°C (Frisch, Pehnt, & Otter, 2010)

The calculation of the estimates of heat demand by industry, temperature ranges and countries were:

$$DS1 \cdot DS2 \cdot DS3 = Final\ Energy\ Demand$$

$$Share\ heat\ demand_{temperature}[\%] \cdot FEC_{industry\ sector}[PJ] \cdot Share\ end\ use\ balance_{PH,SH\ or\ WH}[\%] = Final\ heat\ demand$$

For example, Austria's heat demand in the Iron and Steel Sector for T > 1000°C:

$$\%\ heat\ demand_{PH>1000°C} \cdot FEC_{iron\ \&\ steel} \cdot \%\ end\ use\ for\ PH_{iron\ and\ steel} = Final\ heat\ demand$$

$$75.6\% \cdot 36.92\ PJ \cdot 70.2\% = 19.59\ PJ$$

Following these estimations, the iron and steel sector is studied. The steelmaking routes and the alternatives to the current methods in these processes are described.

Subsequently, mapping the iron and steel industry and the HT-heat demand is made.

The analysis is divided into sections to understand the tendencies and the opportunities for high-temperature industries.

The selected tool for the construction of the maps was QGIS3. The basis of the map is a shapefile retrieved from (Environmental Systems Research Institute, 2015). All the maps use the geographic coordinate system WGS 84 - EPSG:4326.

Firstly, an industrial site database was constructed with the necessary information on the geographical location of the industrial sites for all European Union's 27 regions and the United Kingdom. The database was constructed with data from the Hotmaps Project (Pezzuto, et al., 2019), which is an open-source database that grants free use and access for academic purposes, and the map of all EU production sites (EUROFER, 2020), and additional research through the official sites of each company's websites. The complete structure of the database is described in Table 1.

These georeferenced industrial databases are differentiated by the technology of the process: blast furnace/blast oxygen furnace (BF/BOF) and electric arc furnace (EAF).

For calculating the CO_2 emissions of each steelmaking process, the emission factor provided by the IPCC was used and can be seen in Table 12. (Ottinger & Cai, 2019) The CO_2 emissions are proportional to the production volume of each plant. The complete databases with the information about each plant can be found in Appendix C.

Table 1 Emission factors for iron and steel production. (Ottinger & Cai, 2019)

Process	Unit	Value	Comments
Iron production	tonne CO_2/ tonne hot metal	1.43	
DRI	tonne CO_2 / tonne DRI produced	0.70	
BOF	tonne CO_2 /tonne of steel produced	1.58	This value includes the emissions from the blast furnace iron production
EAF	tonne CO_2/tonne of steel produced	0.18	

Additionally, the high-temperature demand database analyzed in chapter 3 is mapped according to the high-temperature process heat demand in the iron and steel sector. Space and water heating were not considered.

1.3.2. Data collection

In this section, the process for data collection for specific chapters will be described. The data presented below is a combination of energy statistics, available literature, government reports, and own calculations.

High-temperature heat demand

For the data collection of chapter 3, the data sets were gathered and divided as follows:

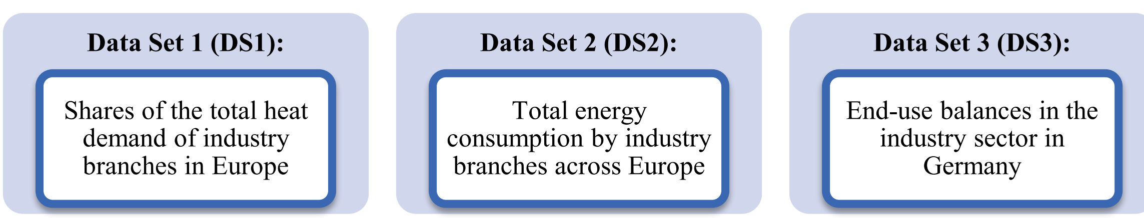


Figure 2 Structure of the data sets for Chapter 3.

DS1: Shares of the total heat demand of industry branches in Europe, differentiated by temperature ranges. The data was obtained based on the German methodology of dividing the different industry branches, so an allocation method was used to categorise the data according to EUROSTAT. (Blesl, 2014)

The data obtained for the mining industry was from a different source. However, assuming the mining processes have not changed in the past years, the temperature usage shares can still be relevant for the study. (Lutsch & Witterhold, 2005)

DS2: Total energy consumption by industry branches across Europe (EUROSTAT Statistical books, 2021)

DS3: End-use balances in the industry sector in Germany. The total shares by each end-use (space heating, water heating and process heating) were calculated using the total final energy consumption for the entire end-use applications with power and fuel consumption. The considered share of the process and space/water heating was calculated with the final energy consumption FEC, including lightning, process cooling, space cooling, IT and mechanical energy. (Appendix A)

The source for these data is the same as (Naegler, Simon, Klein, & Gils, 2015) used, with the only difference being the update of values made by Frauenhofer ISI from 2009 to 2015. The data was obtained based on the German methodology of dividing the different industry branches, so an allocation method was used to categorise the data according to EUROSTAT. (Fraunhofer ISI, 2016)

Mapping

The data collected for the realization of the maps is presented in Figure 3. These databases built with the presented parameters were later manipulated in QGIS for the desired outcome.

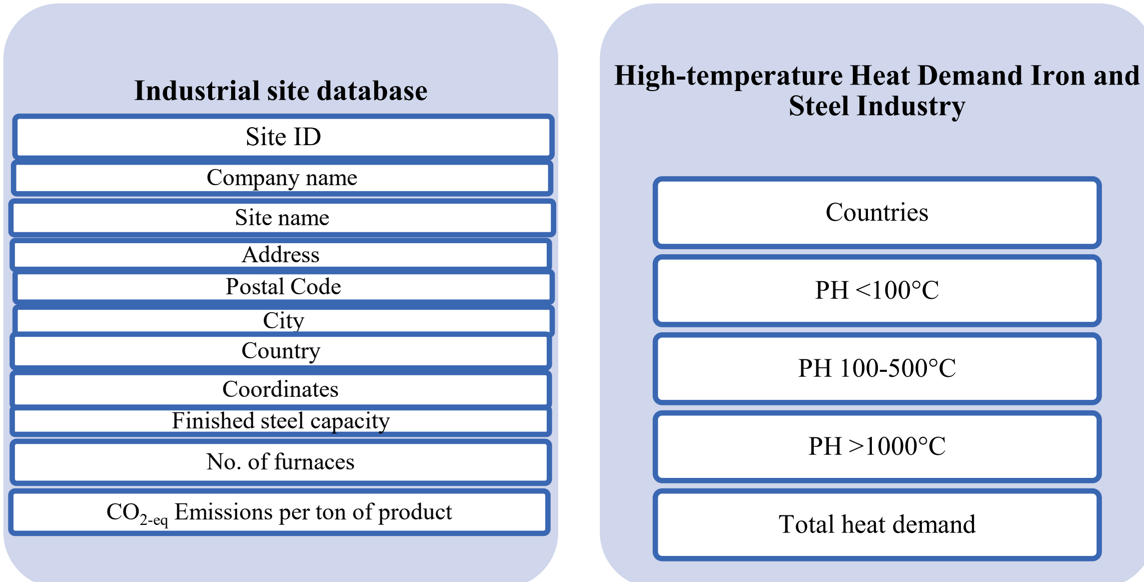


Figure 3 Database structure for mapping.

1.3.3. Data analysis

The analysis of chapters 3, 5, and 6 are centred on the theoretical basis presented in the other chapters. With data from published research, the energy demand for each process is estimated and the effects it has on the path toward energy transformation in Europe, specifically in the iron and steel industry.

2. Hydrogen

2.1. Properties of hydrogen

Hydrogen proves to be a versatile energy carrier and an essential tool for the energy transition.

Hydrogen is the most common element on the planet, but it is not available in nature in its pure form. It can be compressed, liquefied, or transformed into hydrogen-based fuels for higher energy density.

Table 2 Thermodynamic properties of hydrogen (at 25°C and 1 atm), retrieved from (Keçebaş & Kayfeci, 2019)

Property	**Hydrogen**
Density (gaseous)	0.089 kg/m^3 (0°C, 1 bar)
Density (liquid)	70.79 kg/m^3 (-253°C, 1 bar)
Lower heating value (LHV)	120.1 MJ/kg

Higher heating value (HHV)	141.88 MJ/kg
Specific volume	12.1 m^3/kg
Specific heat C_p	14.310 kJ/kgK
Gas constant R	4.126 kJ/kg°C
Thermal conductivity	0.182 W/m °C
Latent heat of fusion	58000 J/kg
Heat of combustion	144000 kJ/kg

Hydrogen has a high combustion velocity and a non-luminous flame, making it hard to monitor. Ways to make the fuel more secure for monitoring is the mix of hydrogen with ammonia.

The low radiation heat transfer makes it better to add carbon-free media like clinker dust to the mix, but the equipment needs redesigning to protect the abrasive properties of clinker dust.

Hydrogen is corrosive when in contact with some metals, so equipment needs more protective measures and new coatings.

2.2. Hydrogen production

There are three colour code classifications of hydrogen production: grey, blue, and green hydrogen, as described in Figure 4.

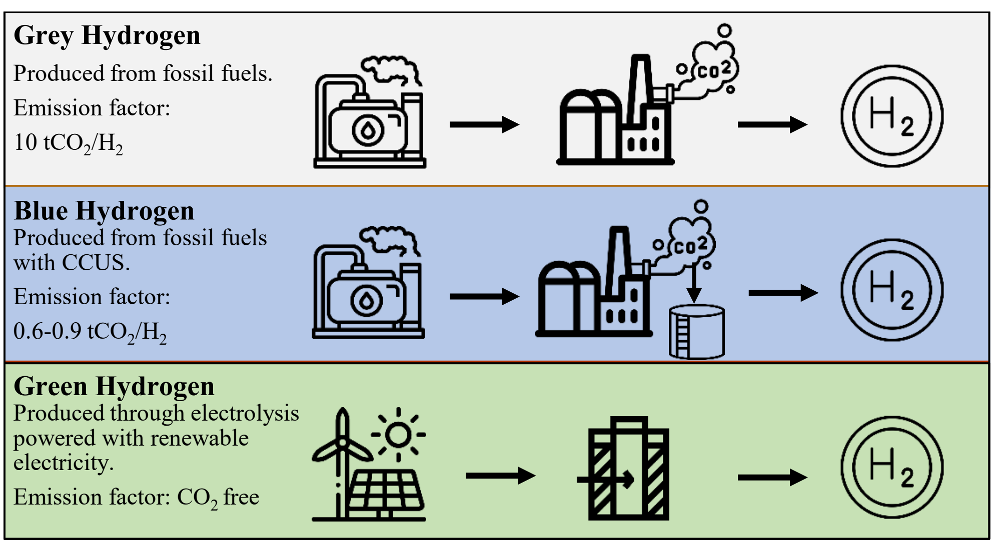


Figure 4 Grey, blue and green hydrogen scheme. (IEA, 2019)

Today, grey hydrogen dominates production. Three-quarters of global hydrogen production comes from natural gas, followed by coal and only 2% from electrolysis. This fossil fuel dependence generates 10 tCO_2 per ton of hydrogen from natural gas, 12t tCO_2/tH_2 from oil products, and 19 $tCO2/tH_2$ from coal. (IEA, 2019)

The fossil-based hydrogen is highly dependent on the natural gas price. The costs for renewable electricity are decreasing (particularly solar PV and wind), so the potential for low-carbon hydrogen increases. Estimated costs for fossil-based hydrogen in the EU are presented in Table 3.

Table 3 Average hydrogen costs according to their production route. (IEA, 2019)

Production costs	**USD/kg**
Grey hydrogen	1.7
Blue hydrogen	2.32
Green hydrogen	2.5-6

The production cost of hydrogen comprises the capital expenditure (CAPEX), operational expenditure (OPEX) and feedstock: natural gas, in the case of grey and blue hydrogen, or the price of the electricity for green hydrogen.

The most common methods are steam methane reforming (SMR), coal gasification and water electrolysis. However, the most attractive technologies for the sake of the study are low-carbon hydrogen technologies.

2.2.1. Steam methane reforming

Natural gas, alongside the water, is both feedstock and fuel during this process. It is the dominant technology for large-scale hydrogen.

To make this technology a low-carbon hydrogen source, carbon capture, utilisation and storage (CCUS) can be applied and reduce their emissions by up to 90%. In plants where hydrogen production is not integrated with ammonia or methanol production (merchant plants[1]), the CO_2 separated from the high-pressure synthesis gas stream costs around USD 53/tCO_2 and USD 80/tCO_2 when captured from the more diluted furnace flue gas. It goes up

[1] i.e. standalone plant – without any integration to an industrial complex. (IEAGHG, 2017)

to USD 90-115t/CO_2 for integrated ammonia and methanol plants. (IEA, 2019)

Regarding the cost of production, as seen in Table 3, hydrogen produced from natural gas with CCUS has a higher price than without CCUS. However, it is still the most economical option for low-carbon hydrogen production.

2.2.2. Coal gasification

This process converts carbon-based raw material into synthetic gas. After its purification, it provides synthetic gases with a high calorific value. Most of this process's hydrogen takes place in China, one of the cheapest pathways to produce clean hydrogen.

This method produces CO_2 emissions of around 19 tCO_2/tH_2, making this technology low-carbon only if coupled with CCUS. The advantages of the coal gasification process are that it comes from a predictable renewable energy source and a renewable carbon source, making it ideal for polygeneration plants. (Midilli, Kucuk, Topal, Akbulut, & Dincer, 2021)

2.2.3. Electrolysis

Electrolysis consists of an electrochemical process separating water into hydrogen and oxygen in gaseous form. Less than 0.1% of the current global hydrogen production is from electrolysis, and the primary market is for high-purity hydrogen. (IEA, 2019)

Electrolytic cells comprise a cathode and an anode, an electrolyte (liquid or solid), two porous layers, and the bipolar plates that provide mechanical support and distribute the flow. It is a non-spontaneous reaction, where the anode is the electrode where the oxidation occurs and the cathode where reduction occurs. The electrolyser technology is categorised based on the electrolyte and temperature of operation.

$$Global\ reaction: \quad H_2O(l) \rightarrow H_2(g) + \frac{1}{2}O_2(g) \qquad Equation\ 1$$

Stacks are composed of multiple electrolytic cells connected in series, seals, frames, and endplates. On a broader system level (also known as balance of plant), it includes equipment for compression, cooling, transformers, rectifiers, water supply treatment and gas output.

Alkaline electrolyser

These electrolysers use an alkaline solution (potassium hydroxide, KOH @30% in H_2O, or NaOH) as the electrolyte solution and nickel (Ni) coated stainless steel electrodes. Low capital costs characterise it compared to other electrolytic technologies since it does not use expensive precious catalysts. It has an operating temperature of 60-80°C and a 1-30 bar operating pressure. (IEA, 2019)

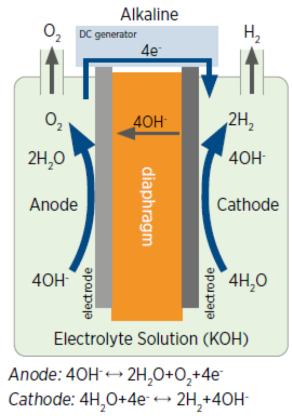


Figure 5 Alkaline electrolyser scheme (IRENA, 2020)

The separator (aka diaphragm like in Figure 5) is responsible for transporting the ions from one electrode to another and keeping the produced gases from mixing.

PEM Electrolyzer

Alongside alkaline electrolysers, PEM electrolysers are the most used commercially. Polymer electrolyte membrane (PEM) electrolysers use pure water as an electrolyte solution, avoiding the recovery and recycling of the electrolyte solution needed with alkaline electrolysis. It has an operating temperature and pressure of 50-80°C and <35 bar. (IRENA, 2020)

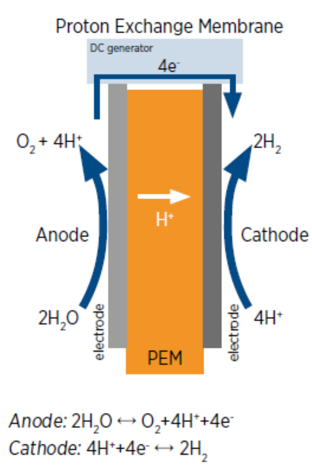


Figure 6 PEM Electrolyser (IRENA, 2020)

This electrolyser proves adequate for mobility applications or intermittent power supplies, thanks to its flexible operation, higher output pressure and small size. However, a disadvantage to scaling up PEM electrolysers is the higher investment costs.

AEM Electrolyser

Anion Exchange Membrane electrolyser is characterised by a less harsh environment than the alkaline electrolysers, uses non-noble catalysts and titanium-free components, and works at differential pressures. (IRENA, 2020)

The AEM has much potential but has not yet reached technological maturity to compete commercially against other electrolysers.

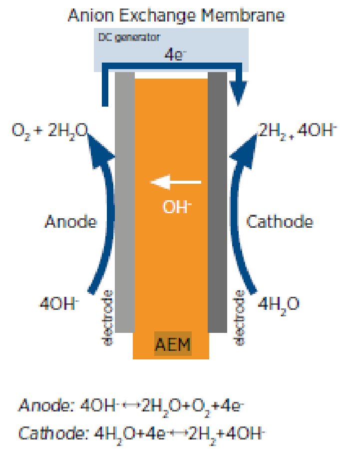


Figure 7 AEM Electrolyser scheme (IRENA, 2020)

SOEC's

Solid Oxide Electrolytic Cells operate at very high temperatures (700-850°C), allowing favourable kinetics, low-cost nickel electrodes, and high electrical efficiency.

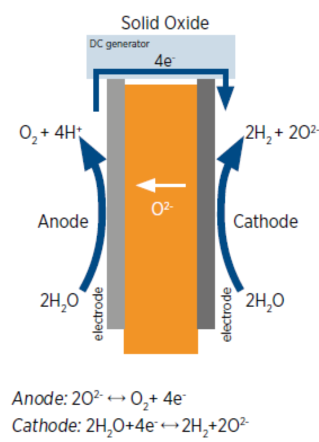


Figure 8 Solid oxide electrolyser scheme (IRENA, 2020)

Their use of steam decreases the electricity demand; this also will enable alternatives for the waste heat usage of the process. High-temperature electrolysis also reverses the process and converts the hydrogen back into electricity.

The comparison of the three leading technologies in terms of operation, efficiency, and capital costs, as seen in Tables 4 and 5, retrieved from (IEA, 2019) and (IRENA, 2020), respectively. It considers the current characteristics and trends for the near and long-term future. In the case of technology advancement, the efficiencies and stack lifetime are set to increase. At the same time, the CAPEX is expected to decrease in the upcoming years, helping the electrolyser supply chain scale up to commercial-scale applications.
The stack lifetime plays a crucial role in the differentiation of technologies. As observed in the following tables, the trend for electrolyser manufacturers will increase efficiency and stack lifetime.

Table 4 Techno-economic characteristics of different electrolyser technologies, retrieved from (IEA, 2019)

	Alkaline electrolyser			**PEM electrolyser**			**SOEC electrolyser**		
	Today	2030	Long term	Today	2030	Long term	Today	2030	Long term
Electrical efficiency [%, LHV]	63-70	65-71	70-80	56-60	63-68	67-74	74-81	77-84	77-90
Operating pressure [bar]		1-30			50-80			1	
Operating temperature [°C]		60-80			50-80			650-1000	
Stack lifetime [h]	60,000–90,000	90,000–100,000	100,000-150,000	30,000-90,000	60,000-90,000	100,000-150,000	10,000-30,000	40,000-60,000	75,000-100,000
Load range [%], relative to nominal load		10-110			0-160			20-100	
Plant footprint [m^2/kW_e]		0.095			0.048				
CAPEX	500-	400-850	200-700	1100-	650-	200-900	2800-	800-	500-

[USD/kW$_e$]	1400		1800	1500		5600	2800	1000

Table 5 Techno-economic characteristics of AEM electrolyser (IRENA, 2020)

	AEM Electrolyser	
	Today	2050
Electrical efficiency [%, LHV]	52-67	75
Operating pressure [bar]	<35	>70
Operating temperature [°C]	40-60°C	80°C
Stack lifetime [h]	>5,000	100,000
Load range [%], relative to nominal load	5-100	5-200
CAPEX [USD/kW$_e$]	Unknown	100-200

Scaling up electrolysers reduce costs, and it is crucial to decarbonise specific sectors, not to mention the importance of further research and development to improve the efficiency and lifetime of the stack.

Water and land use are no obstacles to the scaling-up of electrolysers. An electrolyser can consume between 18 to 24 kg of water per kilo of hydrogen.

The desalination, purifying, and deionising increase the costs, but in terms of the impact, if desalinated seawater is assumed, it will not be problematic. For these issues, every hydrogen plant needs to be locally analysed not to threaten water-stressed regions.

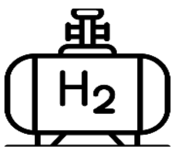
2.3. Hydrogen storage, transmission and distribution

Hydrogen plays an essential role in the energy transition because it can store energy in large quantities or be transported over long distances. Storage, distribution, and transmission costs must adapt to the location, distance, scale, and end-use to play a competitive position. Hydrogen is usually stored and distributed in compressed gas or liquid form.

As seen in Figure 9, there are two classifications for hydrogen storage: long-term and large-scale and short-term and small-scale.

Geological storage for large-scale and long-term storage

- Salt caverns: Efficiency ~98%, The high pressure allows a high discharge rate.
- Depleted oil & gas reservoirs: More permeable, H_2 can be contaminated
- Water aquifers: Least mature tech, both oil & gas reservoirs and aquifers costs' need to be proven.



Storage tanks for small-scale and short-term storage

- Compressed or liquefied hydrogen have high discharge rates and efficiencies ~99%
- Compressed H_2 has less energy density than a tank of gasoline, so ot takes more space. There's continued research to reduce the tank sizes.
- H_2-Storage in solid-state (chemical and metal hydrides) is in early development for commercialapplications, but could provide greater densities of hydrogen.

Figure 9 Hydrogen storage types. (IEA, 2019)

The real advantage of hydrogen storage to help balance demand and supply, the cost needs to be considered for the transformation. The investment cost and the Levelized cost of storage (LCOS) when it is a new facility are expressed in Table 6.

Table 6 Costs of large-scale hydrogen storage. (Cihlar, et al., 2021)

Technology	**Investment costs [EUR2019/ MWh$_{H2\text{-}stored}$]**	**LCOS [EUR2019/ MWh$_{H2}$]**
Depleted gas field	280-424	51-76
Salt caverns	334	6-26
Rock caverns	1232	19-104

When the hydrogen is produced locally to where it is required, transport and storage costs will be low, but when there is a required distribution over longer distances, these costs could be three times the cost of production.

Blending hydrogen into existing natural gas pipelines could avoid capital costs that would require new infrastructure for the hydrogen value chain.

There are some disadvantages to hydrogen blending in NG pipelines, like the tolerance of the equipment, security risks, or volumes needed by the end-user. Additionally, regulation changes when it comes to the blending will be necessary to support the development of this method.

Another alternative is incorporating the hydrogen into other liquid mediums, like liquid organic hydrogen carriers (LOHCs) or ammonia. These appear more attractive than hydrogen in scale, safety, and transportation over long distances, although LCOHs cannot serve as final products, requiring further reconversion. (Abdin, Tang, Liu, & Catchpo, 2021)

For long-distance transmission, the best way is through pipelines. There is approximately 5,000 km of hydrogen pipelines globally against the 3 million km of natural gas transmission pipelines. Currently, there is 2000 km of dedicated hydrogen pipelines in Europe. They are among four countries: Belgium (613 km), Germany (376 km), France (303 km) and The Netherlands (237 km). (Correa Laguna, Duerinck, Meinke-Hubeny, & Valee, 2021)

The European Hydrogen Backbone presents the necessary steps for achieving a hydrogen transport infrastructure in the EU. European gas infrastructure companies are planning to expand to 6,800 km of dedicated hydrogen pipelines by 2030, and their objective is for this network to reach 23,000 km by 2040. (Wang, van der Leun, Peters, & Buseman, 2020)

Government support and high capital are needed to increase this transmission infrastructure.

2.4. Industrial uses of hydrogen

Hydrogen can play a crucial role in achieving carbon-neutrality in industrial production, as energy carriers and feedstock, especially in energy-intensive industries.

Fossil fuels currently supply the industrial demand for hydrogen. The current use of hydrogen by the EU is approximately 339 TWh annually.

90% of the hydrogen consumption in the European Union is for industrial uses, led by ammonia production, methanol, and steel.

Industrial applications dominate the use of hydrogen today: oil refining (33%), ammonia production (27%), methanol production (11%) and steel production via direct reduction of iron ore (3%) are the top four users. (IEA, 2019)

Oil refining

The current role of hydrogen in oil refining is the removal of impurities. Around 60% of this hydrogen comes from natural gas reforming.

Existing policies put pressure on the sector and its role in the energy transition, so there is an opportunity to mitigate the emissions by adopting CCUS on natural gas or coal-based hydrogen production. The biggest challenge for the oil industry is to replace the existing capacity with low-carbon hydrogen since the costs would increase significantly, making it not profitable to change the current operations entirely.

The demand for hydrogen in the oil refining sector is estimated to increase by around 7% by 2030. Even with existing policies and the EU's climate targets, the hydrogen demand for the oil industry will remain the highest. (IEA, 2019)

Chemical production

Hydrogen is essential to ammonia and methanol production. Due to economic and population growth, hydrogen demand will increase by around 30% by 2030. By 2050, methanol and ammonia for clean uses as hydrogen-based fuel will increase.

Coupling the hydrogen production for the chemical sector with CCUS is an opportunity but not available everywhere. The low-carbon hydrogen competitiveness will always depend on the gas and electricity prices

Iron and steel production

In primary steel production, hydrogen serves as feedstock for the direct reduction of iron ore (DRI). This route is more attractive for covering growing steel demand than the blast furnace (BF) route.

The BF-BOF route produces hydrogen as a by-product, contained in works-arising gases (WAG), using more than half of hydrogen on-site while exporting the remaining to other sectors.

Whereas the direct reduction of iron ore and electric arc furnace (EAF) route uses hydrogen as a reducing agent, the production occurs in dedicated facilities and not as a by-product.

Some factors influencing hydrogen demand are the share of the DRI-EAF route in primary steelmaking and the split between primary and secondary steelmaking in overall production.

The transformation of the iron and steel industry has two attractive pathways:

- Blast furnace-basic oxygen furnace (BF-BOF) with hydrogen fuel injection. It proves to be short-to-medium decarbonisation, with a possible reduction of CO_2 emissions by 20%.
- Hydrogen-based direct reduced iron (DRI) – electric arc furnace (EAF). It is a long-term complete decarbonisation pathway.

High-temperature heat

Industrial use of heat covers various applications like melting, gasifying, drying or mobilising chemical reactions. The European industry used for heat has a final annual demand of 3200 TWh, emitting more than 390 Mt of direct CO_2 annually. (Fuel Cells and Hydrogen 2 Joint Undertaking, 2019)

Only 30% of the global demand for high-temperature (HT) heat is outside the chemical, iron & steel sectors. Fossil fuels are the primary source of HT heat today: 65% from coal, 20% from natural gas, 10% from oil and the remaining from biomass and waste heat. (IEA, 2019)

The use of electricity in some processes is also used *directly* (e.g., electric or induction furnaces) or indirectly (e.g., to drive electrochemical reactions).

Besides the hydrogen from the WAG used in the iron & steel and chemical sectors as a by-product, virtually no hydrogen production covers heat demand.

Hydrogen remains an expensive alternative for HT heat supply but can become competitive against NG-sourced hydrogen with CCUS in geographically segmented regions or when the CCUS proves impractical. (IEA, 2019)

Hydrogen in power generation

The decarbonisation of power generation in the EU is essential to meet climate mitigation goals. The high share of renewables is helping the climate mitigation scenarios. Still, ideally, integrating hydrogen-based fuels or hydrogen for energy storage solutions to the energy system will accelerate the needed transformation of the sector.

Currently, the use of hydrogen for power generation is significantly low, but the transition must endure intermittency and seasonal imbalances.

There are opportunities to decarbonise the gas grid that connects Europe's industries, supplying hydrogen and blending it into the existing infrastructure. Using fuel cell-based combined heat and power technology can increase the gas-based system's efficiency.

In the short term, natural gas refining can be low-carbon when coupled with CCUS. The technical and economic challenges must be overcome in long-term scenarios to scale up green hydrogen technologies.

2.5. Green hydrogen value chains

The value chain of green hydrogen comprises four stages, as seen in Figure 10: production, transformation, transportation and end-use.

The value chains can oversee the opportunity for technological investment in each stage and promote economic growth and job opportunities.

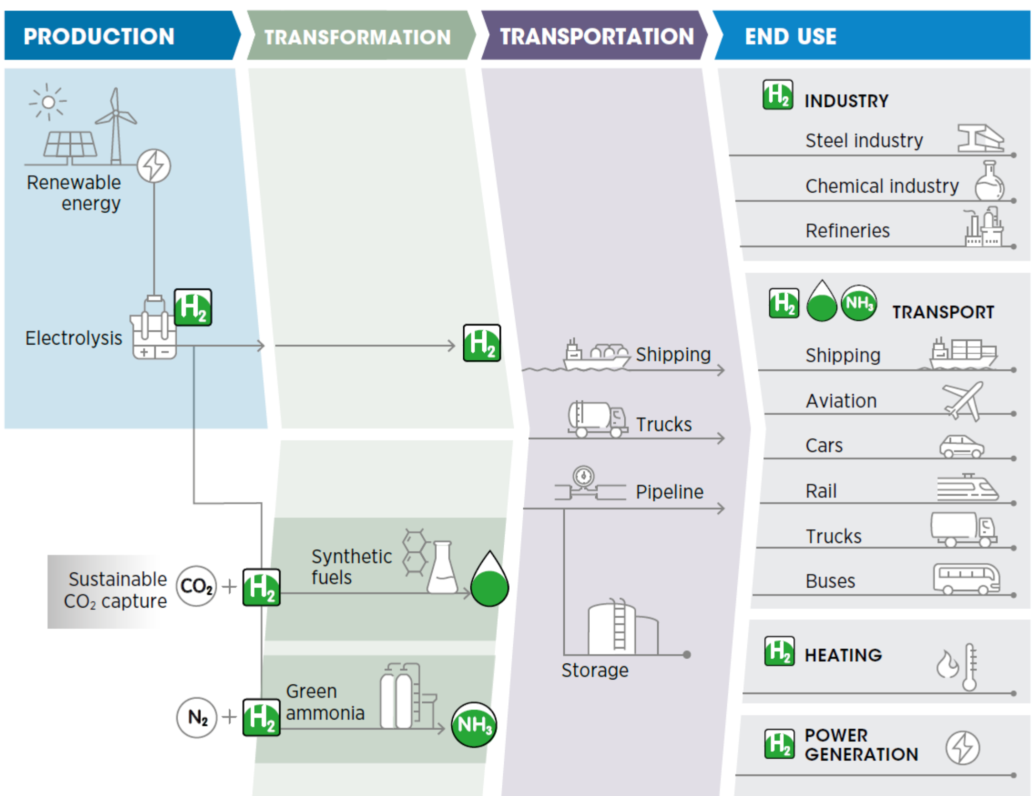


Figure 10 Green hydrogen value chains. (IRENA, 2020)

To effectively transition to a hydrogen ecosystem, data on costs, technicalities, and social and economic impact need broader availability to ease decision-making.

Other stakeholders, regulators, and key players in the decarbonisation of industry include technology manufacturers.

Table 7 enlists the manufacturers of different electrolyser technologies across the globe, essential for the green hydrogen value chains because their manufacturing capacities will proliferate in the coming years.

Table 7 Key players involved in the manufacturing of water electrolysis systems. (IRENA, 2020)

Company	Manufacturing site	Electrolyser type
Aquahydrex	Australia, USA	Alkaline
Asahi Kasei	Japan	Alkaline
Arevah2	France, Germany	PEM
Carbotech	Germany	PEM
Cockerill Jingli	China	Alkaline
CUMMINS – Hydrogenics	Belgium, Canada, Germany	PEM and Alkaline
Denora	Italy, Japan, USA	PEM and Alkaline
Enapter	Italy	AEM
Giner ELX	USA	PEM
Green Hydrogen Systems	Denmark	Alkaline
Haldor Topsoe	Denmark	Solid Oxide
Hitachi Zosen	Japan	Alkaline and PEM
Honda	Japan	PEM
Hydrogenpro	Norway	Alkaline
iGas	Germany	PEM
ITM	UK	PEM
Kobelco	Japan	Alkaline and PEM
Kumatec	Germany	Alkaline
McPhy	France, Italy, Germany	Alkaline
NEL Hydrogen	Denmark, Norway, USA	PEM and Alkaline
PERIC	China	Alkaline
Plug Power	USA	PEM
SHANGHAI ZHIZHEN	China	Alkaline
Siemens Energy	Germany	PEM
SOLIDPower	Italy, Switzerland,	Solid Oxide

	Germany, Australia	
SUNFire	Germany	Solid Oxide
Tianjin	China	Alkaline
Teledyne	USA	PEM
Thyssenkrupp Uhde	Germany	Alkaline
Toshiba	Japan	Solid Oxide

2.6.Hydrogen in Europe

There are three different hydrogen market players: The merchant companies, who produce hydrogen for trading hydrogen; the by-product hydrogen producers, who provide hydrogen as a by-product from chemical processes; and the captive producers, who produce hydrogen on-site for their own plant's purposes. (Roads2HyCom , 2009)

In Europe, most hydrogen is produced by captive producers for their processes, and those merchant plants dedicated only to hydrogen production in Europe are mainly by SMR. Few plants use electrolysis, and none are dedicated green hydrogen plants.

The only producers of hydrogen by electrolysis are listed in the following table.

Table 8 Merchant compressed gas hydrogen production capacity in Europe.

Producer	City	Country
Strandmollen	Funen	Denmark
Strandmollen	Klampenborg	Denmark
Oy Woikoski	Voikoski	Finland
Sauerstoffwerk	Aitrach-Marstetten	Germany
Linde	Mandra	Greece
Linde	Dublin	Ireland
Norsk Hydro	Rjukan	Norway
AGA Gas	Sandviken	Sweden

2.7. Green hydrogen in steel

As mentioned, green hydrogen is produced in electrolysers powered by renewable sources. With the costs of renewably sourced electricity decreasing yearly, the potential for low-carbon hydrogen technologies is thriving.

European countries have published strategies for transforming their industries and power systems into carbon-neutral to meet climate targets.

Hydrogen produced with natural gas through SMR can become low-carbon if the technology is coupled with CCUS. Still, other factors must be added to achieve carbon neutrality, such as fossil-fuels substitution with biomass.

An advantage to hydrogen from natural gas is the infrastructure connecting industrial hubs in Europe, facilitating hydrogen delivery to the demand locations.

The industrial deployment of these technologies requires investments and cooperation from stakeholders and policymakers to ensure the adoption is adequate and thriving.

The European Union aims to install at least 6 GW of renewable electrolysers capacity by 2024 and 40 GW by 2030. (IRENA, 2020)

There is an increasing interest in generating low-emission steel from European governments and the private sectors. These Paris Agreement-aligned projects are described in Table 9.

Table 9 List of hydrogen-based DR projects in the EU. (IEA, 2019)

Company	Country	Description
H2 Green Steel	Sweden	Hydrogen-based steelmaking. Optimising the integrated production process with automation digitisation, they expect to produce up to five million tons of green steel by 2030. They have already sold their entire production, even though they plan to start in 2025.
HYBRIT (SSAB, LKAB, and Vattenfall)	Sweden	Hydrogen-based steelmaking. Currently in the DRI-EAF pilot plant phase, with a hydrogen storage pilot facility, operational from 2022. The SSAB Oxelösund transformation from BF will begin in 2025, and around 2030, they aim to transform SSAB Raahe and Luleå into EAF.
SALCOS (Salzgitter AG and Fraunhofer Institute)	Germany	They aim to use a natural gas-based process and gradually increment the proportion of hydrogen. Part of their project included seven wind turbines powering the PEM electrolyser (WindH_2). GrInHy2.0 is the other project operating a high-temperature electrolyser that uses the steam from the industrial waste heat. The first low-carbon steelmaking plant will be operating in 2026 in Salzgitter Flachstahl, with a CO_2 reduction of 30%.
H2FUTURE (Verbund, Voestalpine, Siemens Energy, APG, K1-MET,	Austria	Switch to green electricity in the short-term, and in the long-term to green hydrogen. The 6 MW PEM electrolyser started operating in 2019, and by now, it has already produced more than 500 tons

and ECN)		of hydrogen.
Σiderwin (ArcelorMittal)	France	CO_2-free steel by electrowinning (a low-temperature electrolysis process that produces solid-state elemental iron ore) with the beginning of the pilot plant in 2022, expecting and energy needs to be 30% lower than with the blast furnace.

3. High-temperature thermal energy demand in Europe

Industrial heat serves various purposes, from melting, gasifying, and drying, among other processes. It can be used directly, like in a furnace, or indirectly, for example, by raising steam and then transferring it for heating needs. (IEA, 2019)

The European heat demand in the industry is dominated by process heat, with space and water heating only having a small share. The heat demand in the industry can be classified as follows:

- *Low-temperature range*: Process heat under 100°C, space heating and water heating also fall into this temperature range.
- *Medium-temperature range*: All processes between the temperatures of 100°C – 500°C
- *High-temperature range*: Between 500°C and 1000°C, and above 1000°C (Frisch, Pehnt, & Otter, 2010)

According to the IEA, around 30% of high-temperature heat in the industry is consumed outside the chemical and steel sectors. The potential for fulfilling the high-temperature heat demand with hydrogen can be part of the decarbonisation strategy of energy-intensive industries. The fossil fuel substitution with hydrogen can reduce emissions of processes like the blast furnace in the steel sector, or for example, as a low-carbon fuel for cement kilns. However, as mentioned in the scope of the study, the scope focuses only on the steel sector.

Around the globe, fossil fuels are the primary source of high-temperature heat, led by coal (65%), natural gas (20%) and oil (10%), leaving small shares of biomass and waste used in specific sectors. (IEA, 2020)

3.1. Results and analysis

The calculation results are presented in the following tables, with the specific sector results in the appendices section. In analysing the results of the new model and the model developed by (Naegler, Simon, Klein, & Gils, 2015), the variations do not differ as much, only on the final values for SH and WH, which in the new model resulted in lower shares.

The reference years for the updated model are 2019 for the total energy consumption by different industry branches in Europe and 2015 for the end-use balances for the German industry.

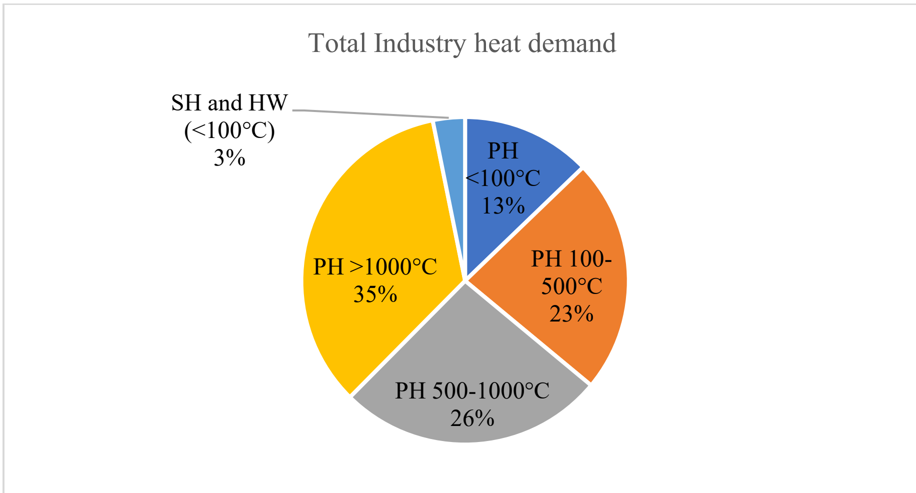


Figure 11 Share of Industries' high-temperature heat demand in Europe.

As seen in Figure 11, the industrial heat demand is led by high temperature, and the demand decreases relative to the temperature range. The process heat demand above 1000°C has the highest share because there are end-uses in energy-intensive industries which require high energy inputs for the operating temperature required.

Table 10 Results for total heat demand in the industry sector in Europe, differentiated by temperature ranges (the reference year being 2019)

	PH <100°C	**PH 100-500°C**	**PH 500-1000°C**	**PH>1000°C**	**Total process heat demand**	**SH and HW (<100°C)**	**Total heat demand**
Austria	24.84	52.65	36.93	54.79	169.21	5.58	174.80
Belgium	38.55	58.24	93.42	89.10	279.31	4.84	284.15
Bulgaria	7.81	12.92	21.38	25.11	67.22	1.54	68.76
Croatia	4.16	5.39	8.29	11.88	29.72	0.99	30.71
Cyprus	0.51	0.64	2.05	3.66	6.85	0.09	6.93
Czech Republic	16.76	29.71	38.82	58.27	143.56	6.27	149.83
Denmark	8.94	10.24	15.54	20.71	55.43	2.51	57.94

Estonia	2.00	2.62	2.32	3.34	10.29	0.47	10.76
Finland	41.64	141.44	27.93	39.39	250.40	4.94	255.34
France	97.45	152.56	200.61	229.38	680.00	22.88	702.88
Germany	161.80	278.83	375.40	479.86	1295.89	49.99	1345.88
Greece	5.88	8.12	16.92	36.45	67.38	1.51	68.89
Hungary	14.74	21.97	31.85	34.11	102.67	4.75	107.42
Ireland	8.28	8.69	15.86	26.22	59.05	1.99	61.04
Italy	61.34	103.52	143.16	236.75	544.76	29.95	574.71
Latvia	6.71	2.76	2.84	4.63	16.95	0.84	17.79
Lithuania	4.91	6.33	9.54	7.35	28.13	0.75	28.88
Luxembourg	0.52	0.89	4.04	10.93	16.38	0.16	16.53
Malta	0.13	0.25	0.19	0.24	0.81	0.11	0.92
Netherlands	52.96	80.75	133.44	88.46	355.60	7.55	363.16
Poland	57.94	88.51	111.85	152.21	410.51	10.51	421.03
Portugal	14.38	36.39	23.92	35.50	110.20	2.21	112.41
Romania	17.71	23.01	47.76	72.13	160.61	4.73	165.34
Slovakia	6.88	16.26	19.58	39.42	82.14	2.20	84.34
Slovenia	3.06	6.05	7.02	13.06	29.20	1.55	30.75
Spain	55.73	92.48	136.81	202.17	487.20	12.05	499.25
Sweden	36.90	123.51	24.27	47.15	231.83	5.59	237.42
EU27	752.54	1364.74	1551.73	2022.27	5691.29	186.57	5877.86
Norway	7.63	15.00	25.16	56.50	104.28	1.34	105.62
Serbia	2.23	3.35	4.36	6.17	16.12	0.67	16.78
Switzerland	10.90	20.75	22.26	25.74	79.65	5.16	84.80
United Kingdom	57.62	108.22	120.34	154.07	440.25	25.62	465.86

As expected, Germany has the highest demand for industrial heat. It is the country with the highest industrial activity in the EU, followed by France, Italy and Spain.
Their heavy industrial applications require large amounts of heat at very high temperatures.
As the temperature range for process heat increases, the demand increases along with it.

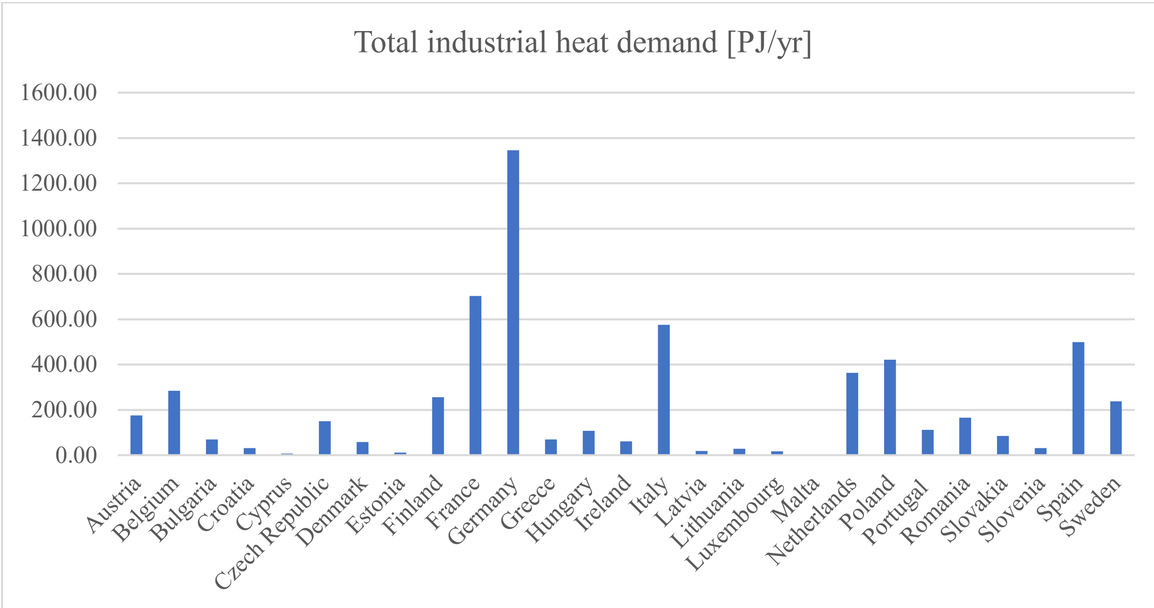


Figure 12 Total industrial heat demand in the EU based on own calculations.

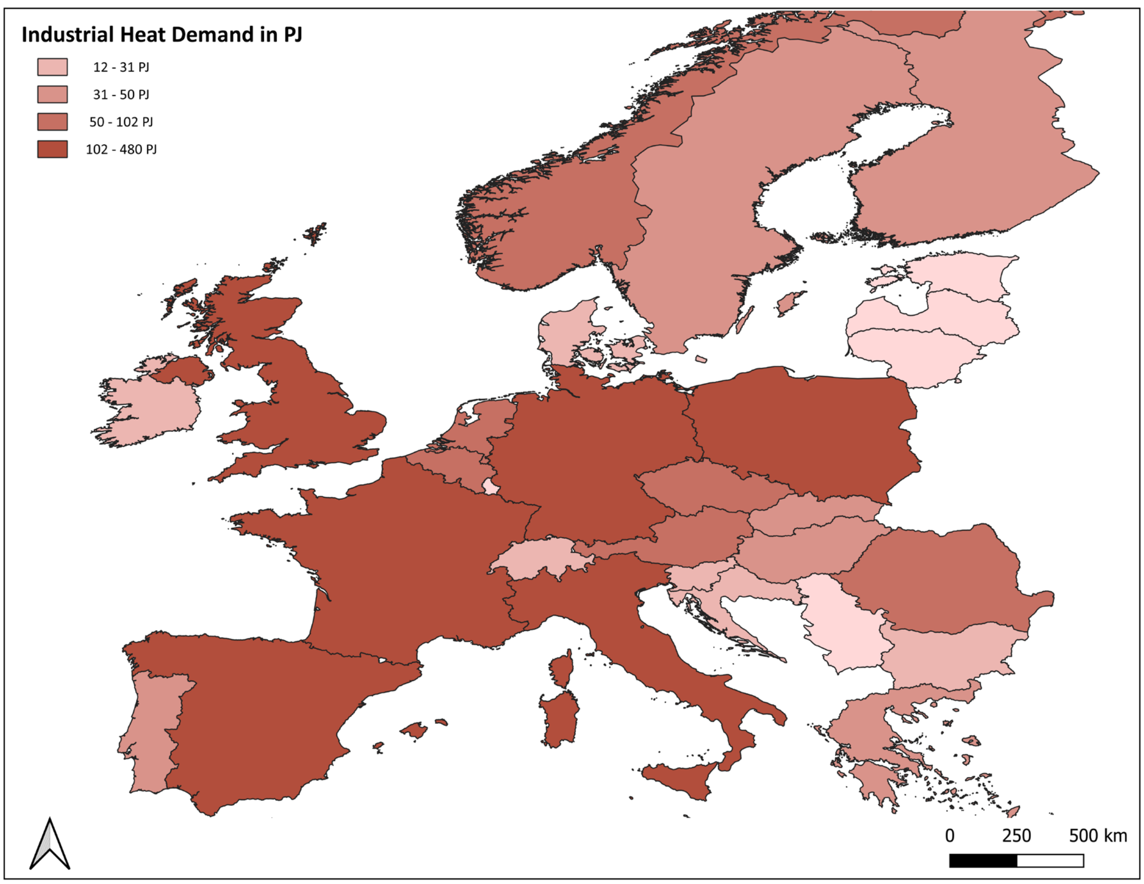


Figure 13 Total industrial heat demand in Europe in PJ.

The transformation of the HT-heat sector would help reduce the GHG emissions related to the demand for this high-grade process heat.

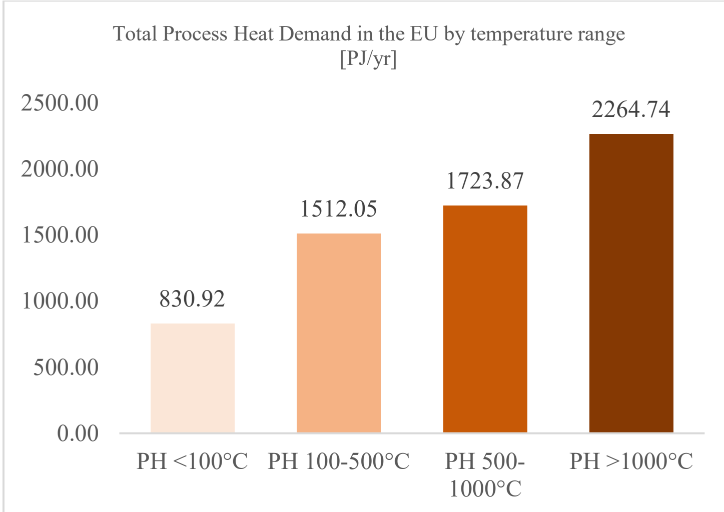


Figure 14 Total process heat demand in the EU by temperature range in PJ/yr

A mapping of the estimation is presented in the following figures for graphical analysis of the heat demand in Europe.

The amount of energy used for process heat in all temperature ranges indicates the industrial activity of each country.

Observing Figure 15, for the temperature ranges below 100°C, the highest demand of one country is around 160 PJ, as the case of Germany. This heat is mainly used for the food industry or other low-intensity sectors.

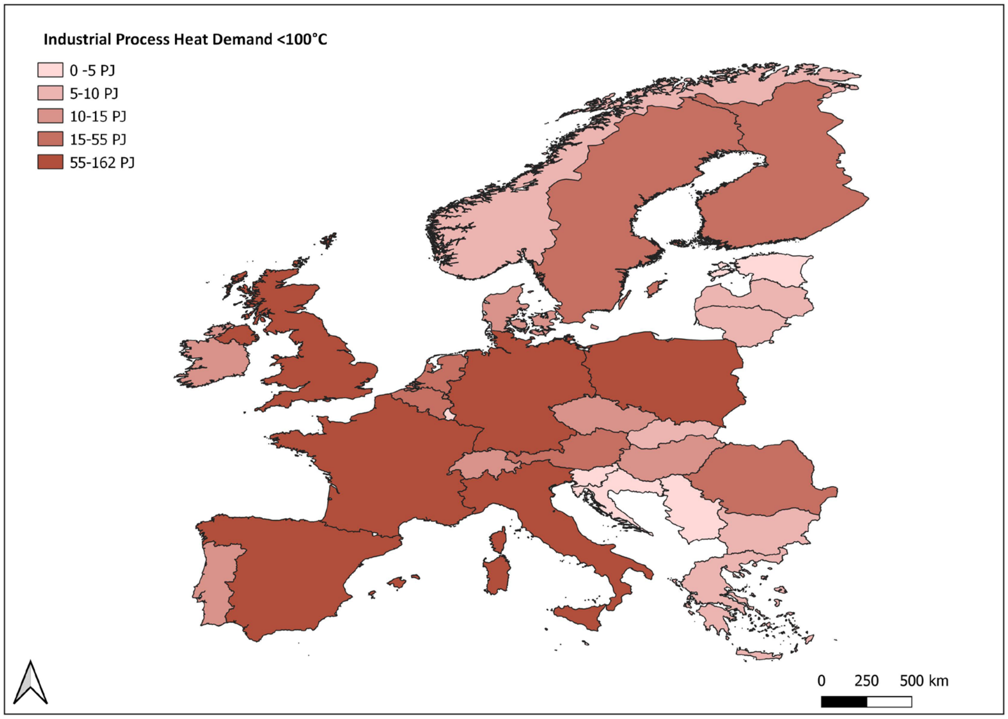


Figure 15 Industrial Process Heat demand lower than 100°C.

For the obtainment of process heat above 100°C, energy carriers from fossil fuels are employed. In figure 16, based on the ODYSSEE database, the share of the energy carriers for industrial uses is plotted. The highest share of energy consumption is tied to gas and electricity use.

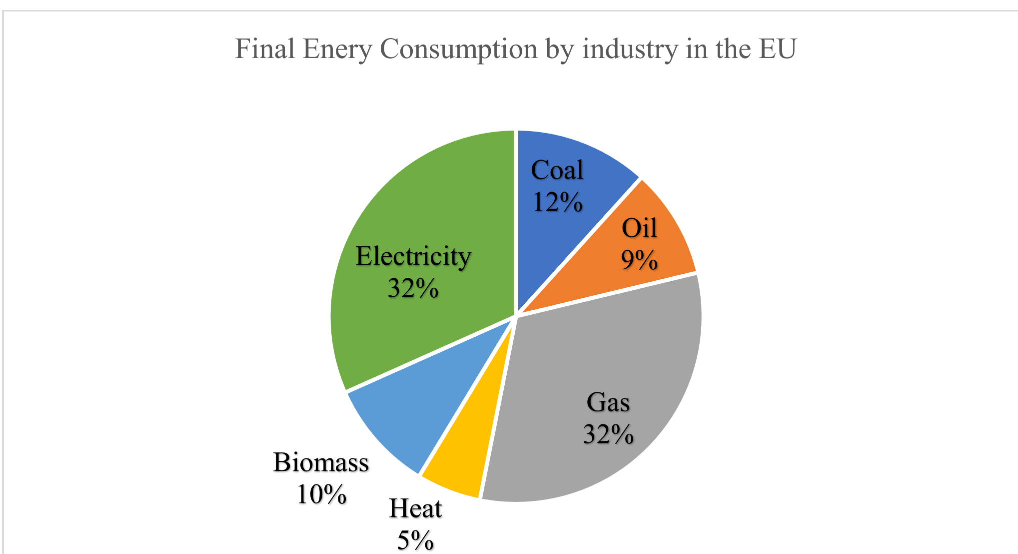


Figure 16 Shares of final energy consumption by industry in the EU. (Enerdata Research Service, 2018)

As seen in Figure 17, the heat demand increases in nordic regions where industrial activity is just as prominent as in other leading industrial countries in Europe. Sweden and Finland have more significant activity in the paper, pulp and print sectors.

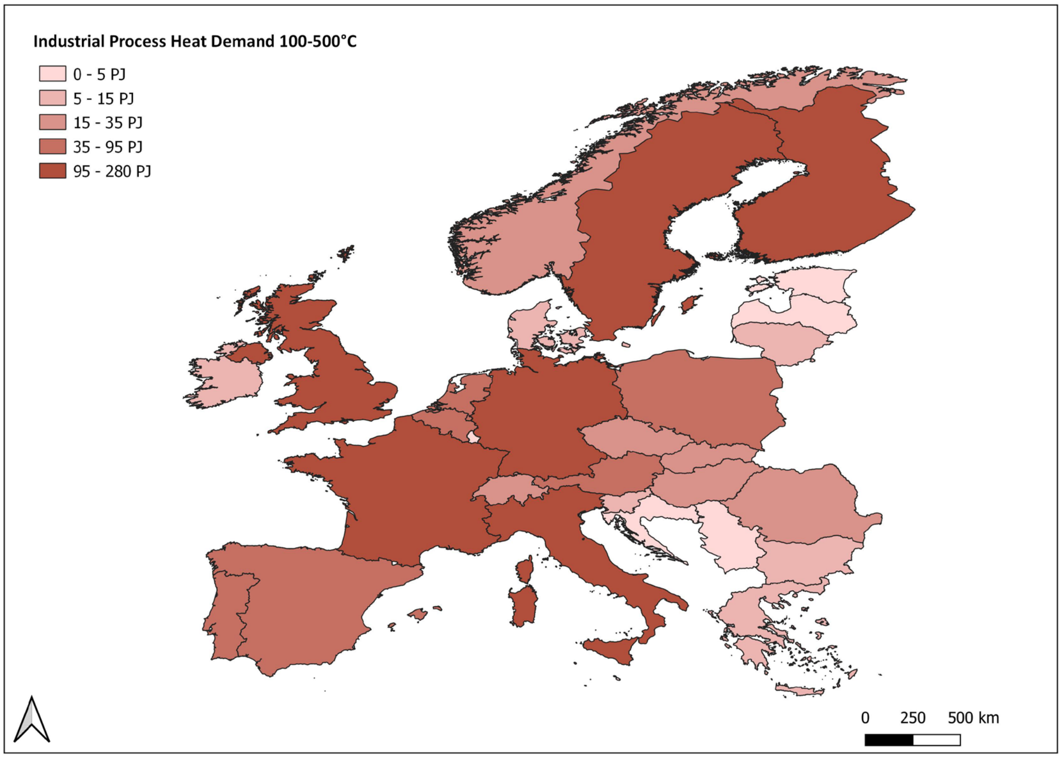


Figure 17 Industrial Process Heat demand between 100°C - 500°C.

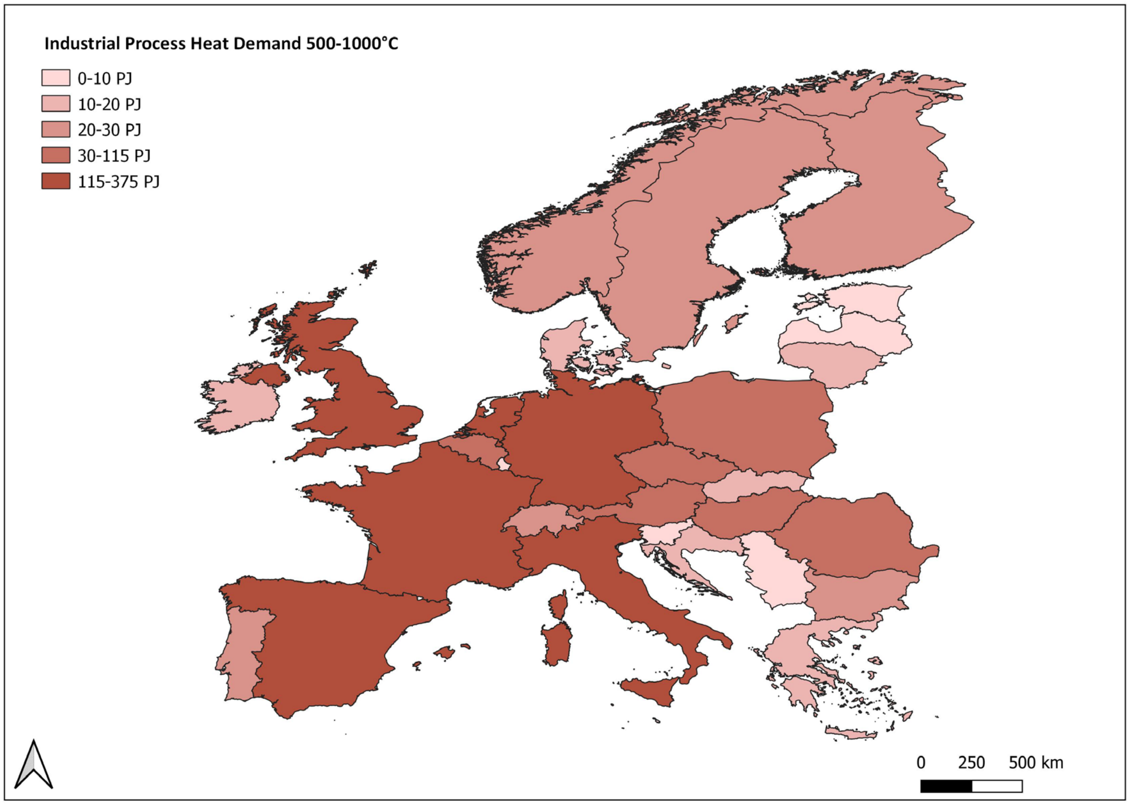


Figure 18 Industrial Process Heat demand between 500°C - 1000°C

The process heat within the ranges shown in Figure 18 is the majority within the chemical sector or with the use of steam in the food industry. Further analysis of each sector can be taken into account, but as presented in the study's boundaries, the main focus is the process heat above 1000°C, in which the iron and steel are large users. The total heat demand for each process across the EU is presented in Appendix B.

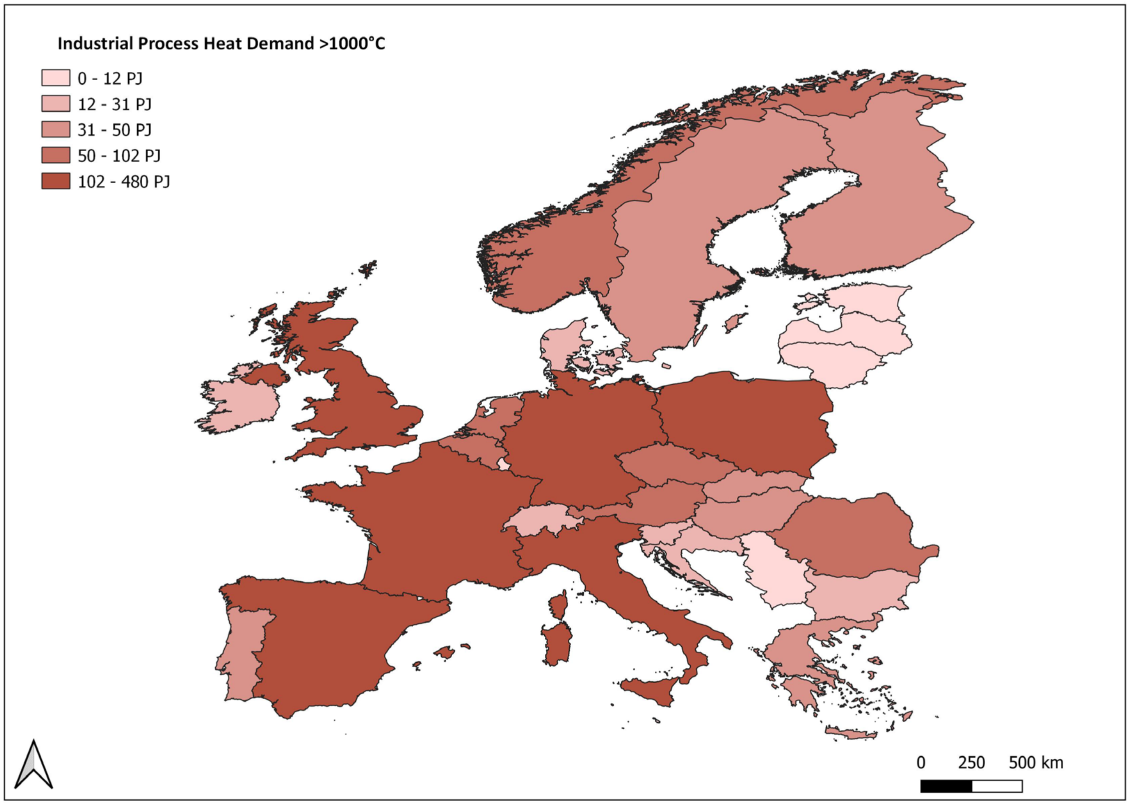


Figure 19 Industrial Process Heat demand higher than 1000°C.

The majority of processes with high thermal energy demand require continuous operation. Industrial processes like cement kilns or steel furnaces operate at temperatures well above 1000°C.

3.1. Hydrogen supply for HT energy demand in Europe

Hydrogen has the potential to become an alternative fuel for energy-intensive industrial applications.

The combustion of hydrogen proves an adequate route for achieving high-grade process heat. Blue hydrogen has an excellent cost profile for retrofitting existing plants with the integration of hydrogen as feedstock for fuel, with only an increase of 10-50% to wholesale production costs. Blue hydrogen as a source of low-carbon heat paves the way for green hydrogen to join the HT-heat market in the future. (Friedmann, Fan, & Tang, 2019)

Pure combustion of hydrogen has not been proven to work for all applications, and there is still further research for the application in a blast furnace. However, hydrogen-based fuels

for heat demand are not cost-competitive for process heat under 400°C, and pure hydrogen cannot replace fuels. The implementation of hydrogen as fuel requires additional security sensors because of the lack of flame when burning. Also, the lifetime of the machinery needs to be considered when it comes to corrosion.
Another use for hydrogen in the heating sector would be with the implementation of fuel cells for electricity generation and implementation in high-temperature processes, e.g. electric arc furnaces in steelmaking.

4. Iron and steel industry

The iron and steel sector comprises integrated steel mills that produce pig iron from iron ore, coke and a blast furnace (BF). After that, there are two main production routes for crude steel:

- ***Primary steelmaking route***: blast furnace (BF)/basic oxygen furnace process (BOF) using primarily iron ore
- ***Secondary steelmaking***: electric arc furnace process (EAF) using primarily scrap and direct reduced iron (DRI)

A simplified scheme of both steelmaking routes can be observed in Figure 14.

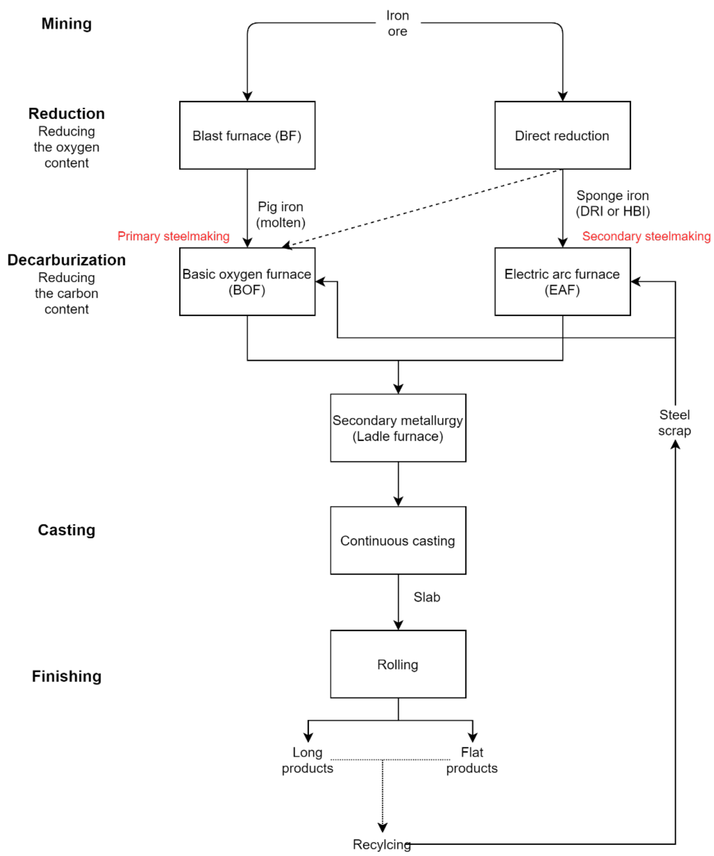


Figure 20 Simplified scheme of iron and steel production. (Worrell, Blinde, Neelis, Blomen, & Masanet, 2010)

Other outdated methods for steelmaking are not considered for the study since they only account for 1% of global steel production. (open-hearth furnaces, smelt reduction process combined with BOF). (IEA, 2019)

4.1.Steelmaking routes

4.1.1. Primary steelmaking

After producing iron ore in a blast furnace, the steelmaking process occurs in a basic oxygen furnace (BOF). Its objective is to adjust the composition of the hot metal so that:

- There is a reduction in the concentration of carbon. The steel produced varies from approximately 4-5% pig iron to less than 1%.
- There is a removal from undesirable impurities by the slag.
- The concentration of desirable elements meets product specifications.

The process occurs by blowing pure oxygen through a water-cooled lance or submerged tuyères in a pear-shaped refractory-lined vessel filled with hot, liquid iron.

This vessel has a 100-200 tons capacity and is insulated to reduce temperature loss to about

100-150°C. The oxygen is produced in a different plant, usually by air liquefaction. About 55 Nm^3 of oxygen is required per ton of liquid steel. The nitrogen, also produced by air liquefaction, can be used for bottom stirring to increase the reaction speed in the vessel.
The oxidation of carbon and other impurities (silicon) is a highly exothermic reaction, and it depends on the scrap inputs (e.g., DRI) added to prevent uncontrollable temperature rise. The hot metal ratio, the ratio of liquid pig iron input and steel input, ranges from 65% to 90%. (Worrell, Blinde, Neelis, Blomen, & Masanet, 2010).
Limestone is added to dissolve impurities and form a slag (later used in road construction). During the process, a gas contains large amounts of carbon monoxide (CO).
After the oxidation cycle is completed, the liquid steel is tapped into ladles by tilting the vessel in these ladles, where secondary metallurgy operations take place. Secondary metallurgy operations include a vacuum facility, a ladle furnace, and a tundish of a continuous caster. Their target is the conditioning of the liquid steel to achieve a homogeneous chemical composition.

Figure 21 Simplified scheme of the primary steelmaking route (EUROFER, 2020)

BOF is considered an autogenous process, but it is not a zero-energy process since installing ladle furnaces, vacuum degassers, and lime and oxygen production increases energy consumption.
In theory, the BOF itself does not consume energy besides the amount needed for oxygen

production since the oxidation of the carbon content of the hot metal is exothermal. It could even be a net producer when recovering sensible and latent heat in off-gas and the furnace itself. (European Comission, 2016)

4.1.2. Secondary steelmaking

The direct smelting of iron materials occurs in an electric arc furnace (EAF) via electric arcs between a cathode and an anode (one for DC or three for AC). The electrode is made of carbon, and it is consumed during operations. The temperature of an electric arc using carbon electrodes exceeds 4000°C. (Tupkary & Tupkary, 2018)

The main charge for EAF is ferrous scrap. In addition, manufactured iron units (DRI – direct reduced iron, pig iron) are great scrap substitutes.

Some facilities have integrated scrap preheating by the off-gas to recover energy, especially in countries with high electricity costs.

The iron units are loaded with limestone (slag formation) and charged into the furnace. The furnace is never fully charged at first; only 50-60% of scraped is loaded, the roof is closed, and the electrodes strike an electric arc from approximately 200-300 mm from the load. After the first charge is melted, the remainder of the scrap is added. (Remus, Aguado-Monsonet, Roudier, & Delgado Sancho, 2013)

Oxygen can be injected to promote metallurgical reactions (oxidation of carbon present), and coal powder can help with slag formation.

After the EAF process, the liquid steel is tapped into ladles. Similar to the BOF, secondary metallurgy operations take place at this time.

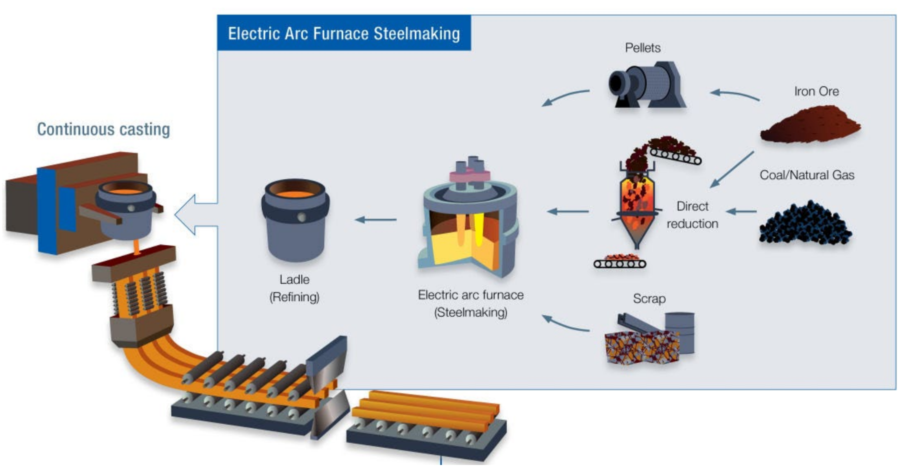


Figure 22 Simplified scheme of the EAF steelmaking route (EUROFER, 2020)

The specific final energy consumption is about 3GJ/t steel. It is lower than the consumption in the blast furnace route; the primary energy demand depends on the generation of the required electricity.

Specific energy consumption depends on the input material and the technology used. The quality of the scrap influences the quality of steel. If a higher quality of steel is required, the addition of DRI (or hot metal from blast furnaces) must be added.

The electricity consumed for melting the scraps of steel is a crucial variable because of the specific temperature the liquid steel needs to reach a particular specification to go into the next step (casting).

4.2. Direct reduction of iron

Direct reduced iron (DRI) is a high-quality metallic product produced from iron ore. It is used as feedstock in electric arc furnaces, blast furnaces, and other iron and steelmaking applications. The process of direct reduction of iron consists of the reduction of iron ore by carbon monoxide and hydrogen:

$$\begin{aligned} Reduction: \quad & Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O \\ & Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2 \end{aligned}$$

Hot briquetted iron (HBI) is a compacted form of DRI designed for easy shipping, handling, and storage. (Midrex Technologies, 2020)

HBI refers to DRI that has been briquetted at temperatures exceeding 650°C to a density exceeding 5g/cm^3. The DRI must be around 700°C before it passes between two rollers to make briquettes. The first purpose of this conversion was to avoid problems during maritime shipping. (Battle, Srivastava, Kopfle, Hunter, & McClelland, 2014).

4.2.1. DRI technologies

In 2019, gas-based shaft furnaces, MIDREX and ENERGIRON, were the leading producers of DRI with approximately 75.8%, followed by coal-based rotary kiln furnaces (mainly in India) with 24% and 0.2% of gas-based fluidised bed processes. Table 11 describes the feed requirements, input, reducing agent and product for each type of furnace. (Midrex

Technologies, 2020)

Table 11 Commercial Ironmaking processes and Feed Requirements (Battle, Srivastava, Kopfle, Hunter, & McClelland, 2014)

Type of furnace	Process	Iron ore	Reductant	Product
Shaft furnace	Blast furnace	Sinter, pellets	Metallurgical coke, pulverised coal	Molten iron
	MIDREX	Pellets, lump	Natural gas, syngas	DRI
	HyL/ ENERGIRON	Pellets, lump	Natural gas, syngas	
Fluidised bed	Finex	Fines	Coal	
	FINMET	Fines (size 0.15-7mm)	Natural gas	
Rotary kiln	SL/RN	Lump, pellets	Coal and recycled char	
	Krupp-CODIR	Lump, pellets	Char Coal	
Rotary hearth	FASTMET	Composite pellets, (size 16-22 mm)	Coal	
	Inmetco	Composite pellets	Coal	

According to MIDREX Technologies, the production of DRI in Western Europe was 0.56 Mt, the region with the lowest production volume globally. The only country that produces DRI is Germany, with a production plant by ArcelorMittal Hamburg. ArcelorMittal Hamburg has been operating since 1971 and has a capacity of 0.4 Mt/yr. They operate a MIDREX shaft.

4.2.1.1. Gas-based direct reduction

This process occurs in a shaft furnace, as seen in Figure 17, where the reducing gas is fed and moves upward against the iron ore flow. The spent top gas is fed into a reformer and natural gas to make for reducing gas. Natural gas cannot be used as a reducing agent itself. Still, it is used as a feedstock to produce the reducing gas, as a fuel to make necessary heat in the furnace, and as a coolant and carburising agent for the freshly prepared DRI. Natural gas is reformed into carbon monoxide and hydrogen before reducing iron oxide. The reforming agents are typically steam and carbon dioxide.

The presence of a nickel-based catalyst can be added for higher efficiency. (Battle, Srivastava, Kopfle, Hunter, & McClelland, 2014)

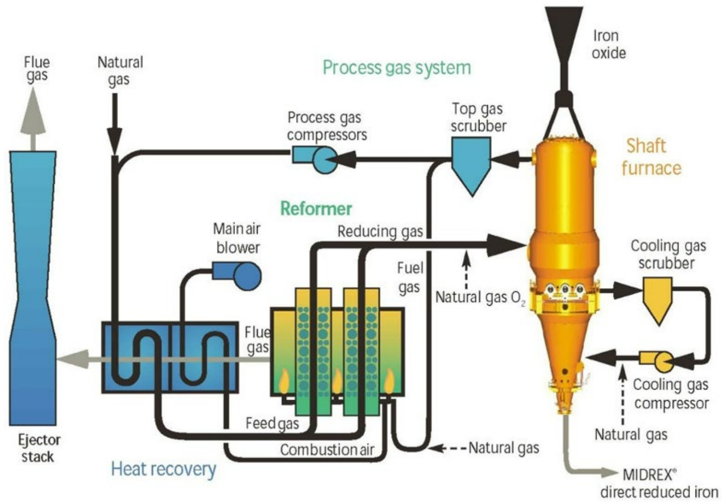


Figure 23 Scheme of the standard MIDREX process of direct reduction.

MIDREX technology differs from others because the off-gas process from the top of the reduction shaft furnace contains enough CO_2 and H_2O, so a separate steam addition for reforming is not required.

A significant difference between MIDREX and ENERGIRON is the operation of the reformer. In the MIDREX, the reformer operates with a mix of natural gas and top gas without any steam added. ENERGIRON only feeds natural gas to their reformers using externally generated steam. The reformed natural gas is cooled to remove water and combined with top gas.

4.2.1.2. Coal-based direct reduction

Rotary kiln (RK) technologies are used for coal-based direct reduction, which uses coal as the reducing agent.

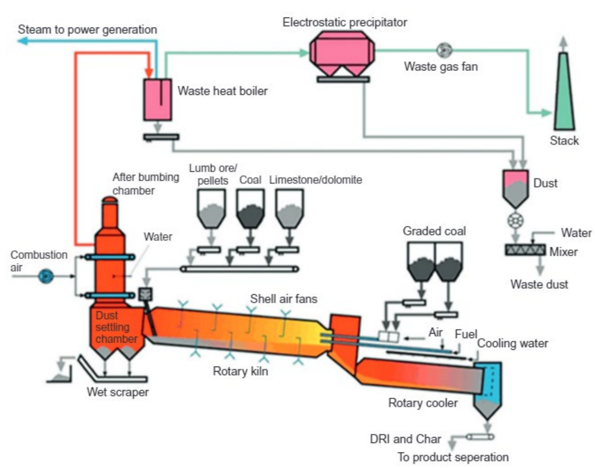


Figure 24 Flow sheet of the SL/RN process (Battle, Srivastava, Kopfle, Hunter, & McClelland, 2014)

4.2.1.3. Reducing agents

The most common reductants for metal oxides are some forms of carbon and hydrogen. Different from the BF, the reductants work at a lower temperature. The reactions are solid-solid or solid-gas, so the process kinetics must be highly prioritised compared to the other high-temperature reduction processes.

Unlike iron oxide reduction in the blast furnace, direct reduction occurs in the solid-state, making it difficult to remove some impurities. Most of these impurities will end up in the DRI product, making it more attractive to use higher-purity reductants for the process. (Battle, Srivastava, Kopfle, Hunter, & McClelland, 2014)

4.2.1.4. Hydrogen-based direct reduction

The H_2-DR route uses hydrogen as a reducing agent.

Currently, hydrogen production in Europe relies on fossil fuels, and using pure hydrogen as a reducing agent would ideally imply zero CO_2 emissions.

The H_2-DR route uses hydrogen as a reducing agent to obtain DRI (aka sponge iron). The reaction occurs in a shaft furnace, with operating temperatures around 800°C, and the resulting off-gas is H_2O which can be separated by condensation.

In terms of thermodynamics and kinetics, hydrogen proves to be a better reductant than carbon monoxide. It is more temperature optimum, with a small atomic size and high diffusivity. (Tacke & Steffen, 2004)

The hydrogen can be fossil sourced or fossil-free. As mentioned in chapter 2, the most common hydrogen production method is steam methane reforming.

According to (Vogl, Åhman, & Nilsson, 2018), a fossil-free direct reduction of iron requires 3.48 MWh of electricity per ton of steel. The primary electricity use is for the electrolyser, with production costs ranging from 326-640 EUR per tonne of steel.

4.3.Semi-finished products – Casting

After the desired steel quality is obtained, the steel is dispatched to casting ladles. Currently, continuous casting is preferred over ingot casting, and the semi-finished steel products are slabs, blooms, or billets with continuous casting.

4.3.1. Ladle preheating

The ladle of the caster is preheated with gas burners. Fuel consumption for preheating the ladle containing liquid steel is estimated at 0.02 GJ/t liquid steel.

4.3.2. Tundish heating

Tundishes are heated to reduce the heat loss of the molten steel, avoid bubbles in the first slab at the beginning of the casting sequence, and avoid degeneration of the refractory due to the thermal shocks. Tundishes heated by electrical induction have the potential to reach efficiency levels of 98% and contribute to higher product quality.

4.3.3. Integrated casting and rolling

The casted slab is rolled directly in the hot strip mill, saving handling and energy costs when applying direct rolling. Direct production of the hot-rolled strip by connecting the thin slab caster with the hot-rolling process was introduced around 1990.

Information about emissions from secondary metallurgy processes and continuous casting is limited, but it is reported that the emission factors before abatement can be between 6 – 15 kg dust/t LS. (Worrell, Blinde, Neelis, Blomen, & Masanet, 2010)

4.4. Finished products – Shaping

The semi-finished steel products from the casting operations are further processed to produce finished steel products in shaping and finishing operations. It is beyond the scope to assess all operations and products in detail, so only standard shaping processes will be discussed.

4.4.1. Hot rolling

The reheating furnace is critical in determining the end-product quality and total costs. According to (Worrell, Blinde, Neelis, Blomen, & Masanet, 2010), it has a total primary energy requirement of an average of 1.2 GJ/t cast steel.

4.4.2. Cold rolling

The purpose of the cold mills is to produce rolled sheets of tinplate with a thinner thickness, used for various uses like car bodies or tin cans. It is reheated to make the cold-rolled steel soft and malleable, heating up to 700°C and slow cooling.

4.5. Environmental issues

Primary steelmaking creates around1.9 t CO_2/t CS, the secondary route around 0.4 t CO_2/t CS, and the production via direct reduction with natural gas 1.2 t CO_2/t CS, according to (Wörtler, et al., 2013).

The emissions during the various processes for steelmaking can vary on the input. The emissions include dust, solid wastes, and wastewater.

There are primary and secondary emissions: primary emissions are 95% off-gases, and the furnace needs a complete enclosure with adequate gas extraction.

Secondary emissions are those off-gases and fumes generated during scrap handling, tapping and charging. They are captured by a canopy hood located above the furnace.

The dust collected from the emissions contains metals, nitrogen, sulfur oxides and organic matter. The organic matter depends on the quality of the scrap input since sometimes it contains paint, oils and other organic matters.

The heavy metals include zinc which has the highest emission factor. Chromium and nickel emissions are higher in the manufacturing of stainless steel. Part of the chromium can also occur as hexavalent chromium, which is highly carcinogenic by inhalation.

During scrap preheating, organic pollutants can be generated because of the combustion of the unknown quality of the scrap.

As the slag is cooled off, the water results in high alkaline fumes, and after solidification, further treatment and braking can lead to dust.

Water is used for the following purposes: cooling the EAF, rapid quenching of the hot off-gases, scrubbing water if wet dedusting is applied, vacuum generation, and direct cooling in continuous casting or ingot.

There is no waste when water is used for cooling since it is in a closed cycle.

4.6. Energy indicators in the iron and steel industry

Energy consumption in processes before steelmaking accounts for approximately 75% of energy demand in the iron and steel sector. (European Comission, 2016)

This sector consumes 10% of the final energy in Europe. The process is the same in all countries; they vary regarding their energy efficiency practices, but based on the energy use by the sector in Germany, it can be observed that coal is the primary feedstock.

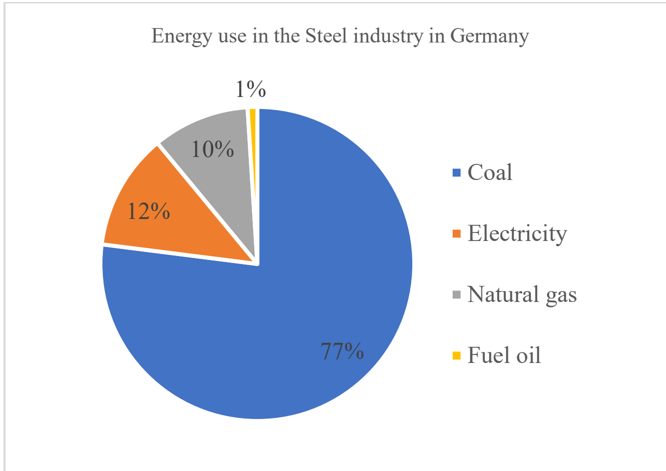


Figure 25 Energy use of the steel industry in Germany. (Schlemme, Schimmel, & Achtelik, 2019)

4.6.1. Specific energy consumption

The specific energy consumptions (SECs) are expressed in GJ of primary energy production per tonne of crude steel (GJ/tcs) for the different production routes. They represent the best practice values, i.e. the lowest values achieved in one plant (Jeroen, 2000). Regarding SEC of both production routes, the values vary since, in some countries, the BOF is utilized more than EAF. The assumed values for SEC can be implied as the most efficient plants. The following table enlists the specific energy consumption of different steps of the steelmaking process according to the technology used.

Table 12 Specific energy consumption of steelmaking technologies (Worrell, Blinde, Neelis, Blomen, & Masanet, 2010)

	Technology characterization		Mean specific energy consumption	Specific energy consumption range	Notes
Primary steel production	BOF		0.39 GJ/t	-	
Secondary steel production	EAF		2 GJ/t	1.3 – 2-7 GJ/tcs	
Semi-finished products	Casting		3 GJ/t	0.2 GJ/t (slab casting) – 3 GJ/t (hot strip coil)	It depends on the grade of finalization, but the average is estimated by accounting for the multiple reheating and subsequent process steps
Finished products	Hot rolling		1.2 GJ/tcs	-	
	Cold	Coating	0.5 GJ/t	-	Assuming 10 mm

(Shaping)	rolling			thickness of the coil
		Annealing	0.75 GJ/t	-
		Pickling	1.1 GJ/t	-

The following table presents the best practice values for the DRI-EAF route.

Table 13 Best Practice Final and Primary Energy Intensity Values for the DRI-EAF Steelmaking Route. (Worrell, Price, Neeils, Galitsky, & Nan, 2008)

Direct Reduced Iron - Electric Arc Furnace Route			**GJ/t**
Ironmaking	Direct Reduced Iron	Fuel	12.9
		Electricity	-1.2
		Final Energy	11.7
		Primary Energy	9.2
Steelmaking	Electric Arc Furnace	Fuel	0.6
		Electricity	1.7
		Oxygen	0.3
		Final Energy	2.5
		Primary Energy	5.9

4.7. Steel production in the EU

According to EUROFER, the crude steel output by production route in EU27 is 58.5% for primary steel making and 41.4% for secondary steelmaking.

Crude steel production in the EU was around 145 Mt in 2021. As seen in Figure 20, Germany leads in crude steel production, followed by Italy, France, and Spain. (EUROFER, 2022)

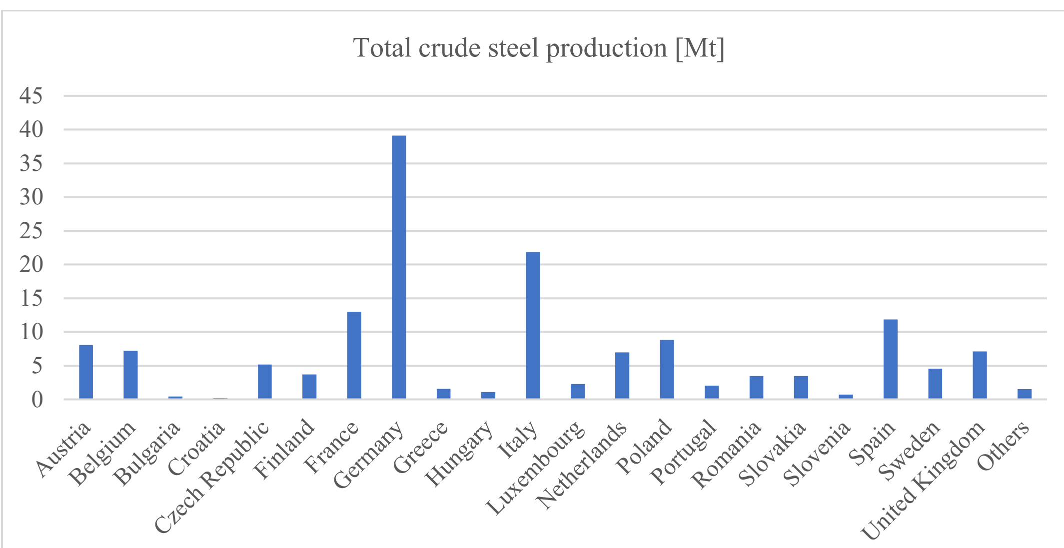


Figure 26 Crude steel production in 2021 in Mt (EUROFER, 2022)

Since 2020, there have been disruptions in the supply chain of steel. The possibility of a recession has put the steel sector at risk because of the increasing energy and carbon prices.

5. Mapping

5.1. Steel production plants

The leading producers of crude steel in the EU are located in Germany, Italy and France.

The geolocalization of the steel plants helped identify industrial clusters with the potential for developing "green hydrogen hubs."

The mapping of these operating plants helps us identify these clusters. The production capacity of one single EAF could be one-tenth of the production from a BF/BOF plant. Moreover, even though the total primary steelmaking plants are only 26 in the defined region, the remaining 126 EAF plants do not compete with the total production annually.

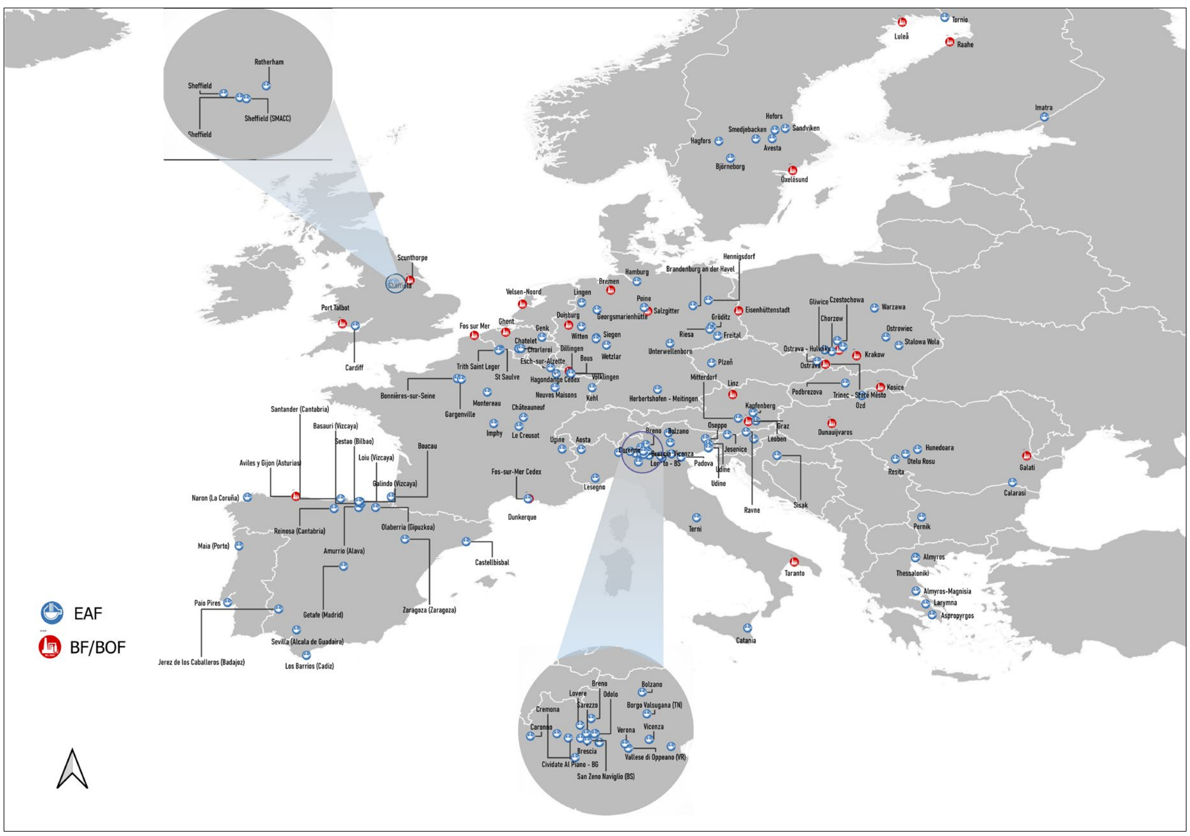


Figure 27 Operating steelmaking plants by BF/BOF and the EAF route. [own making]

The size of the steel industry in Europe is of great importance to the economy. Steel is a crucial economic and social factor that allows technological development, economic growth and many artefacts used in day-to-day life.

To better understand the maps, the map with both technologies presented in Figure 27 was divided into their respective technology route.

Figure 28 presents only the operating plants for the BF/BOF route. Although the primary steelmaking route has a higher share in total production output, the number of operating plants is a third of the total for the secondary route.

Figure 28 Operating steelmaking plants by BF/BOF. [own making]

Figure 29 shows only the plants with EAF. The concentration of the EAF plants in specific locations is higher than with the BF/BOF route. These integrated steel mills are located in industrial zones where more than one competitive steel producer is close.

There can be observed that a high number of EAF plants are in proximity to each other, not by close kilometres, but these clusters help us identify opportunities for deployment of hydrogen hubs.

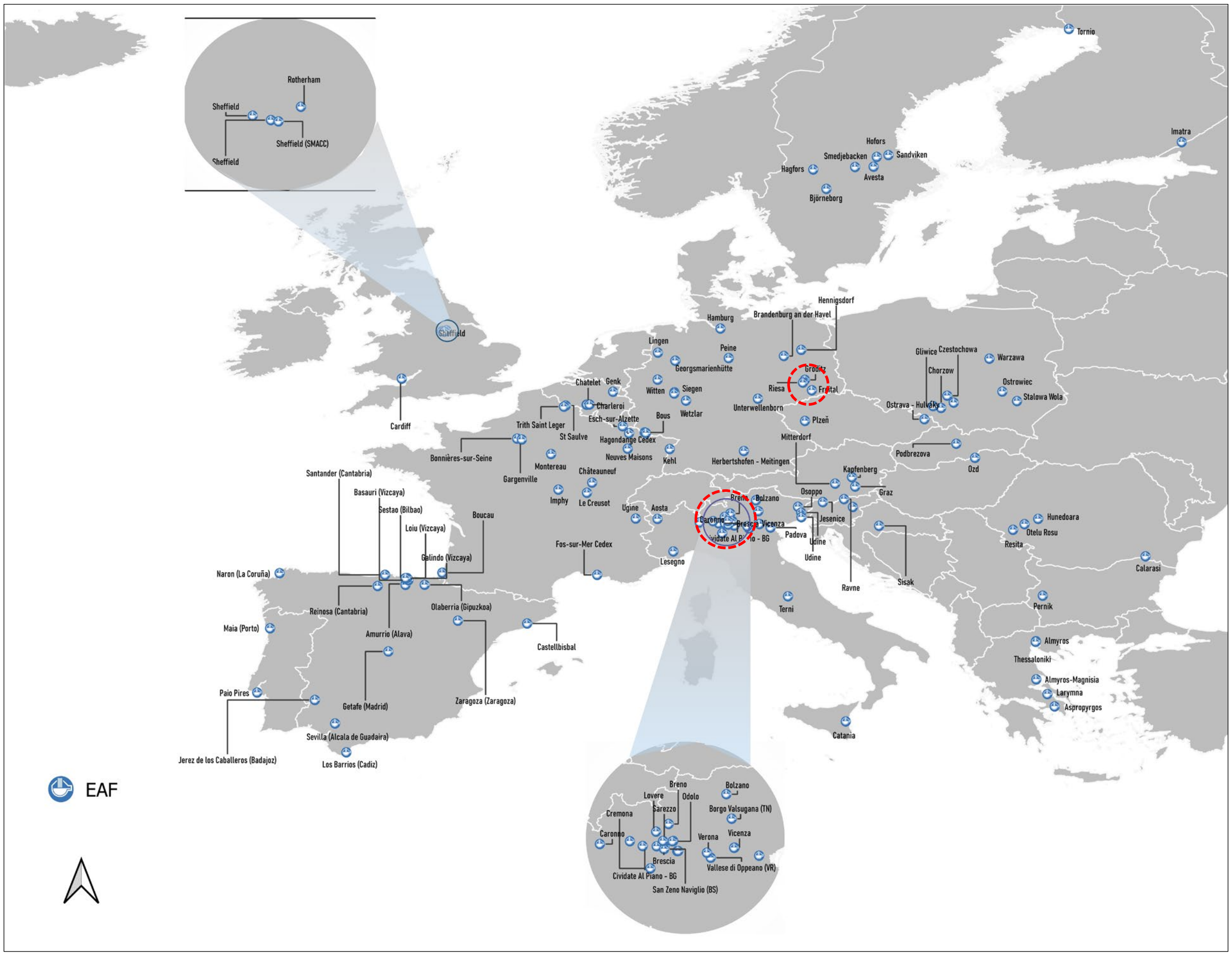


Figure 29 Operating steelmaking plants by the EAF route. [own making]

The red circles could be identified as an example of the potential of a hydrogen hub.

For example, Figure 30 shows a close-up of the northern region of Italy, specifically Lombardia, with a high concentration of EAF steel producers. An advantage of the closeness of these is the facilitation of the distribution and transport of hydrogen.

A green hydrogen hub is beneficial because of its geographical location. It considers the abundant renewable energy sources of the region and takes advantage of the potential investment for producing green hydrogen for a specific cluster of industries.

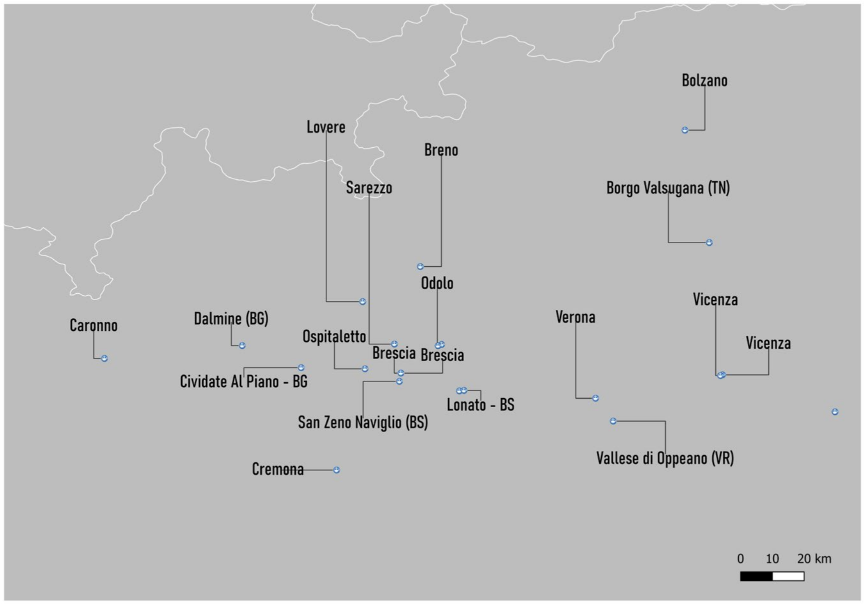


Figure 30 Close-up of the northern Italy EAF steel producers.

This opportunity can be advantageous for the steelmakers in the referenced area, and the transition toward fossil-free steel could be encouraged to transition as soon as possible. Green hydrogen hubs will enable business development by facilitating production, storage, and transportation.

5.2. CO_2 emissions

The CO_2 emissions for each steelmaking route are presented in Figures 30 and 31. It is proportional to the production volume of each plant, as explained in chapter 1.

The BF/BOF route is an energy-intensive process. Each plant's emissions include those from the ironmaking and the steelmaking, which leads to a higher environmental impact.

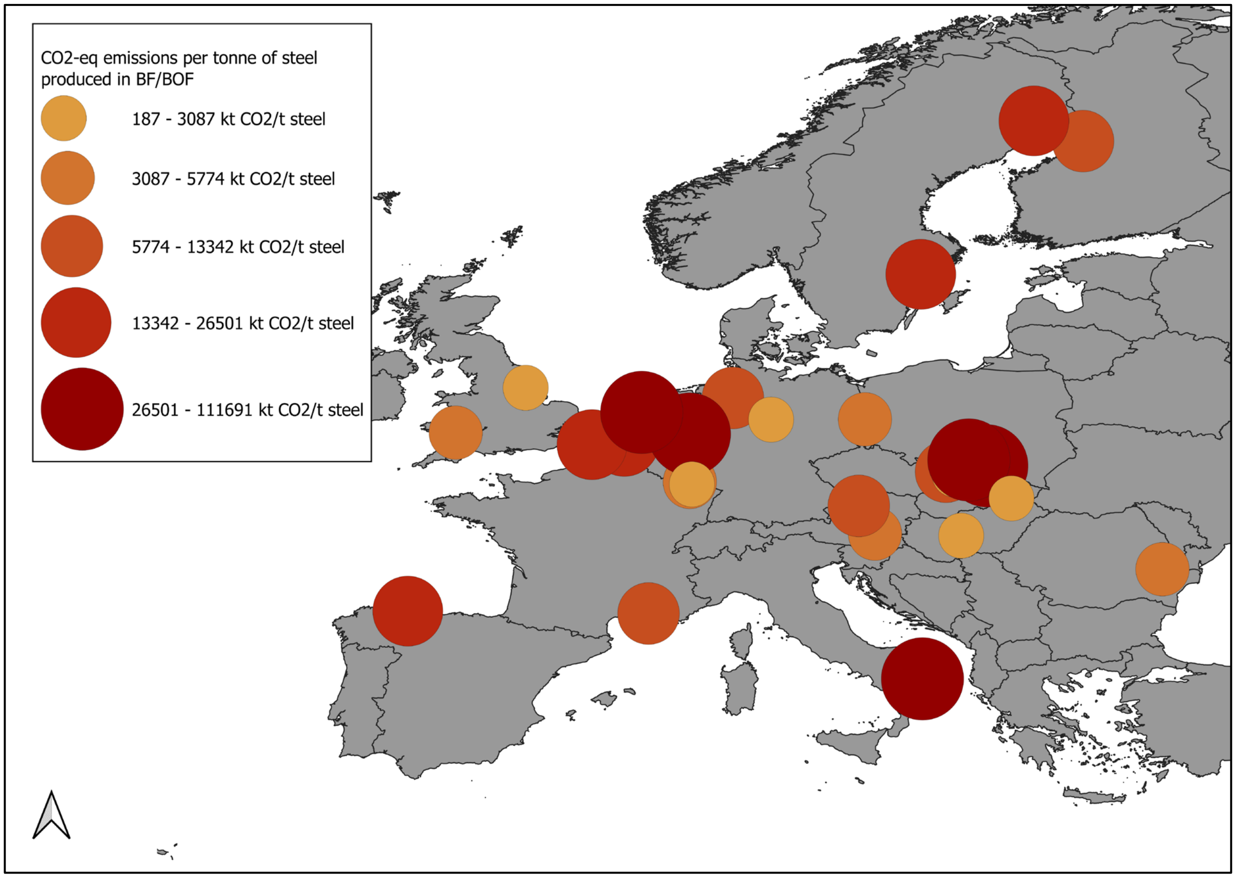


Figure 31 Equivalent CO_2 emission per tonne of steel produced s of the BF/BOF operating plants. [own making]

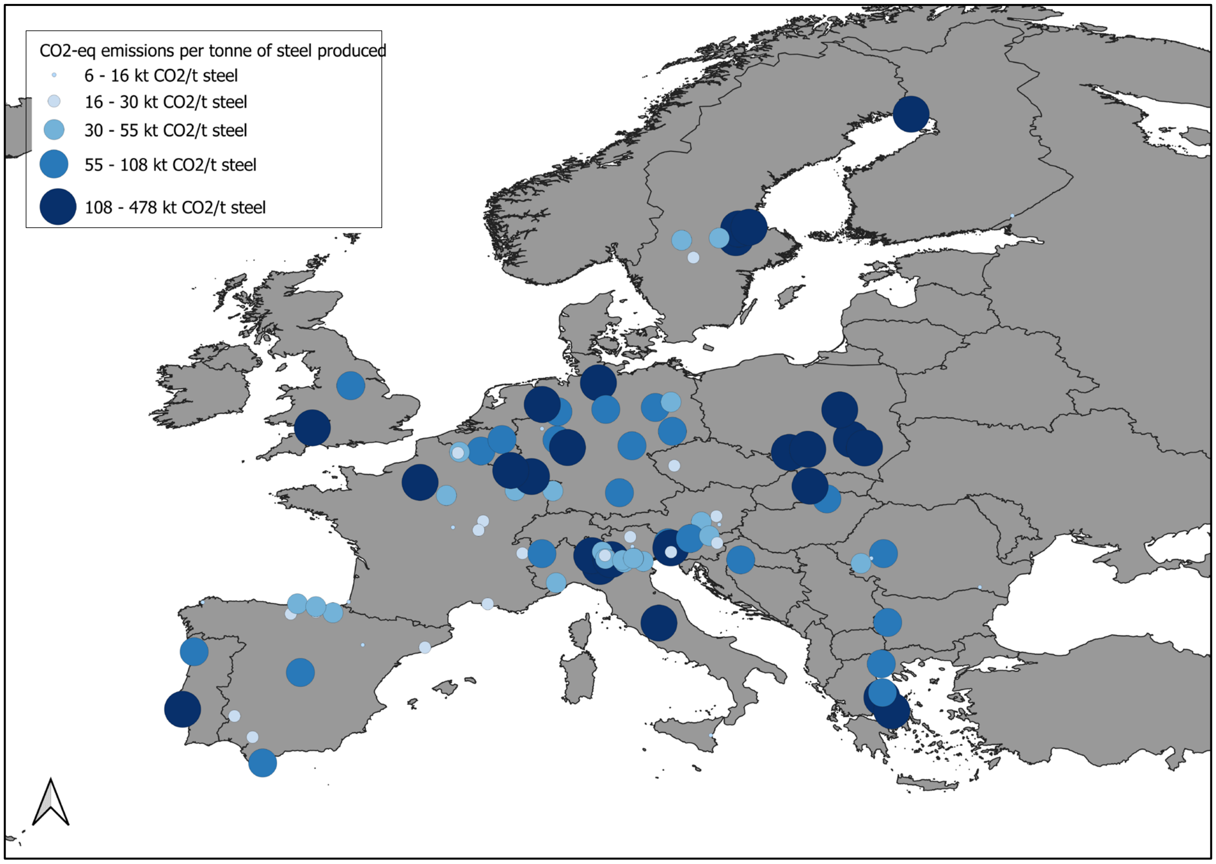


Figure 32 Equivalent CO2 emissions per tonne of steel produced by the BF/BOF operating plants. [own making]

Compared with the EAF route, their use of scrap and other ferrous inputs reduces the emission's intensity since it does not consider the ironmaking or the DRI process. It can be observed in Figure 31 that the kt of CO_2 is far smaller than the BF/BOF. The highest emission does not even compare with the highest of the BF/BOF route.

6. Hydrogen production feasibility

The localization of the steel plants gave an insight into the advantages of their geographical location. Local and national regulators could take advantage of the funding for implementing hydrogen technologies and transform them into a hydrogen economy. To meet the necessary demand for secondary steelmaking routes to transition towards a hydrogen-based process, the main component to reduce the cost is renewable electricity

The following section will describe the feasibility factors for supporting the transition of the scale-up of a hydrogen plant for providing hydrogen to a DRI-EAF route in Europe.

6.1. Electrolyser

Reducing the electrolyser cost is a challenge to overcome in the following years. The green electricity supply, as mentioned earlier, is the most significant cost component. Nevertheless, the performance of the electrolyser needs to be improved while reducing manufacturing costs.

Regarding commercially available electrolysers, both alkaline and PEM are already available for large-scale projects. However, as mentioned in previous chapters, the alkaline electrolyser is a more cost-effective solution for multi-watt H_2 installations.

The electricity consumption comprises the highest cost component of the project, hence the importance of finding a location with abundant RES for low-electricity prices.

The required nominal power of the electrolyser in this scenario depends on the hydrogen output and the demand hourly and seasonally, which for the iron and steel industry does not vary. The following table enlists the specifications of an alkaline electrolyser available for commercial deployment from one of the already available electrolyser manufacturers.

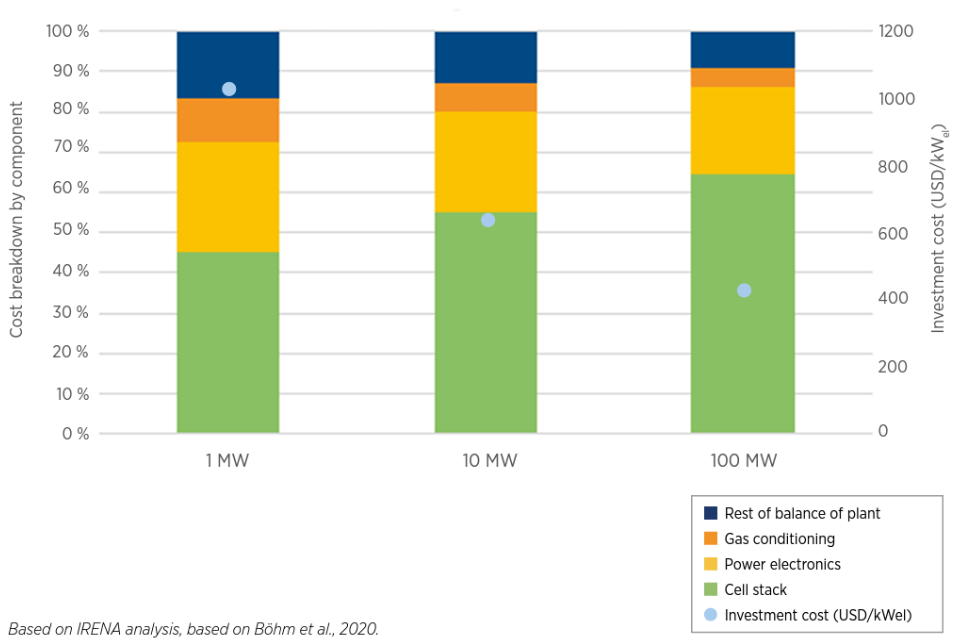


Figure 33 Cost breakdown by major component for alkaline electrolyser, retrieved from (IRENA, 2021)

The following table shows the general specifications of commercially available electrolysers on a medium scale.

Table 14 Electrolyser specifications by (Thyssenkrupp, 2019)

	10 MW module (Thyssenkrupp)	**20 MW module (Thyssenkrupp)**
Design capacity H_2	2000 Nm^3/h	4000 Nm^3/h
Efficiency electrolyzer (DC)	>82%$_{HHV}$*	
Power consumption (DC)	4.3 kWh/ Nm^3 H_2	
Water consumption	< 1l/Nm^3 H_2	
Standard operation window	10-100%	
H_2 product quality at electrolyser outlet	>99.95% purity (dry basis)	
H_2 product quality after treatment (optional)	As required by the customer, up to 99.999%	
H_2 product pressure at module outlet	~300 mbar	
Operating temperature	Up to 90°C	

*HHV = calculated regarding the higher heating value of hydrogen
All values may vary depending on operating conditions

The water consumption of an alkaline electrolyser is 15 L/kg. (Roland Berger GmbH , 2017) The electrolysers efficiency is the factor that is crucial to improve for the cost reduction since the improvement of power consumption could result in the same H_2 output but a more feasible cost/kW.

The system cost is divided into operational expenditures OPEX and capital expenditures CAPEX.

The CAPEX of an electrolyser will increase when aiming for larger stacks, increasing manufacturing and the overall performance for better durability, and it will decrease when making the stacks less durable.

A more efficient stack will reduce electricity costs and increase the OPEX. Regarding the OPEX trade-offs, decreasing the OPEX will reduce maintenance, lower output quality, and increase the operation's pressure. (IRENA, 2020)

6.2.DRI

The commercially available gas-based shafts give the capacity of the direct-reduction shaft. MIDREX, the producers of the DRI shaft, have stated that theoretically, the shaft can operate on pure hydrogen.

The amount of hydrogen required for reducing 1 ton of iron ore to sponge iron (aka DRI) is around 49 kg, according to (Vogl, Åhman, & Nilsson, 2018)

The MIDREX shaft has an energy input of 10.5 GJ/t product, with a metalisation higher than 92%, and a typical plant has a capacity of 1000 kt/yr. (Worrell, Price, Neeils, Galitsky, & Nan, 2008)

6.3. Energy requirements

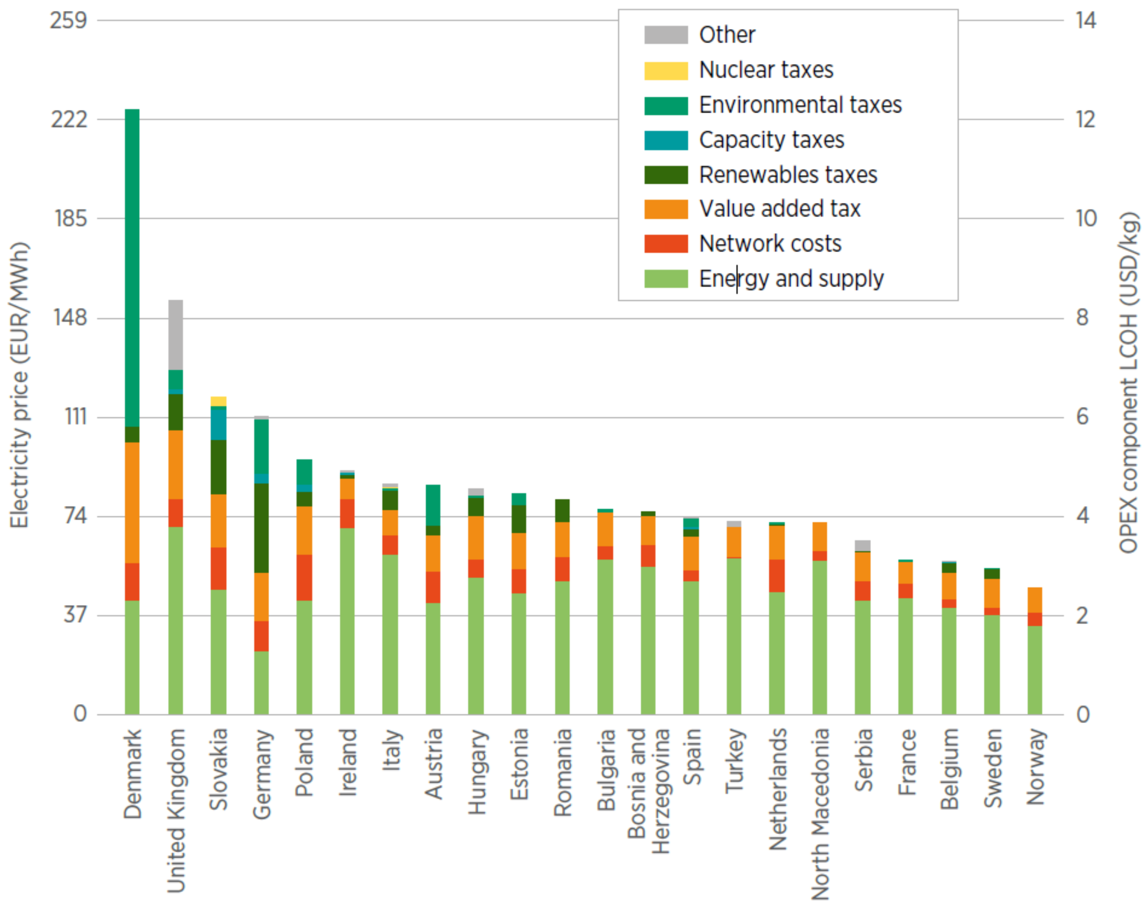
The power required depends on the capacity of the DRI plant. The renewable electricity prices for industrial customers can be very high in some regions.

When it comes to the electricity prices for industrial customers in Italy, the prices before charges and taxes for customers of all classes remain among the leading European countries. However, industrial electricity consumers remain to pay lower prices than their German counterparts. (Autorità di Regolazione per Energia Reti e Ambiente, 2021)

An average price for industrial power supply in major industrial countries would be 154 USD/MWh in Germany and 111 USD/MWh in Europe. (Friedmann, Fan, & Tang, 2019)

According to (Vogl, Åhman, & Nilsson, 2018),

Industrial electricity prices include taxes and fees, which can increase the operational component of the final cost. Figure 33 was retrieved from (IRENA, 2021), and comprises the prices for industrial consumers in a decreasing order.



Notes: Electricity prices for consumption above 150 GWh per year. LCOH = levelised cost of hydrogen. Right-axis values assume an electrolyser efficiency of 66%.

Source: IRENA analysis based on Eurostat (2020).

Figure 34 Industrial electricity prices by component, in selected European countries, 2019. (IRENA, 2021)

This past figure can also be supported by Figure 34, which shows the regions where green hydrogen has high potential. Some countries do not include the electricity tax for electrolytic processes, such as France, Norway and the Netherlands, which are shown to be among the countries with the lowest industry prices. These examples of industrial policy supporting the use of technology make the investment more attractive because of the cost reduction.

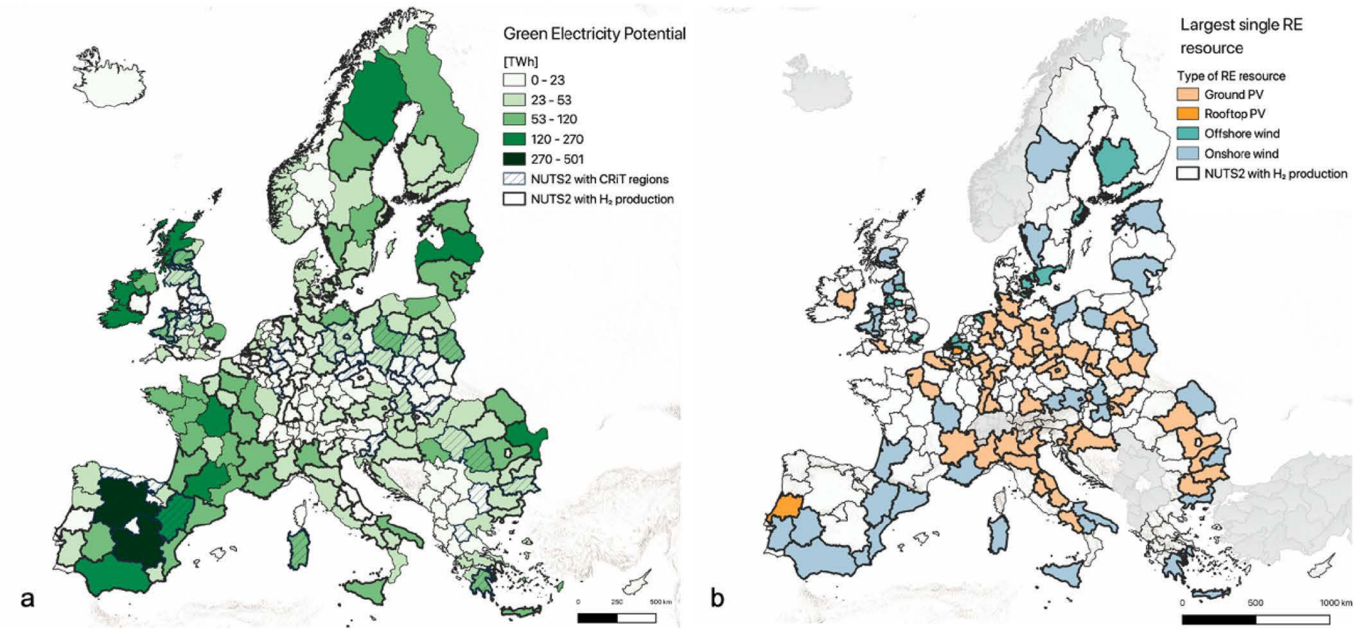


Figure 35 Based on NUTS2 regions, (a) Technical potential for green electricity per region, and (b) Largest resource available in that region. (Kakoulaki, et al., 2021)

The technical potential for electricity generation from RES is pictured in Figure #, where the potential on a regional level is noticed to understand the available resources better. According to (Kakoulaki, et al., 2021), alkaline electrolysers consume 50-51 kWh/kg.

7. Hydrogen Policies

The European Union aspire to become a leader in clean hydrogen and large-scale importers, exporters or transit hubs of hydrogen. The EU has the premise of producing zero-emission hydrogen but uses low-emission hydrogen as a transitional measure. Within the EU, France and Germany are the countries that have committed the most funding to hydrogen projects for the next decade.

There is a vast potential for some countries to grow as energy exporters. The Americas, the Middle East, Oceania and Africa have the highest technical potential to produce large volumes of low-cost green hydrogen. Their current energy mix, the government support and the existing infrastructure come into consideration.

Hydrogen will shift the geostrategic importance of several fossil-fuel importing countries. They will take advantage of their hydrogen production potential.

Fossil fuel-producing countries will be affected by this hydrogen transition and will have to

diversify their economies from relying on oil and gas. Nevertheless, they can take advantage of their existing pipelines, ports and storage facilities.
It is essential to mention that for the cooperation of the policies to be successful, it has to benefit all key players. The regulations must cover employment growth, creating a market, supporting international trade, increase demand and infrastructure.

7.1. Current trends

In partnership with Hydrogen Europe, the European Commission launched HyLaw to identify the legal barriers to hydrogen deployment.
It takes time for new technologies to incorporate into new markets. The scaling up of hydrogen technology will boost the innovation from involved actors in the market.
The Covid-19 health crisis triggered the economic recovery plans from many European countries, which took into account the energy value chain disrupted since 2020.
In line with the European Green Deal, the Next Generation EU is a EUR 750 billion stimulus to kick-start European economies and build resilience, with the expectation from them to prioritise clean energy technologies, energy-efficient building renovations, sustainable transport, broadband rollout, digitalisation of public administration, European cloud computing capacities, and improving digital skills into education. (IEA, 2020)
France has targets to increase their electrolyser capacity up to 6.5GW in 2030, and Italy and Germany are targetting a 5 GW electrolyser capacity.

7.2. Funding

The public funding opportunities given by various EU programmes dedicate specific investment to research, development & innovation, demonstration & pioneer plants, and finally, roll-out & infrastructure. (Draxler, et al., 2021)
The most significant public programmes are:

- Horizon Europe (HEU)
- Clean Steel Partnership (CSP)
- Research Fund for Coal and Steel (RFCS)
- Innovation Fund (IF)
- LIFE
- European Green Deal Investment Plant (EGDIP)
- Digital Europe (DE)

- Connecting Europe Facility
- Erasmus+
- ERA-NET
- SME Instrument
- Important project of common European interest (IPCEI)

These funding programmes do not represent the total investment necessary for transforming the iron and steel industry. If the available funding for the steel sector is considered, the total investment for the upcoming decades would be as seen in Figure 32.
Those programmes not considered in the graph do not contribute to the reduction of CO2 in the iron and steel industry and, therefore, have no dedicated funding for the decarbonization of this sector.

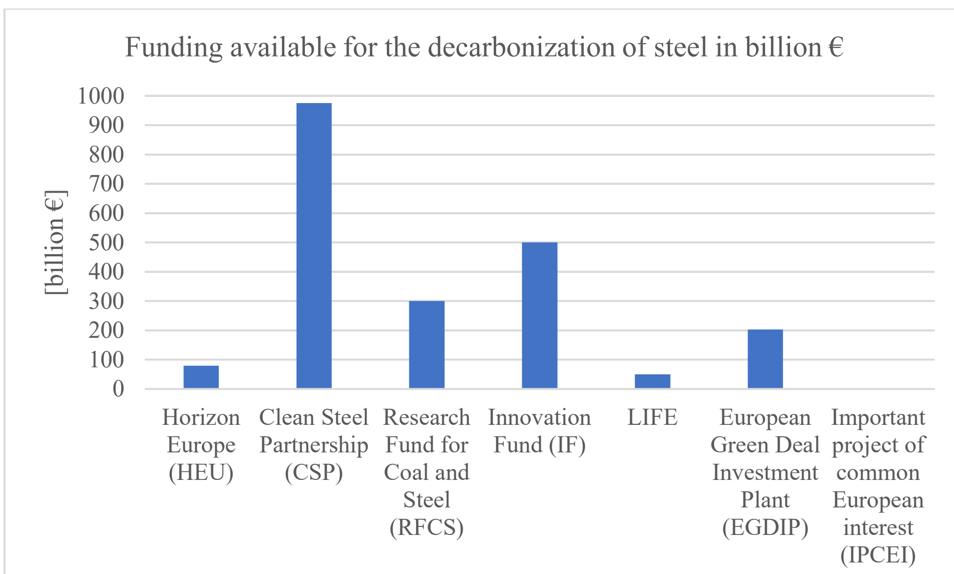


Figure 36 Funding available from EU programmes for the decarbonization of steel in billion €. (Draxler, et al., 2021)

The funding for IPCEI is 2 billion €, but it cannot be detected in the previous graph because of the high investments from the other programmes.

7.3. Future trends

The potential to increase hydrogen use in the industry today is expanding. Moreover, the opportunity to adapt hydrogen production from clean energy sources must be considered.

Hydrogen will play an essential role in the industry with current tendencies. Policymakers need to intervene and enforce policy to stimulate growth in the use of hydrogen.

The hydrogen demand needs to be incentivised through these policies. The distribution of this demand will be settled because of the adaptability of different regions to green hydrogen. Some regions have the highest potential for green hydrogen production, but those regions' strategies and national goals can get in the way of practical usage.

There are upcoming giga-scale projects for green hydrogen in Spain (HyDeal Ambition), Germany (AquaVentus), and Ireland (Green Marlin), with an expectation to accelerate the deployment of a hydrogen economy.

8. Conclusion

In theory and practice, it has been clear that hydrogen is crucial for energy transformation and reaching the Paris Agreement objectives.

The hydrogen demand must be equally distributed to the requiring industries and consider the capacity of renewable energy sources needed for hydrogen production.

The highest cost component of a hydrogen project will be the electricity prices. Renewable electricity is most significant in enabling iron and steel's decarbonisation. Other decarbonisation routes are more attractive than the green hydrogen DRI.

Those countries with higher steel production from primary steelmaking are great candidates for the transition towards hydrogen-based DR. The trend of carbon prices increasing make it more attractive for the shift.

The projects developing green steel are still on demonstration levels, with a mixture of private and public funding. Nevertheless, adequate financial support must be available for the time scope given by the EU to meet decarbonisation goals.

The transition towards green hydrogen, with support on injecting hydrogen into the gas network, is supported by research and the government as a strategy for achieving their targets. The proposal makes it more attractive for industries to use the grid to comply with carbon policies and reduce their carbon tax.

Policy support is vital for driving innovation and attracting investment in the technologies. Electrolyser costs also need to decrease, and its efficiency is a crucial component that needs to be lowered to produce the same amount of hydrogen for less.

The political environment, geopolitical reliance on gas imports, and the fragility of these connections because of these socio-political transformations. The disruptions in the energy supply in Europe are not always due to technical failures. As seen with the current war in Ukraine, the energy supply in Europe is in jeopardy because of the disruption of gas imports from Russia.

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10. Appendices

Appendix A: High-temperature heat estimation data sets

Table 15 Data set 1: Shares of total heat demand differentiated by temperature ranges in the German industry sector

PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)
Steel	0.52%	1.64%	19.27%	75.60%	97.03%	2.97%
NF-metals	0.52%	1.64%	19.27%	75.60%	97.03%	2.97%
Chemical	13.82%	21.49%	45.90%	11.31%	92.53%	7.47%
Minerals	1.30%	2.01%	30.09%	62.30%	95.70%	4.30%
Mining	51.33%	42.75%	0.00%	0.00%	94.08%	5.92%
Food and tobacco	33.37%	41.00%	0.00%	0.00%	74.36%	25.64%
Textile	58.65%	0.00%	0.00%	0.00%	58.65%	41.35%
Paper and Print	14.39%	69.32%	0.00%	0.00%	83.71%	16.29%
Transport	15.52%	11.76%	5.63%	16.02%	48.94%	51.06%
Machinery	15.36%	11.77%	6.14%	15.87%	49.15%	50.85%
Wood	69.12%	17.65%	0.00%	0.00%	86.76%	13.24%

Construction	7.00%	24.00%	16.00%	35.00%	82.00%	18.00%
Other	7.75%	25.61%	16.46%	34.22%	84.03%	15.97%

Table 16 Data set 2: Total energy consumption by industry branches in Europe

2019 [PJ/a]	**Iron and steel**	**Chemical and petrochemical**	**Non-ferrous metals**	**Non-metallic minerals**	**Mining and quarrying**	**Food, beverages and tobacco**	**Textile and leather**
Austria	36.92	46.35	9.13	36.36	11.67	21.64	2.67
Belgium	42.95	167.11	12.54	54.54	2.23	68.61	7.11
Bulgaria	4.86	33.00	8.87	23.47	4.43	10.12	2.58
Croatia	0.74	6.32	0.85	15.17	0.22	8.20	1.01
Cyprus	0.01	0.31	0.03	6.16	0.40	1.75	0.02
Czech Republic	35.47	43.73	3.78	48.72	3.46	23.36	5.13
Denmark	3.69	11.27	0.00	20.88	3.22	24.75	0.70
Estonia	0.05	1.45	0.03	4.21	0.33	2.75	0.38
Finland	31.64	41.10	10.43	12.55	6.99	17.06	0.76
France	74.87	273.12	43.84	156.66	16.78	214.64	12.14
Germany	298.09	567.57	94.50	281.84	14.60	213.48	17.32
Greece	6.01	3.72	26.42	26.87	3.76	19.08	3.62
Hungary	8.73	47.38	4.88	25.55	1.48	27.81	1.69
Ireland	0.00	10.88	20.08	17.35	2.06	21.69	1.23
Italy	151.57	128.70	27.78	175.83	5.22	116.71	46.80
Latvia	0.05	0.89	0.04	6.80	0.44	3.27	0.30
Lithuania	0.06	17.47	0.00	6.82	0.28	7.55	1.31
Luxembourg	13.81	1.23	0.00	5.93	0.05	0.70	1.33
Malta	0.00	0.17	0.00	0.02	0.06	0.27	0.11
Netherlands	39.80	296.43	12.68	22.65	4.70	83.78	4.03
Poland	66.53	131.54	22.95	132.34	19.15	93.04	5.18
Portugal	8.13	19.57	1.14	45.79	3.18	19.48	12.75
Romania	48.52	61.85	17.73	45.73	1.57	24.09	7.13
Slovakia	37.41	19.12	11.02	18.64	2.48	6.58	0.94
Slovenia	6.53	6.45	5.96	8.79	0.79	2.85	0.65

Spain	81.45	150.42	52.22	168.47	20.17	99.13	15.92
Sweden	39.40	21.34	13.34	14.36	22.53	14.63	0.87
EU27	1037.28	2108.48	400.23	1382.53	152.27	1147.02	153.67
Norway	19.95	26.83	74.98	3.38	1.48	10.67	0.25
Serbia	3.31	4.54	1.60	2.71	1.63	5.85	1.35
Switzerland	9.08536	30.2706	2.4283	20.4316	0	21.478	2.5958
United Kingdom	35.45	137.84	24.85	100.22	0.41	116.03	21.89

Continuation: Table Data set 2

2019 [PJ/a]	**Paper, pulp and print**	**Transport equipment**	**Machinery**	**Wood and wood products**	**Construction**	**Other industry**	**Industry total**
Austria	76.96	4.89	21.54	22.76	12.59	7.44	310.93
Belgium	27.17	5.17	11.45	9.52	8.72	14.75	431.86
Bulgaria	8.74	0.70	5.67	2.92	3.15	3.40	111.91
Croatia	3.01	0.37	2.65	3.76	4.56	2.22	49.08
Cyprus	0.10	0.01	0.10	0.02	0.47	0.18	9.58
Czech Republic	28.26	21.60	28.73	8.76	7.36	15.08	273.46
Denmark	2.36	0.58	8.39	5.38	6.91	4.90	93.04
Estonia	2.60	0.35	1.28	3.05	2.06	0.87	19.40
Finland	274.00	2.54	13.59	22.20	16.80	7.03	456.70
France	96.94	41.96	76.90	25.70	64.10	54.35	1152.00
Germany	223.93	120.25	214.30	72.31	104.78	109.12	2332.07
Greece	3.21	0.30	3.65	1.25	5.65	4.80	108.34
Hungary	10.24	9.83	18.81	5.12	12.23	12.81	186.55
Ireland	0.69	0.17	5.70	6.45	4.13	5.52	95.95
Italy	86.15	16.92	146.60	20.27	17.89	69.89	1010.32
Latvia	0.22	0.24	0.66	20.43	1.12	1.24	35.69
Lithuania	2.22	0.18	1.62	3.72	1.79	3.48	46.50
Luxembourg	0.11	0.04	0.29	0.16	0.92	1.29	25.87
Malta	0.10	0.07	0.44	0.01	0.15	0.88	2.29
Netherlands	22.13	4.71	22.17	2.40	29.44	14.82	559.74
Poland	78.90	20.60	31.77	47.66	8.15	34.44	953.85
Portugal	58.20	3.48	6.44	6.15	6.09	2.95	193.35
Romania	6.71	12.19	17.98	13.49	15.87	6.01	278.89

Slovakia	21.28	7.55	10.20	2.11	1.00	6.63	144.98
Slovenia	7.23	1.55	7.75	2.12	1.63	3.04	55.35
Spain	71.22	26.91	34.56	24.99	58.60	22.78	826.84
Sweden	236.88	8.37	13.47	23.98	13.91	34.23	457.30
EU27	1349.58	311.50	706.73	356.68	410.07	444.16	9960.20
Norway	14.07	1.43	3.81	2.21	5.01	1.55	165.63
Serbia	1.81	0.92	2.37	0.48	1.22	2.45	30.25
Switzerland	20.4316	0	26.63	0	9.462	0	142.812
United Kingdom	72.10	45.61	91.65	3.34	29.79	202.70	881.88

Table 17 End-use energy balances for the German industry sector

	Power consumption		**Fuel consumption**		
Modified according to Eurostat industry sectors	Space and water heating [PJ/a]	Process heat [PJ/a]	Space heating [PJ/a]	Water heating [PJ/a]	Process heat [PJ/a]
Iron and steel	0.136	22.107	4.037	0.335	327.214
Chemical and petrochemical	0.12	34.52	5.1	0.44	269.84
Non-ferrous metals	0.12	34.69	5.26	0.37	44.59
Non-metallic minerals	0.1	0	2.902	0.2	126.004
Mining and quarrying	0	0.3	0.8	0.1	7.5
Food, beverages and tobacco	0.4	8.7	17.4	1.4	122.8
Textile and leather	1	8.5	38.9	3.4	75.4
Paper, pulp and print	0.1	0	4	0.3	154.9
Transport equipment	0.7	6.4	27	2.1	27.2

Machinery	0.381	2.9	15.228	1.379	8.103
Wood and wood products	1	8.5	38.9	3.4	75.4
Construction	1	8.5	38.9	3.4	75.4
Other industry	0.36	3.06	14.004	1.224	27.144

Table 18 Shares of end-use balances in the FEC of the German industry sectors for space and water heating and process heating.

	Total FEC		
	Space and water heating [PJ/a]	Process heat [PJ/a]	Total FEC
Iron and steel	1%	70%	100%
Chemical and petrochemical	1%	73%	100%
Non-ferrous metals	5%	68%	100%
Non-metallic minerals	2%	82%	100%
Mining and quarrying	6%	52%	100%
Food, beverages and tobacco	9%	63%	100%
Textile and leather	21%	41%	100%
Paper, pulp and print	2%	67%	100%
Transport equipment	24%	27%	100%

Machinery	31%	20%	100%
Wood and wood products	21%	41%	100%
Construction	21%	41%	100%
Other industry	21%	41%	100%
Total	9%	59%	100%

Appendix B: High-temperature thermal energy demand results

2019	**Iron and steel**						
PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)	Total heat demand
Austria	0.13	0.42	4.99	19.59	25.15	0.01	25.16
Belgium	0.16	0.49	5.81	22.79	29.25	0.01	29.26
Bulgaria	0.02	0.06	0.66	2.58	3.31	0.00	3.31
Croatia	0.00	0.01	0.10	0.40	0.51	0.00	0.51
Cyprus	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Czech Republic	0.13	0.41	4.80	18.82	24.16	0.01	24.17
Denmark	0.01	0.04	0.50	1.96	2.52	0.00	2.52
Estonia	0.00	0.00	0.01	0.02	0.03	0.00	0.03
Finland	0.12	0.36	4.28	16.79	21.55	0.01	21.56
France	0.27	0.86	10.13	39.73	50.99	0.02	51.01
Germany	1.09	3.42	40.33	158.18	203.01	0.08	203.09
Greece	0.02	0.07	0.81	3.19	4.09	0.00	4.09
Hungary	0.03	0.10	1.18	4.63	5.95	0.00	5.95
Ireland	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Italy	0.55	1.74	20.50	80.43	103.22	0.04	103.26
Latvia	0.00	0.00	0.01	0.02	0.03	0.00	0.03
Lithuania	0.00	0.00	0.01	0.03	0.04	0.00	0.04
Luxembourg	0.05	0.16	1.87	7.33	9.41	0.00	9.41
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Netherlands	0.15	0.46	5.38	21.12	27.11	0.01	27.12
Poland	0.24	0.76	9.00	35.30	45.31	0.02	45.33
Portugal	0.03	0.09	1.10	4.31	5.54	0.00	5.54
Romania	0.18	0.56	6.56	25.75	33.05	0.01	33.06
Slovakia	0.14	0.43	5.06	19.85	25.48	0.01	25.49
Slovenia	0.02	0.07	0.88	3.46	4.45	0.00	4.45
Spain	0.30	0.94	11.02	43.22	55.47	0.02	55.49
Sweden	0.14	0.45	5.33	20.91	26.83	0.01	26.84
EU27	3.78	11.91	140.33	550.42	706.44	0.28	706.72
Norway	0.07	0.23	2.70	10.59	13.59	0.01	13.59
Serbia	0.01	0.04	0.45	1.76	2.26	0.00	2.26
Switzerland	0.03	0.10	1.23	4.82	6.19	0.00	6.19
United Kingdom	0.13	0.41	4.80	18.81	24.14	0.01	24.15

2019	**Chemical and petrochemical**						
PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)	Total heat demand
Austria	4.71	7.32	15.63	3.85	31.50	0.05	31.55
Belgium	16.97	26.39	56.36	13.88	113.60	0.17	113.77
Bulgaria	3.35	5.21	11.13	2.74	22.43	0.03	22.47
Croatia	0.64	1.00	2.13	0.52	4.29	0.01	4.30
Cyprus	0.03	0.05	0.11	0.03	0.21	0.00	0.21
Czech Republic	4.44	6.91	14.75	3.63	29.73	0.04	29.77
Denmark	1.14	1.78	3.80	0.94	7.66	0.01	7.67
Estonia	0.15	0.23	0.49	0.12	0.99	0.00	0.99
Finland	4.17	6.49	13.86	3.41	27.94	0.04	27.98

France	27.74	43.13	92.11	22.69	185.66	0.28	185.94
Germany	57.64	89.63	191.40	47.15	385.82	0.58	386.40
Greece	0.38	0.59	1.26	0.31	2.53	0.00	2.53
Hungary	4.81	7.48	15.98	3.94	32.21	0.05	32.26
Ireland	1.10	1.72	3.67	0.90	7.39	0.01	7.41
Italy	13.07	20.32	43.40	10.69	87.49	0.13	87.62
Latvia	0.09	0.14	0.30	0.07	0.60	0.00	0.60
Lithuania	1.77	2.76	5.89	1.45	11.88	0.02	11.90
Luxembourg	0.12	0.19	0.41	0.10	0.83	0.00	0.83
Malta	0.02	0.03	0.06	0.01	0.12	0.00	0.12
Netherlands	30.10	46.81	99.97	24.63	201.51	0.30	201.81
Poland	13.36	20.77	44.36	10.93	89.42	0.13	89.55
Portugal	1.99	3.09	6.60	1.63	13.30	0.02	13.32
Romania	6.28	9.77	20.86	5.14	42.04	0.06	42.11
Slovakia	1.94	3.02	6.45	1.59	12.99	0.02	13.01
Slovenia	0.65	1.02	2.17	0.54	4.38	0.01	4.39
Spain	15.28	23.75	50.73	12.50	102.25	0.15	102.41
Sweden	2.17	3.37	7.20	1.77	14.51	0.02	14.53
EU27	214.13	332.96	711.05	175.16	1433.30	2.15	1435.45
Norway	2.73	4.24	9.05	2.23	18.24	0.03	18.27
Serbia	0.46	0.72	1.53	0.38	3.09	0.00	3.09
Switzerland	3.07	4.78	10.21	2.51	20.58	0.03	20.61
United Kingdom	14.00	21.77	46.48	11.45	93.70	0.14	93.84

2019	**Non-ferrous metals**						
PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)	Total heat demand
Austria	0.03	0.10	1.20	4.71	6.04	0.01	6.05
Belgium	0.04	0.14	1.65	6.46	8.30	0.02	8.31
Bulgaria	0.03	0.10	1.17	4.57	5.87	0.01	5.88
Croatia	0.00	0.01	0.11	0.44	0.56	0.00	0.56
Cyprus	0.00	0.00	0.00	0.02	0.02	0.00	0.02

Czech Republic	0.01	0.04	0.50	1.95	2.50	0.01	2.50
Denmark	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Estonia	0.00	0.00	0.00	0.01	0.02	0.00	0.02
Finland	0.04	0.12	1.37	5.38	6.90	0.02	6.92
France	0.16	0.49	5.76	22.60	29.01	0.06	29.08
Germany	0.33	1.05	12.42	48.72	62.53	0.14	62.67
Greece	0.09	0.29	3.47	13.62	17.48	0.04	17.52
Hungary	0.02	0.05	0.64	2.52	3.23	0.01	3.24
Ireland	0.07	0.22	2.64	10.35	13.28	0.03	13.31
Italy	0.10	0.31	3.65	14.32	18.38	0.04	18.42
Latvia	0.00	0.00	0.01	0.02	0.03	0.00	0.03
Lithuania	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Luxembourg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Netherlands	0.04	0.14	1.67	6.54	8.39	0.02	8.41
Poland	0.08	0.26	3.02	11.83	15.19	0.03	15.22
Portugal	0.00	0.01	0.15	0.59	0.75	0.00	0.76
Romania	0.06	0.20	2.33	9.14	11.73	0.03	11.76
Slovakia	0.04	0.12	1.45	5.68	7.29	0.02	7.31
Slovenia	0.02	0.07	0.78	3.07	3.94	0.01	3.95
Spain	0.18	0.58	6.86	26.92	34.55	0.08	34.63
Sweden	0.05	0.15	1.75	6.88	8.83	0.02	8.85
EU27	1.42	4.47	52.61	206.35	264.84	0.59	265.43
Norway	0.27	0.84	9.86	38.66	49.62	0.11	49.73
Serbia	0.01	0.02	0.21	0.83	1.06	0.00	1.06
Switzerland	0.01	0.03	0.32	1.25	1.61	0.00	1.61
United Kingdom	0.09	0.28	3.27	12.81	16.44	0.04	16.48

2019	**Mining and quarrying**						
PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)	Total heat demand

Austria	3.14	2.61	0.00	0.00	5.75	0.04	5.79
Belgium	0.60	0.50	0.00	0.00	1.10	0.01	1.11
Bulgaria	1.19	0.99	0.00	0.00	2.18	0.02	2.20
Croatia	0.06	0.05	0.00	0.00	0.11	0.00	0.11
Cyprus	0.11	0.09	0.00	0.00	0.20	0.00	0.20
Czech Republic	0.93	0.77	0.00	0.00	1.70	0.01	1.72
Denmark	0.87	0.72	0.00	0.00	1.59	0.01	1.60
Estonia	0.09	0.07	0.00	0.00	0.16	0.00	0.16
Finland	1.88	1.56	0.00	0.00	3.44	0.02	3.47
France	4.51	3.76	0.00	0.00	8.27	0.06	8.33
Germany	3.92	3.27	0.00	0.00	7.19	0.05	7.24
Greece	1.01	0.84	0.00	0.00	1.85	0.01	1.86
Hungary	0.40	0.33	0.00	0.00	0.73	0.01	0.74
Ireland	0.55	0.46	0.00	0.00	1.02	0.01	1.02
Italy	1.40	1.17	0.00	0.00	2.57	0.02	2.59
Latvia	0.12	0.10	0.00	0.00	0.22	0.00	0.22
Lithuania	0.08	0.06	0.00	0.00	0.14	0.00	0.14
Luxembourg	0.01	0.01	0.00	0.00	0.02	0.00	0.02
Malta	0.02	0.01	0.00	0.00	0.03	0.00	0.03
Netherlands	1.26	1.05	0.00	0.00	2.31	0.02	2.33
Poland	5.14	4.29	0.00	0.00	9.43	0.07	9.50
Portugal	0.86	0.71	0.00	0.00	1.57	0.01	1.58
Romania	0.42	0.35	0.00	0.00	0.77	0.01	0.78
Slovakia	0.67	0.55	0.00	0.00	1.22	0.01	1.23
Slovenia	0.21	0.18	0.00	0.00	0.39	0.00	0.39
Spain	5.42	4.51	0.00	0.00	9.93	0.07	10.00
Sweden	6.05	5.04	0.00	0.00	11.09	0.08	11.17
EU27	40.91	34.08	0.00	0.00	74.99	0.54	75.54
Norway	0.40	0.33	0.00	0.00	0.73	0.01	0.73
Serbia	0.44	0.37	0.00	0.00	0.80	0.01	0.81
Switzerland	0.00	0.00	0.00	0.00	0.00	0.00	0.00
United Kingdom	0.11	0.09	0.00	0.00	0.20	0.00	0.21

2019	**Food, beverages and tobacco**

PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)	Total heat demand
Austria	4.56	4.56	4.56	4.56	18.23	0.51	18.74
Belgium	14.45	14.45	14.45	14.45	57.81	1.62	59.43
Bulgaria	2.13	2.13	2.13	2.13	8.53	0.24	8.76
Croatia	1.73	1.73	1.73	1.73	6.91	0.19	7.10
Cyprus	0.37	0.37	0.37	0.37	1.47	0.04	1.52
Czech Republic	4.92	4.92	4.92	4.92	19.68	0.55	20.23
Denmark	5.21	5.21	5.21	5.21	20.85	0.58	21.44
Estonia	0.58	0.58	0.58	0.58	2.31	0.06	2.38
Finland	3.59	3.59	3.59	3.59	14.37	0.40	14.77
France	45.21	45.21	45.21	45.21	180.85	5.07	185.92
Germany	44.97	44.97	44.97	44.97	179.87	5.04	184.91
Greece	4.02	4.02	4.02	4.02	16.08	0.45	16.53
Hungary	5.86	5.86	5.86	5.86	23.43	0.66	24.09
Ireland	4.57	4.57	4.57	4.57	18.27	0.51	18.79
Italy	24.58	24.58	24.58	24.58	98.34	2.76	101.09
Latvia	0.69	0.69	0.69	0.69	2.76	0.08	2.83
Lithuania	1.59	1.59	1.59	1.59	6.36	0.18	6.54
Luxembourg	0.15	0.15	0.15	0.15	0.59	0.02	0.60
Malta	0.06	0.06	0.06	0.06	0.23	0.01	0.23
Netherlands	17.65	17.65	17.65	17.65	70.59	1.98	72.57
Poland	19.60	19.60	19.60	19.60	78.39	2.20	80.59
Portugal	4.10	4.10	4.10	4.10	16.42	0.46	16.88
Romania	5.07	5.07	5.07	5.07	20.30	0.57	20.87
Slovakia	1.39	1.39	1.39	1.39	5.54	0.16	5.70
Slovenia	0.60	0.60	0.60	0.60	2.40	0.07	2.47
Spain	20.88	20.88	20.88	20.88	83.52	2.34	85.87
Sweden	3.08	3.08	3.08	3.08	12.33	0.35	12.67
EU27	241.61	241.61	241.61	241.61	966.43	27.10	993.53
Norway	2.25	2.25	2.25	2.25	8.99	0.25	9.24
Serbia	1.23	1.23	1.23	1.23	4.93	0.14	5.07

Switzerland	4.52	4.52	4.52	4.52	18.10	0.51	18.60
United Kingdom	24.44	24.44	24.44	24.44	97.76	2.74	100.50

2019	**Textile and leather**						
PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)	Total heat demand
Austria	0.64	0.00	0.00	0.00	0.64	0.23	0.87
Belgium	1.70	0.00	0.00	0.00	1.70	0.62	2.31
Bulgaria	0.61	0.00	0.00	0.00	0.61	0.22	0.84
Croatia	0.24	0.00	0.00	0.00	0.24	0.09	0.33
Cyprus	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Czech Republic	1.23	0.00	0.00	0.00	1.23	0.45	1.67
Denmark	0.17	0.00	0.00	0.00	0.17	0.06	0.23
Estonia	0.09	0.00	0.00	0.00	0.09	0.03	0.12
Finland	0.18	0.00	0.00	0.00	0.18	0.07	0.25
France	2.90	0.00	0.00	0.00	2.90	1.05	3.95
Germany	4.13	0.00	0.00	0.00	4.13	1.50	5.64
Greece	0.86	0.00	0.00	0.00	0.86	0.31	1.18
Hungary	0.40	0.00	0.00	0.00	0.40	0.15	0.55
Ireland	0.29	0.00	0.00	0.00	0.29	0.11	0.40
Italy	11.17	0.00	0.00	0.00	11.17	4.06	15.23
Latvia	0.07	0.00	0.00	0.00	0.07	0.03	0.10
Lithuania	0.31	0.00	0.00	0.00	0.31	0.11	0.43
Luxembourg	0.32	0.00	0.00	0.00	0.32	0.12	0.43
Malta	0.03	0.00	0.00	0.00	0.03	0.01	0.04
Netherlands	0.96	0.00	0.00	0.00	0.96	0.35	1.31
Poland	1.24	0.00	0.00	0.00	1.24	0.45	1.69
Portugal	3.04	0.00	0.00	0.00	3.04	1.11	4.15
Romania	1.70	0.00	0.00	0.00	1.70	0.62	2.32
Slovakia	0.23	0.00	0.00	0.00	0.23	0.08	0.31
Slovenia	0.15	0.00	0.00	0.00	0.15	0.06	0.21

Spain	3.80	0.00	0.00	0.00	3.80	1.38	5.18
Sweden	0.21	0.00	0.00	0.00	0.21	0.08	0.28
EU27	36.67	0.00	0.00	0.00	36.67	13.34	50.02
Norway	0.06	0.00	0.00	0.00	0.06	0.02	0.08
Serbia	0.32	0.00	0.00	0.00	0.32	0.12	0.44
Switzerland	0.62	0.00	0.00	0.00	0.62	0.23	0.84
United Kingdom	5.22	0.00	0.00	0.00	5.22	1.90	7.13

2019	**Paper, pulp and print**						
PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)	Total heat demand
Austria	7.37	35.50	0.00	0.00	42.87	0.24	43.11
Belgium	2.60	12.53	0.00	0.00	15.13	0.08	15.22
Bulgaria	0.84	4.03	0.00	0.00	4.87	0.03	4.90
Croatia	0.29	1.39	0.00	0.00	1.68	0.01	1.69
Cyprus	0.01	0.05	0.00	0.00	0.06	0.00	0.06
Czech Republic	2.71	13.04	0.00	0.00	15.74	0.09	15.83
Denmark	0.23	1.09	0.00	0.00	1.32	0.01	1.32
Estonia	0.25	1.20	0.00	0.00	1.45	0.01	1.46
Finland	26.23	126.38	0.00	0.00	152.62	0.84	153.46
France	9.28	44.71	0.00	0.00	53.99	0.30	54.29
Germany	21.44	103.29	0.00	0.00	124.73	0.69	125.42
Greece	0.31	1.48	0.00	0.00	1.79	0.01	1.80
Hungary	0.98	4.72	0.00	0.00	5.70	0.03	5.73
Ireland	0.07	0.32	0.00	0.00	0.38	0.00	0.39
Italy	8.25	39.74	0.00	0.00	47.99	0.27	48.25
Latvia	0.02	0.10	0.00	0.00	0.12	0.00	0.12
Lithuania	0.21	1.02	0.00	0.00	1.24	0.01	1.24
Luxembourg	0.01	0.05	0.00	0.00	0.06	0.00	0.06
Malta	0.01	0.05	0.00	0.00	0.06	0.00	0.06
Netherlands	2.12	10.21	0.00	0.00	12.33	0.07	12.39

Poland	7.55	36.39	0.00	0.00	43.95	0.24	44.19
Portugal	5.57	26.85	0.00	0.00	32.42	0.18	32.60
Romania	0.64	3.10	0.00	0.00	3.74	0.02	3.76
Slovakia	2.04	9.81	0.00	0.00	11.85	0.07	11.92
Slovenia	0.69	3.33	0.00	0.00	4.03	0.02	4.05
Spain	6.82	32.85	0.00	0.00	39.67	0.22	39.89
Sweden	22.68	109.26	0.00	0.00	131.94	0.73	132.67
EU27	129.20	622.50	0.00	0.00	751.70	4.16	755.86
Norway	1.35	6.49	0.00	0.00	7.84	0.04	7.88
Serbia	0.17	0.84	0.00	0.00	1.01	0.01	1.02
Switzerland	1.96	9.42	0.00	0.00	11.38	0.06	11.44
United Kingdom	6.90	33.26	0.00	0.00	40.16	0.22	40.38

2019	**Transport equipment**						
PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)	Total heat demand
Austria	0.21	0.16	0.08	0.21	0.65	0.61	1.26
Belgium	0.22	0.17	0.08	0.23	0.69	0.64	1.33
Bulgaria	0.03	0.02	0.01	0.03	0.09	0.09	0.18
Croatia	0.02	0.01	0.01	0.02	0.05	0.05	0.09
Cyprus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Czech Republic	0.92	0.69	0.33	0.95	2.89	2.67	5.56
Denmark	0.02	0.02	0.01	0.03	0.08	0.07	0.15
Estonia	0.01	0.01	0.01	0.02	0.05	0.04	0.09
Finland	0.11	0.08	0.04	0.11	0.34	0.31	0.65
France	1.78	1.35	0.65	1.84	5.61	5.19	10.80
Germany	5.10	3.86	1.85	5.26	16.07	14.88	30.95
Greece	0.01	0.01	0.00	0.01	0.04	0.04	0.08
Hungary	0.42	0.32	0.15	0.43	1.31	1.22	2.53
Ireland	0.01	0.01	0.00	0.01	0.02	0.02	0.04
Italy	0.72	0.54	0.26	0.74	2.26	2.09	4.36

Latvia	0.01	0.01	0.00	0.01	0.03	0.03	0.06
Lithuania	0.01	0.01	0.00	0.01	0.02	0.02	0.05
Luxembourg	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Malta	0.00	0.00	0.00	0.00	0.01	0.01	0.02
Netherlands	0.20	0.15	0.07	0.21	0.63	0.58	1.21
Poland	0.87	0.66	0.32	0.90	2.75	2.55	5.30
Portugal	0.15	0.11	0.05	0.15	0.46	0.43	0.89
Romania	0.52	0.39	0.19	0.53	1.63	1.51	3.14
Slovakia	0.32	0.24	0.12	0.33	1.01	0.93	1.94
Slovenia	0.07	0.05	0.02	0.07	0.21	0.19	0.40
Spain	1.14	0.86	0.41	1.18	3.60	3.33	6.93
Sweden	0.35	0.27	0.13	0.37	1.12	1.04	2.15
EU27	13.21	10.01	4.79	13.63	41.64	38.54	80.18
Norway	0.06	0.05	0.02	0.06	0.19	0.18	0.37
Serbia	0.04	0.03	0.01	0.04	0.12	0.11	0.24
Switzerland	0.00	0.00	0.00	0.00	0.00	0.00	0.00
United Kingdom	1.93	1.47	0.70	2.00	6.10	5.64	11.74

2019	**Machinery**						
PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)	Total heat demand
Austria	0.66	0.51	0.26	0.68	2.11	3.38	5.49
Belgium	0.35	0.27	0.14	0.36	1.12	1.79	2.92
Bulgaria	0.17	0.13	0.07	0.18	0.56	0.89	1.44
Croatia	0.08	0.06	0.03	0.08	0.26	0.42	0.68
Cyprus	0.00	0.00	0.00	0.00	0.01	0.02	0.03
Czech Republic	0.88	0.68	0.35	0.91	2.82	4.50	7.32
Denmark	0.26	0.20	0.10	0.27	0.82	1.32	2.14
Estonia	0.04	0.03	0.02	0.04	0.13	0.20	0.33
Finland	0.42	0.32	0.17	0.43	1.33	2.13	3.46
France	2.36	1.81	0.94	2.44	7.54	12.05	19.59

Germany	6.57	5.04	2.63	6.79	21.02	33.58	54.60
Greece	0.11	0.09	0.04	0.12	0.36	0.57	0.93
Hungary	0.58	0.44	0.23	0.60	1.84	2.95	4.79
Ireland	0.17	0.13	0.07	0.18	0.56	0.89	1.45
Italy	4.49	3.45	1.80	4.64	14.38	22.97	37.35
Latvia	0.02	0.02	0.01	0.02	0.06	0.10	0.17
Lithuania	0.05	0.04	0.02	0.05	0.16	0.25	0.41
Luxembourg	0.01	0.01	0.00	0.01	0.03	0.05	0.07
Malta	0.01	0.01	0.01	0.01	0.04	0.07	0.11
Netherlands	0.68	0.52	0.27	0.70	2.17	3.47	5.65
Poland	0.97	0.75	0.39	1.01	3.12	4.98	8.10
Portugal	0.20	0.15	0.08	0.20	0.63	1.01	1.64
Romania	0.55	0.42	0.22	0.57	1.76	2.82	4.58
Slovakia	0.31	0.24	0.13	0.32	1.00	1.60	2.60
Slovenia	0.24	0.18	0.10	0.25	0.76	1.22	1.98
Spain	1.06	0.81	0.42	1.09	3.39	5.42	8.81
Sweden	0.41	0.32	0.17	0.43	1.32	2.11	3.43
EU27	21.66	16.61	8.67	22.39	69.32	110.75	180.07
Norway	0.12	0.09	0.05	0.12	0.37	0.60	0.97
Serbia	0.07	0.06	0.03	0.07	0.23	0.37	0.60
Switzerland	0.82	0.63	0.33	0.84	2.61	4.17	6.78
United Kingdom	2.81	2.15	1.12	2.90	8.99	14.36	23.35

2019	**Wood and wood products**						
PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)	Total heat demand
Austria	6.40	1.63	0.00	0.00	8.04	0.63	8.67
Belgium	2.68	0.68	0.00	0.00	3.36	0.26	3.62
Bulgaria	0.82	0.21	0.00	0.00	1.03	0.08	1.11
Croatia	1.06	0.27	0.00	0.00	1.33	0.10	1.43
Cyprus	0.01	0.00	0.00	0.00	0.01	0.00	0.01

Czech Republic	2.46	0.63	0.00	0.00	3.09	0.24	3.34
Denmark	1.51	0.39	0.00	0.00	1.90	0.15	2.05
Estonia	0.86	0.22	0.00	0.00	1.08	0.08	1.16
Finland	6.24	1.59	0.00	0.00	7.84	0.62	8.45
France	7.23	1.85	0.00	0.00	9.07	0.71	9.79
Germany	20.33	5.19	0.00	0.00	25.53	2.01	27.54
Greece	0.35	0.09	0.00	0.00	0.44	0.03	0.48
Hungary	1.44	0.37	0.00	0.00	1.81	0.14	1.95
Ireland	1.81	0.46	0.00	0.00	2.28	0.18	2.46
Italy	5.70	1.46	0.00	0.00	7.16	0.56	7.72
Latvia	5.75	1.47	0.00	0.00	7.21	0.57	7.78
Lithuania	1.05	0.27	0.00	0.00	1.31	0.10	1.42
Luxembourg	0.05	0.01	0.00	0.00	0.06	0.00	0.06
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Netherlands	0.67	0.17	0.00	0.00	0.85	0.07	0.91
Poland	13.40	3.42	0.00	0.00	16.83	1.32	18.15
Portugal	1.73	0.44	0.00	0.00	2.17	0.17	2.34
Romania	3.79	0.97	0.00	0.00	4.76	0.38	5.14
Slovakia	0.59	0.15	0.00	0.00	0.74	0.06	0.80
Slovenia	0.60	0.15	0.00	0.00	0.75	0.06	0.81
Spain	7.03	1.79	0.00	0.00	8.82	0.69	9.52
Sweden	6.74	1.72	0.00	0.00	8.46	0.67	9.13
EU27	100.31	25.61	0.00	0.00	125.92	9.91	135.83
Norway	0.62	0.16	0.00	0.00	0.78	0.06	0.84
Serbia	0.13	0.03	0.00	0.00	0.17	0.01	0.18
Switzerland	0.00	0.00	0.00	0.00	0.00	0.00	0.00
United Kingdom	0.94	0.24	0.00	0.00	1.18	0.09	1.27

2019	**Construction**

PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)	Total heat demand
Austria	0.36	1.23	0.82	1.79	4.20	0.48	4.68
Belgium	0.25	0.85	0.57	1.24	2.91	0.33	3.24
Bulgaria	0.09	0.31	0.21	0.45	1.05	0.12	1.17
Croatia	0.13	0.45	0.30	0.65	1.52	0.17	1.69
Cyprus	0.01	0.05	0.03	0.07	0.16	0.02	0.18
Czech Republic	0.21	0.72	0.48	1.05	2.46	0.28	2.73
Denmark	0.20	0.67	0.45	0.98	2.31	0.26	2.57
Estonia	0.06	0.20	0.13	0.29	0.69	0.08	0.77
Finland	0.48	1.64	1.09	2.39	5.61	0.64	6.24
France	1.83	6.26	4.17	9.13	21.39	2.42	23.81
Germany	2.98	10.23	6.82	14.92	34.96	3.96	38.92
Greece	0.16	0.55	0.37	0.80	1.88	0.21	2.10
Hungary	0.35	1.19	0.80	1.74	4.08	0.46	4.54
Ireland	0.12	0.40	0.27	0.59	1.38	0.16	1.54
Italy	0.51	1.75	1.16	2.55	5.97	0.68	6.64
Latvia	0.03	0.11	0.07	0.16	0.37	0.04	0.41
Lithuania	0.05	0.17	0.12	0.25	0.60	0.07	0.66
Luxembourg	0.03	0.09	0.06	0.13	0.31	0.03	0.34
Malta	0.00	0.01	0.01	0.02	0.05	0.01	0.05
Netherlands	0.84	2.88	1.92	4.19	9.82	1.11	10.94
Poland	0.23	0.80	0.53	1.16	2.72	0.31	3.03
Portugal	0.17	0.59	0.40	0.87	2.03	0.23	2.26
Romania	0.45	1.55	1.03	2.26	5.29	0.60	5.89
Slovakia	0.03	0.10	0.07	0.14	0.34	0.04	0.37
Slovenia	0.05	0.16	0.11	0.23	0.54	0.06	0.61
Spain	1.67	5.72	3.82	8.35	19.55	2.21	21.77
Sweden	0.40	1.36	0.91	1.98	4.64	0.53	5.17
EU27	11.68	40.04	26.70	58.40	136.82	15.50	152.32
Norway	0.14	0.49	0.33	0.71	1.67	0.19	1.86
Serbia	0.03	0.12	0.08	0.17	0.41	0.05	0.45

Switzerland	0.27	0.92	0.62	1.35	3.16	0.36	3.51
United Kingdom	0.85	2.91	1.94	4.24	9.94	1.13	11.06

2019	**Other industry**						
PJ/a	PH <100°C	PH 100-500°C	PH 500-1000°C	PH>1000°C	Total process heat demand	SH and HW (<100°C)	Total heat demand
Austria	0.23	0.78	0.50	1.04	2.55	0.25	2.80
Belgium	0.47	1.54	0.99	2.05	5.04	0.49	5.54
Bulgaria	0.11	0.35	0.23	0.47	1.16	0.11	1.28
Croatia	0.07	0.23	0.15	0.31	0.76	0.07	0.83
Cyprus	0.01	0.02	0.01	0.03	0.06	0.01	0.07
Czech Republic	0.48	1.57	1.01	2.10	5.16	0.51	5.66
Denmark	0.15	0.51	0.33	0.68	1.68	0.16	1.84
Estonia	0.03	0.09	0.06	0.12	0.30	0.03	0.33
Finland	0.22	0.73	0.47	0.98	2.40	0.24	2.64
France	1.71	5.66	3.64	7.57	18.58	1.82	20.40
Germany	3.44	11.37	7.31	15.19	37.31	3.66	40.97
Greece	0.15	0.50	0.32	0.67	1.64	0.16	1.80
Hungary	0.40	1.33	0.86	1.78	4.38	0.43	4.81
Ireland	0.17	0.57	0.37	0.77	1.89	0.18	2.07
Italy	2.20	7.28	4.68	9.73	23.90	2.34	26.24
Latvia	0.04	0.13	0.08	0.17	0.42	0.04	0.46
Lithuania	0.11	0.36	0.23	0.48	1.19	0.12	1.31
Luxembourg	0.04	0.13	0.09	0.18	0.44	0.04	0.48
Malta	0.03	0.09	0.06	0.12	0.30	0.03	0.33
Netherlands	0.47	1.54	0.99	2.06	5.07	0.50	5.56
Poland	1.09	3.59	2.31	4.80	11.78	1.15	12.93
Portugal	0.09	0.31	0.20	0.41	1.01	0.10	1.11
Romania	0.19	0.63	0.40	0.84	2.06	0.20	2.26
Slovakia	0.21	0.69	0.44	0.92	2.27	0.22	2.49
Slovenia	0.10	0.32	0.20	0.42	1.04	0.10	1.14

Spain	0.72	2.37	1.53	3.17	7.79	0.76	8.55
Sweden	1.08	3.57	2.29	4.77	11.70	1.15	12.85
EU27	14.01	46.27	29.74	61.84	151.87	14.89	166.76
Norway	0.05	0.16	0.10	0.22	0.53	0.05	0.58
Serbia	0.08	0.25	0.16	0.34	0.84	0.08	0.92
Switzerland	0.00	0.00	0.00	0.00	0.00	0.00	0.00
United Kingdom	6.39	21.12	13.57	28.22	69.31	6.80	76.10

Appendix C: Mapping database

Operating BF/BOF Plants in the EU and the UK

Site ID	Company name	Site name	Address	Postal code	City	Country
1	voestalpine AG	voestalpine Stahl Donawitz GmbH	Kerpelystraße 199, 8700 Leoben, Austria	8700	Leoben	Austria
2	voestalpine AG	voestalpine Stahl Linz GmbH	voestalpine-Straße 3, 4020 Linz, Austria	4020	Linz	Austria
3	ArcelorMittal	ArcelorMittal Ghent	John Kennedylaan 51, B-9042 Gent, Belgium	9042	Ghent	Belgium
4	Liberty Ostrava a.s.	Liberty Ostrava a.s.	Vratimovska 689/117	71900	Ostrava	Czech Republic
5	TZ-MS group	Třinec Iron and Steel Works	Průmyslová 1000	73961	Trinec - Staré Město	Czech Republic
6	SSAB	SSAB Raahe	Rautaruukintie 155	92100	Raahe	Finland

7	ArcelorMittal	ArcelorMittal Dunkerque	Rue du Comte Jean, Grande Synthe 2508	59381	Dunkerque	France
8	ArcelorMittal	ArcelorMittal Méditerranée - Fos sur Mer	Zone Industrielle, Aile 22	13776	Fos sur Mer	France
9	ArcelorMittal	ArcelorMittal Bremen GmbH	Carl-Benz-Strasse 30, Bremer Industrie-Park	28237	Bremen	Germany
10	AG der Dillinger Hüttenwerke	AG der Dillinger Hüttenwerke	Werkstraße 1, Dillingen	66763	Dillingen	Germany
11	Thyssenkrupp Steel Europe AG	ThyssenKrupp Steel Europe AG Werk Schwelgern	Oxygenstahlwerk Buerogebaude, 100, Kaiser-Wilhelm-Straße, Bruckhausen	47166	Duisburg	Germany
12	ArcelorMittal	ArcelorMittal Eisenhüttenstadt GmbH	ArcelorMittal, Eisenhuttenstadt, Oder-Spree	15890	Eisenhüttenstadt	Germany
13	Salzgitter Flachstahl GmbH Abt. Umweltschutz / 08 TUI	Salzgitter Flachstahl GmbH	Salzgitter Flachstahl GmbH Weiterbildungszentrum "Waldhaus", 99, Eisenhuttenstraße	38239	Salzgitter	Germany
14	Saarstahl AG	Saarstahl AG - Werk Völklingen	Bismarckstrasse 57-59	66333	Völklingen	Germany
15	ISD Dunaferr	ISD Dunaferr	ISD-Dunaferr, Eszperanto ut, Baratsag varosresz, Dunaujvaros, Dunaujvarosi jaras	2400	Dunauijvaros	Hungary
16	ILVA S.P.A.	ILVA S.P.A. Stabilimento di Taranto	S.S. Appia Km. 648 SNC	74123	Taranto	Italy
17	Tata Steel Group	Tata Steel IJmuiden BV	Wenckebachstraat 1	1951	Velsen-Noord	Netherlands
18	ArcelorMittal	ArcelorMittal Poland S.A. Oddział Kraków	Ujastek 1	31752	Krakow	Poland
19	ArcelorMittal	ArcelorMittal Poland S.A. Oddział Dąbrowa Górnicza	J. Piłsudskiego 92	41308	Dąbrowa Górnicza	Poland
20	ArcelorMittal	SC ARCELORMITTAL GALATI SA	Smardan nr.1	800698	Galati	Romania
21	U.S.Steel s.r.o.	U.S.Steel s.r.o.	Vstupný areál U. S. Steel	4454	Kosice	Slovakia
22	ArcelorMittal	ArcelorMittal Gijón	Veriña de Abajo 570	33200	Aviles y Gijon (Asturias)	Spain
23	SSAB	SSAB Öxelösund AB	SSAB	61380	Öxelösund	Sweden
24	SSAB	SSAB Luleå	Svartövägen 1	97188	Luleå	Sweden
25	Tata Steel Group	Port Talbot Steel Works	Abbey Works, Margam --	SA13 2NG	Port Talbot	United Kingdom
26	Tata Steel Europe Limited	Scunthorpe Integrated Iron And Steel Works	Brigg Road, Scunthorpe, North Lincolnshire, DN16 1BP	DN16 1XJ	Scunthorpe	United Kingdom

Continuation: Operating BF/BOF Plants in the EU and the UK

Site ID	Latitude	Longitude	Hot metal capacity (thousand tonnes/year)	Finished Steel Capacity (thousand tonnes/year)	No. Of furnaces	tonne CO_2/tonne of steel produced
1	47.03378	15.067806	1370	1570	2	4308147.38
2	48.281944	14.343056	4340	6000	3	13342930.7
3	51.176716	3.8143601	4430	5000	2	15439098.2
4	49.81623067	18.25685166	3200		3	6553840
5	49.68810552	18.64728154	2100	2400	2	544119.389
6	64.65408	24.40966	2400	2600	2	8074405.54
7	43.45	4.9	6800	6750	3	10744000
8	51.03	2.36	5160	5100	2	26501737.5
9	53.12493044	8.68672853	3960	3800	2	9312940.15
10	49.35717217	6.754136982	4790	2760	2	3099351.57
11	51.5036903	6.735907484	11600	11560	4	29923165.3
12	52.16614052	14.61768224	2340	2400	2	5774191.91
13	52.15476492	10.40307531	4800	5200	3	187979.868
14	49.25200518	6.84706277	-	3240	BOF only	350254.1
15	46.943314	18.940529	1310	1650	2	2487834.77
16	40.516667	17.2	9590	11500	4	38455237.6
17	52.47656	4.59217	6310	7500	2	87622845.6
18	50.080333	20.092361	1310	2600	1	37322357.4
19	50.343379	19.281864	4500	5000	2	111691956
20	45.437667	27.977934	3250	3200	2	4834800
21	48.617783	21.198325	2850	4500	2	2954600
22	43.55611	-5.91113	4480	5400	2	14452738.3
23	58.67690172	17.12562022	1800	1700	2	18596479.2
24	65.56349277	22.20601065	2200	1700	1	14353830.3
25	51.5679	-3.75946	4770	4900	2	3676914.87
26	53.5813	-0.620035	3590	3200	3	3087058.51

Operating EAF Plants in the EU and the UK

Site ID	Company name	Site name	Address	Postal code	City	Country
27	Stahl- und Walzwerk Marienhütte Gesellschaft m.b.H.	Stahlwerk Marienhütte GmbH	Südbahnstrasse 21	8021	Graz	Austria

28	Böhler Edelstahl GmbH & Co KG	Stahlproduktion Böhler Edelstahl Kapfenberg	Mariazellerstrasse 25	8605	Kapfenberg	Austria
29	Breitenfeld Edelstahl AG	Breitenfelder Edelstahl Mitterdorf	Breitenfeld Strasse 22	8662	Mitterdorf	Austria
30	INDUSTEEL BELGIUM S.A.	INDUSTEEL BELGIUM S.A.	RUE DE CHATELET 266	6030	Charleroi	Belgium
31	THY-MARCINELLE	THY MARCINELLE sa	RUE DE L'ACIER 1	6000	Charleroi	Belgium
32	Aperam Stainless Belgium SA	APERAM STAINLESS BELGIUM SA	RUE DES ATELIERS 14	6200	Chatelet	Belgium
33	APERAM STAINLESS BELGIUM	APERAM STAINLESS BELGIUM	Swinnenwijerweg,INDUSTRIEZONE GENK-ZUID: ZONE 6A, 3600 GENK 5	3600	Genk	Belgium
35	Stomana-Indastri	Stomana Indastri AD	Vladaysko vastanie 1	2304	Pernik	Bulgaria
36	ABS SISAK	ABS Sisak doo	Braće Kavurić 12	44010	Sisak	Croatia
37	VÍTKOVICE STEEL, a.s.	VÍTKOVICE STEEL, a.s.	Å tramberskÃ¡ 2871/47	70900	Ostrava - Hulváky	Czech Republic
38	PILSEN STEEL s.r.o.	PILSEN STEEL - Elektrická oblouková pec	Tylova 1/57	31600	Plzeň	Czech Republic
39	Ovako Imatra Oy Ab	Imatran terÃ¤stehdas	Terästehtaantie 1	55100	Imatra	Finland
40	Outokumpu Chrome Oy, Outokumpu Stainless Oy, Tornion tehtaat	Outokumpu Chrome Oy, Outokumpu Stainless Oy, Tornion tehtaat	Terästie 1	95400	Tornio	Finland
41	ITON SEINE	ITON-SEINE	Quai de Seine	78270	Bonnières-sur-Seine	France
42	CELSA FRANCE	CELSA FRANCE (Aciérie de l'Atlantique)	Rue Maurice Perse	64340	Boucau	France
43	ArcelorMittal	Industeel France - Châteauneuf	Rive de Gier BP 68/	42800	Châteauneuf	France
44	ASCOMETAL	ASCO INDUSTRIES - Usine de Fos-sur-Mer	Route de Port-Saint-Louis-du-Rhône	13270	Fos-sur-Mer Cedex	France
45	RIVA GROUP	ALPA Gargenville	Immeuble ALPA, ZI Limay Porcheville	78440	Gargenville	France
46	ASCOMETAL	ASCO INDUSTRIES - Usine d' Hagondange	Avenue de France BP 90038/	57301	Hagondange Cedex	France
47	APREAM	APERAM ALLOYS IMPHY	Avenue Jean Jaures BP 1/	58160	Imphy	France
48	ArcelotMittal	INDUSTEEL FRANCE - CREUSOT	56 Rue Clemenceau	71200	Le Creusot	France
49	RIVA GROUP	SAM Montereau	36, rue de la Grande Haie	77130	Montereau	France
50	RIVA GROUP	SAM Neuves Maisons	1 rue Victor de Lespinats BP 1	54230	Neuves Maisons	France

51	Saarstahl Ascoval	Vallourec Tuberie De Saint-Saulve Ascoval	ZI N°4 – Rue du Galibot	59880	St Saulve	France
52	LME Beltrame Group	Laminés Marchands Européens	2 Rue Emile Zola	59125	Trith Saint Leger	France
53	UGITECH	UGITECH Aciéries Électrique d'Ugine	Avenue Paul Girod	73400	Ugine	France
54	Stahlwerk Bous GmbH	Elektrostahlwerk Bous	Saarstrasse 1	66359	Bous	Germany
55	B.E.S. Brandenburger Elektrostahlwerke GmbH	B.E.S. Brandenburger Elektrostahlwerke GmbH	Woltersdorfer Strasse 40	14770	Brandenburg an der Havel	Germany
56	BGH Edelstahl Freital GmbH	Elektrostahlwerk einschliesslich Strangiessanlage	Am Stahlwerk 1	1705	Freital	Germany
57	GMH GmbH	Georgsmarienhütte GmbH	Neue Hüttenstrasse 1	49124	Georgsmarie nhütte	Germany
58	GMH GmbH	Schmiedewerke Gröditz	Riesaer Strasse 1	1609	Gröditz	Germany
59	ArcelorMittal Duisburg GmbH	ArcelorMittal Hamburg GmbH	Dradenaustrasse 33	21129	Hamburg	Germany
60	H.E.S.Hennigsdorfer Elektrostahlwerke GmbH	H.E.S. Hennigsdorfer Elektrostahlwerke GmbH	Wolfgang-Küntscher-Strasse 18	16761	Hennigsdorf	Germany
61	Lech-Stahlwerke GmbH	Lech-Stahlwerke	Industriestrasse 1	86405	Herbertshofe n - Meitingen	Germany
62	Mosecker GmbH & Co. KG	Mosecker Lingen	Beckstraße 26	49809	Lingen	Germany
63	Badische Stahlwerke GmbH	Stahlwerk Kehl	Graudenzerstrasse 45	77694	Kehl	Germany
64	Peiner Träger GmbH	Peiner Träger GmbH	Gerhard-Lucas-Meyer-Strasse 10	31226	Peine	Germany
65	ESF Elbe-Stahlwerke Feralpi GmbH	ESF Elbe-Stahlwerke Feralpi GmbH	Gröbaer Strasse 3	1591	Riesa	Germany
66	Deutsche Edelstahlwerke GmbH	Deutsche Edelstahlwerke GmbH Werk Siegen	Obere Kaiserstrasse	57078	Siegen	Germany
67	BGH Edelstahl Siegen GmbH	Schmelz- und Giessbetrieb Siegen Eintracht	Stumme Loch Weg 1	57072	Siegen	Germany
68	Stahlwerk Thüringen GmbH	Stahlwerk Thüringen GmbH	Kronacher Strasse 6	7333	Unterwellen born	Germany
69	Saarstahl AG	Saarstahl AG - Werk Völklingen	Bismarckstr. 57-59	66333	Völklingen	Germany
70	Buderus Edelstahl GmbH	Buderus Edelstahl GmbH	Buderusstrasse 25	35576	Wetzlar	Germany
71	Deutsche Edelstahlwerke GmbH	Elektrostahlwerk Witten	Auestrasse 4	58452	Witten	Germany
72	SIDENOR S.A.	AEIFOROS METAL PROCESSING S.A.	Tsiggeli	37100	Almyros	Greece

73	SIDENOR S.A.	SOVEL S.A.	Tsingeli	37100	Almyros-Magnisia	Greece
74	Hellenic Halyvourgia	Steel Center S.A. ΚΕΝΤΡΟ ΧΑΛΥΒΩΝ Α.Ε.Β.Ε.	Diilistirion Avenue	19300	Aspropyrgos	Greece
75	Larco General Mining and Metallurgical Company S.A.	LARYMNA METALLURGIC PLANT	Larymna Lokridos	35012	Larymna	Greece
76	SIDENOR S.A	SIDENOR STEEL INDUSTRY S.A. Thessaloniki Plant	12th km Old National Road Thessaloniki-Veria	57008	Thessaloniki	Greece
77	Hellenic Halyvourgia	Velestino Steel Plant	EO Volou Larisas, Rigas Fereos	38500	Velestino	Greece
78	The Max Aicher Group	Ózd Steelworks, Ltd.	Max Aicher út 1	3600	Ozd	Hungary
79	Cogne Acciai Speciali S.p.A.	COGNE ACCIAI SPECIALI S.p.A.	Via Paravera, 16	11100	Aosta	Italy
80	Valbruna Group	Acciaierie Valbruna S.P.A	Via Alessandro Volta, 4	39100	Bolzano	Italy
81	Leali Steel S.p.A.	LEALI STEEL SPA - Stabilimento di Borgo Valsugana	Via Puisle, 4	38051	Borgo Valsugana (TN)	Italy
82	Metalcam S.p.A.	Metalcam S.p.A.	Leonardo da Vinci, 3	25043	Breno	Italy
83	O.R.I. MARTIN S.P.A.	O.R.I. MARTIN S.P.A.	Via Canovetti 13	25128	Brescia	Italy
84	ALFA ACCIAI SPA	ALFA ACCIAI SPA	Via San Polo 152	25100	Brescia	Italy
85	Riva Acciaio S.p.A.	Riva Steel Caronno Pertusella	Bergamo, 1484	21042	Caronno	Italy
86	ACCIAIERIE DI SICILIA S.p.A.	ACCIAIERIE DI SICILIA S.p.A.	Stradale Passo Cavaliere, 1/A	95100	Catania	Italy
87	Acciaieria Di Cividate Al Piano (S.P.A.)	Acciaieria Di Cividate Al Piano	Cascina Motta Alta, 14	24050	Cividate Al Piano - BG	Italy
88	Acciaieria Arvedi S.p.A.	Acciaieria Arvedi S.p.A.	Via Acquaviva 18	26100	Cremona	Italy
89	DALMINE S.P.A.	Tenaris Dalmine Stabilimento di Dalmine	Piazza Caduti 6 Luglio 1944 1	24044	Dalmine (BG)	Italy
90	Riva Acciaio S.p.A.	RIVA Acciaio - Stabilimento di Lesegno	Strada Statale 28 Nord, SNC	12076	Lesegno	Italy
91	Feralpi Group	Feralpi Siderurgica S.p.A.	Carlo Nicola Pasini 11	25017	Lonato - BS	Italy
92	Fonderia di Lonato	Fonderia di Lonato	Via Montebello, 7/9	25017	Lonato - BS	Italy
93	Lucchini RS S.p.A.	Stabilimento di Lovere	via G. Paglia, 45	24065	Lovere	Italy
94	FERRIERA VALSABBIA SPA	Stabilimento di Odolo (BS)	Marconi, 13	25076	Odolo	Italy
95	INDUSTRIE RIUNITE ODOLESI I.R.O. SPA	Industrie Riunite Odolesi I.R.O. s.p.a.	Via Brescia, 12	25076	Odolo	Italy

96	FERRIERE NORD SPA	FERRIERE NORD STABILIMENTO DI OSOPPO	Zona Industriale Rivoli	33010	Osoppo	Italy
97	ASO SIDERURGICA SPA UNIPERSONALE	ASO SIDERURGICA SRL	Via Seriola, 122	25035	Ospitaletto	Italy
98	ACCIAIERIE VENETE S.p.A.	ACCIAIERIE VENETE STABILIMENTO DI CAMIN	Riviera Francia, 9/11	35100	Padova	Italy
99	TRAVI E PROFILATI DI PALLANZENO SRL	SAN ZENO ACCIAI - DUFERCO SRL	Via Armando Diaz, 248	25010	San Zeno Naviglio (BS)	Italy
100	ACCIAIERIE VENETE S.p.A.	ACCIAIERIE VENETE S.p.A. Stabilimento di Sarezzo	Via Antonini, 82	25068	Sarezzo	Italy
101	ACCIAI SPECIALI TERNI SPA CON UNICO SOCIO	ACCIAI SPECIALI TERNI S.P.A. - stabilimento di TERNI	Viale Brin 218	5100	Terni	Italy
102	Acciaierie Bertoli Safau SpA	Danieli ABS Pozzuolo del Friuli	Via Buttrio, 28	33050	Udine	Italy
103	Marcegaglia Palini e Bertoli SpA	Marcegaglia Palini e Bertoli San Giorgio di Nogaro steel plant	Via E. Fermi, 28	33058	Udine	Italy
104	NLMK VERONA S.P.A.	NLMK VERONA S.P.A.	Via Antonio Salieri 22	37050	Vallese di Oppeano (VR)	Italy
105	RIVA ACCIAIO S.P.A.	Riva Acciaio S.p.A. Stabilimento di Verona	VIA LUNGADIGE GALTAROSSA 21/C 21/C	37100	Verona	Italy
106	Acciaierie Valbruna S.p.A.	Stabilimento di Vicenza	DELLA SCIENZA, 25	36100	Vicenza	Italy
107	AFV ACCIAIERIE BELTRAME SPA	AFV ACCIAIERIE BELTRAME SPA	VIALE DELLA SCIENZA, 81	36100	Vicenza	Italy
108	ArcelorMittal	ArcelorMittaL Esch-Belval	Rue de Luxembourg 66	4221	Esch-sur-Alzette	Luxembourg
109	ALCHEMIA S.A.	STALOWNIA	Dyrekcyjna 6	41506	Chorzow	Poland
110	Liberty Steel	ISD Huta Czestochowa steel plant	Wojciecha Korfantego 39	42202	Czestochowa	Poland
111	Ferrostal Łabędy	Cognor SA Branch in Gliwice Labedy Ferrostal	Anny Jagiellonki 47	44109	Gliwice	Poland
112	Celsa Polska Holding Sp. z o.o.	Celsa "Huta Ostrowiec" Sp. z o.o.	Jana Samsonowicza 2	27400	Ostrowiec	Poland
113	Wtór - Steel Sp. z o. o.	Wtór - Steel Stawola Wola	Władysława Grabskiego 12	37450	Stalowa Wola	Poland

114	AM Global Holding S.A.R.L. z siedzibÄ… w Luxemburgu	ARCELORMITTAL WARSZAWA Sp. z o.o.	Kasprowicza 132	1949	Warzawa	Poland
115	CMC Poland Sp. z o. o.	CMC Poland Zawiercie	ul. Pilsudskiego 82	42400	Zawiercie	Poland
116	Metalurgica Galaica S.A.	SN Seixal - Siderurgia Nacional, S.A.	Avenida Siderurgia Nacional	284007 5	Paio Pires	Portugal
117	Metalurgica Galaica S.A.	SN Maia - Siderurgia Nacional, S.A.	Rua da Siderurgia 4425-393	442539 3	Maia (Porto)	Portugal
118	SC DONALAM SRL	SC DONALAM SRL Calarasi	Prelungirea Bucuresti,nr.162	910125	Calarasi	Romania
119	SC ARCELORMITTAL HUNEDOARA SA	ARCELORMITTAL HUNEDOARA SA	DJ 687, Nr.4	331111	Hunedoara	Romania
120	SC Ductil Steel SA	SC Ductil Steel SA Buzau-Punct de Lucru Otelu Rosu	Street Mihai Eminescu No. 10	325700	Otelu Rosu	Romania
121	Resita Iron And Steel	Integrated Iron and Steel Resita	Strada Traian Lalescu 36	320050	Resita	Romania
122	ZP Group	Železiarne Podbrezová a. s.	Kolkáreň 35	97681	Podbrezova	Slovakia
123	ACRONI, D.O.O.	SIJ Acroni Jesenice	Cesta Borisa Kidriča 44	4270	Jesenice	Slovenia
124	METAL RAVNE, D.O.O.	Metal Ravne d.o.o.	Koroška cesta 14	2390	Ravne	Slovenia
125	Štore Steel d.o.o.	Štore Steel d.o.o.	Železarska cesta 3	3220	Store	Slovenia
126	TUBOS REUNIDOS INDUSTRIAL, S.I.	TUBOS REUNIDOS INDUSTRIAL, S.I.	Calle Sagarribai, 2	1470	Amurrio (Alava)	Spain
127	Aceralava	Aceria De Alava S.A.	POLIGONO INDUSTRIAL SARACHO, S/N	1470	Amurrio (Alava)	Spain
128	GERDAU ACEROS ESPECIALES EUROPA, S.L.	Sidenor Aceros Especiales	Barrio Ugarte s/n	48970	Basauri (Vizcaya)	Spain
129	Compania Espanola de Laminacion SL	Celsa Barcelona	Celsa Barcelona, Carrer de la Ferralla, 12	8755	Castellbisbal	Spain
130	Productos Tubulares, SAU	Productos Tubulares, S.A.	Ctra. Galindo a Ugarte, s/n	48510	Galindo (Vizcaya)	Spain
131	Corrugados Getafe S.L.U.	Corrugados Getafe, S.L.	Polígono Industrial Los Ángeles Carpinteros, 5	28906	Getafe (Madrid)	Spain
132	Grupo Gallardo Balboa SL	Siderurgica Balboa	Ctra. Zafra-Villanueva del Fresno, km.22,5	6380	Jerez de los Caballeros (Badajoz)	Spain
133	ACEROS INOXIDABLES OLARRA, SA	Aceros Inoxidables Olarra, S.A.	Larrabarri Bidea,1	48180	Loiu (Vizcaya)	Spain

134	ACERINOX, S.A.	Acerinox Europa Los Barrios	Acerinox Europa Av, Polígono Industrial de Palmones	11370	Los Barrios (Cadiz)	Spain
135	Megasa Siderúrgica, S.L.	Megasa Siderúrgica, S.L.	Carretera de Castilla, 802	15570	Naron (La Coruña)	Spain
136	ArcelorMittal	ArcelorMittal Olaberria-Bergara	Ctra. Madrid - Irún Km 417	20212	Olaberria (Gipuzkoa)	Spain
137	Sidenor	Sidenor Reinosa	Paseo Alejandro Calonje s/n	39200	Reinosa (Cantabria)	Spain
138	GLOBAL STEEL WIRE, S.A.	Celsa Global Steel Wire Santander	Poligono Industrial Nueva Montana S/N	39011	Santander (Cantabria)	Spain
139	ArcelorMittal	ArcelorMittal Sestao	Chavarri 6	48910	Sestao (Bilbao)	Spain
140	Siderurgica Sevillana SA	Riva Siderurgica Sevillana	Autovía A-92. Km. 6	41500	Sevilla (Alcala de Guadaira)	Spain
141	Metalurgica Galaica SA	Megasider Zaragoza	Av. Jose Lopez Soriano, 100	50720	Zaragoza (Zaragoza)	Spain
142	Outokumpu Stainless AB	Outokumpu Stainless AB, Avesta	Bergsnäsgatan 11	77492	Avesta	Sweden
143	Scana Steel Björneborg AB	Scana Steel Björneborg AB	Kristinehamnsvägen 2	68071	Björneborg	Sweden
144	Uddeholms AB	Hagfors Jernverk	Uddeholms AB	68385	Hagfors	Sweden
145	OVAKO AB	OVAKO Hofors AB	Olof Hjorts väg 2	81335	Hofors	Sweden
146	AB Sandvik Materials Technology	AB Sandvik Materials Technology	Storgatan 2	81181	Sandviken	Sweden
147	OVAKO AB	Ovako SmeBox	Smedjegatan 1	77780	Smedjeback en	Sweden
148	Liberty Steel	Iron and Steel Rotherham	Aldwarke Lane	S60 1DW	Rotherham	United Kingdom
149	ELG Haniel Metals Ltd	ELG Carrs Stainless Steels	Pluto Works, Penistone Road North, Wadsley Bridge		Sheffield	United Kingdom
150	Sheffield Forgemasters Engineering Limited	Sheffield Forgemasters Heavy Forge and Foundry	Brightside Lane	S9 2RW	Sheffield	United Kingdom
151	Outokumpu Stainless Ltd	Outokumpu Stainless Ltd	Europa Link	S9 1TZ	Sheffield (SMACC)	United Kingdom
152	CELSA Manufacturing (UK) Limited	CELSA Manufacturing (UK) Ltd	Castle Works East Moors Road		Cardiff	United Kingdom

Continuation: Operating EAF Plants in the EU and the UK

Site ID	Latitude	Longitude	Finished Steel	No. Of furnaces	Production (tonnes/year)	tonne CO_2/tonne

			Capacity (thousand tonnes/year)			of steel produced
27	47.057951	15.417293	365	1	36445.82	6560.248
28	47.443615	15.285738	180	1	125776.91	22639.84
29	47.177878	14.599636	300	1		54000
30	50.4099	4.4111	850	1	233669.45	42060.5
31	50.4099	4.4312	350	1	229337.01	41280.66
32	50.416	4.5355	1000	1	406827.05	73228.87
33	50.938103	5.499037	1200	2	349085.35	62835.36
35	42.593002	23.10493	1000	2	445958.81	80272.59
36	45.45209	16.39656	350	1		63000
37	49.81623067	18.256851661111	120	1	18407.61	3313.37
38	49.745126	13.363195	150	2		27000
39	61.154446	28.79742	360	1	73301.01	13194.18
40	65.7842	24.1758	1300	2	944815.73	170066.8
41	49.02	1.57	550	1	94453.95	17001.71
42	43.53299878	-1.4959593739555208	1200	1	77675.56	13981.6
43	47.218608	4.640049	100	1	102007.3	18361.31
44	43.44350101	4.847773499143128	480	1	114313.01	20576.34
45	48.98431407	1.7589218962834536	700	1		126000
46	49.24113474	6.155830757661457	460	1	122501.99	22050.36
47	46.933646	3.261076	90	1	45796.82	8243.428
48	46.805108	4.429369	150	1	130604.1	23508.74
49	48.39	2.96	720	1	200802.58	36144.46
50	48.61	6.1	800	1	196389.22	35350.06
51	50.372576	3.56105	730	1	175779.15	31640.25
52	50.329231	3.487947	800	1	163961.73	29513.11
53	45.748545	6.431069	250	2	131996.12	23759.3
54	49.274184	6.794735	350	1	56911.02	10243.98
55	52.40195019	12.498885660274	1800	2	583049.39	104948.9
56	50.998987	13.644266	90	1	36831.79	6629.722
57	52.2091444	8.049501107037	1100	1	335135.18	60324.33
58	51.427045	13.360164	100	1	23384.89	4209.28
59	53.52478497	9.900051078411	1100	1	1146768.93	206418.4

60	52.65326784	13.211427001547	1000	2	220750.12	39735.02
61	48.51211887	10.859350531635	1180	2	336228.5	60521.13
62	52.53831257	7.338532522848379	620	1		111600
63	48.594136	7.822683	2500	2	269290.71	48472.33
64	52.31635646	10.238186117919	1000	1	402897.64	72521.58
65	51.3130646	13.277830046886	900	1	321913.22	57944.38
66	50.9173709	8.014246705028	600	1	474755.75	85456.04
67	50.865991	8.007217	150	1	41532.13	7475.783
68	50.65350467	11.434288262033	1100	1	442354.81	79623.87
69	49.25200518	6.847062770056	300	1	855176.89	153931.8
70	50.57494118	8.489228686291	400	1	628679.74	113162.4
71	51.434468	7.326471	480	1	88063.62	15851.45
72	39.169977	22.825116695798094	1200	1		216000
73	38.061372	22.840557	1200	1		6225.253
74	38.565389	23.591301	400	1	34584.74	368573.6
75	40.70433664	23.29475	1150	1	2047631.32	108000
76	39.39354734	22.815320991988667	600	1		81000
77	48.232872	22.86812336467989	450	1		107100
78	46.498113	20.331112	400	1	595000	62251.11
79	46.051568	7.322222	260	1	345839.5	16919.87
80	45.956324	11.35478	200	2	93999.27	12200.09
81	45.533333	11.45144	600	1	67778.28	15401.13
82	45.533333	10.30404	100	1	85561.84	63813.54
83	45.591337	10.226944	1200	2	354519.68	58529.26
84	37.446266	10.226944	350	1	325162.54	23406.98
85	45.554879	9.049864	780	1	130038.77	12833.09
86	45.14823	15.032774	500	1	71294.97	11506.86
87	45.6425	9.83096	250	1	63926.98	182599.2
88	44.402234	9.971544	3850	2	1014440.23	261120.7
89	45.4625	9.596944	700	1	1450670.46	35173.65
90	45.46451576	7.97084	600	1	195409.17	55106.19
91	45.816882	10.459167	1100	1	306145.52	198000
92	45.64685	10.477430942463851	600	1		55783.49
93	45.641851	10.075214	150	1	309908.25	29788.39
94	46.230556	10.388449	900	1	165491.07	19558.17

95	45.550364	10.37454	800	1	108656.51	95079.34
96	45.379353	13.077778	2200	1	528218.55	7509.247
97	45.500528	10.084512	150	1	41718.04	52887.73
98	45.64842	11.950704	600	1	293820.71	34396.57
99	42.566667	10.221115	800	1	191092.04	30603.86
100	45.995556	10.201334	540	1	170021.43	182991.3
101	45.80649	12.666667	1450	2	1016618.47	128127.2
102	45.34270089	13.206944	1100	2	711817.95	16635.58
103	45.433333	13.215433	600	1	92419.89	42879.53
104	45.526381	11.069864718537659	450	1	238219.62	39002.97
105	45.523387	11	1250	2	216683.17	32090.71
106	49.52597	11.503777	170	1	178281.71	54529.88
107	50.274807	11.495927	1200	1	302943.76	174857.1
108	50.77664631	5.89753	2250	2	971428.57	61921.57
109	50.351552	18.941392	145	1	344008.7	25064.64
110	50.94671	19.194893582594005	840	1	139248.02	121713.7
111	50.556111	18.615042	250	1	676187.49	478245.3
112	52.29226	21.4481	900	1	2656918.27	124476.3
113	50.494444	22.049208	240	1	691535.02	232159.6
114	38.62994848	20.9196	750	1	1289775.82	469754.6
115	41.25754726	19.457222	1340	2	2609747.82	169996.4
116	44.203393	-9.08216376659	1100	1	944424.4	105403.6
117	45.735183	-8.55443252906	600	1	585575.59	8728.931
118	45.519829	27.315083	470	1	48494.06	90506.84
119	45.289011	22.916270	550	1	502815.77	675.9612
120	48.81073017	22.357742	830	1	3755.34	50058.01

121	46.423994	21.887768	450	1	278100.06	117958.2
122	46.545542	19.563290486506666	350	1	655323.34	55874.3
123	46.221351	14.094645	500	1	310412.77	39042.55
124	43.07459341	14.963014	140	1	216903.06	18303.15
125	43.0347173	15.32154	150	1	101684.16	20394.83
126	43.227282	-2.997272015	360	1	113304.62	12754.15
127	41.454855	-3.0032057332772304	150	1	70856.41	30890.93
128	43.305223	-2.884676	740	1	171616.29	19058.25
129	40.310803	1.980107	2400	2	105879.15	8032.617
130	38.324639	-3.016938	400	1	44625.65	72000
131	43.314765	-3.703568	600	1		25574.35
132	36.181686	-6.714513	1300	1	142079.72	7890.575
133	43.51421	-2.938888	130	1	43836.53	69907.41
134	43.03829	-5.426626	1200	3	388374.48	13163.68
135	42.988955	-8.163839	700	1	73131.57	33823.68
136	43.445344	-2.219625	2450	1	187909.34	25656.99
137	43.313144	-4.142732	240	1	142538.81	44506.63
138	37.362968	-3.839228	750	1	247259.03	38458.93
139	41.56988	-2.998964	2000	2	213660.72	24043.1
140	60.148821	-5.886865	1300	2	133572.75	15481.81
141	59.241686	-0.856566	500	1	86010.03	153000
142	60.032052	16.172808	500	1	850000	17018.97
143	60.548682	14.238757	95	1	94549.81	50305.43
144	60.624017	13.700239	120	1	279474.63	116463.3
145	60.13552	16.302815	500	1	647018.55	134611.6
146	53.450712	16.780314	200	1	747842.06	52643.94

147	53.41818	15.414372	480	1	292466.32	31496.43
148	53.402338	-1.323025	1220	2	174980.15	27000
149	53.39747	-1.498937				4618.314
150	51.472502	-1.432639	150	1	25657.3	90000
151	51.472502	-1.404783	500	1		6267.632
152	51.472502	-3.157583	1200	2	34820.18	216000