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**HYDROGEN DRI FOR STEEL
IN A RESOURCE-CONSTRAINED
EUROPE: HOW MUCH
RENEWABLE ELECTRICITY IS
NEEDED TO DECARBONISE
THE SECTOR WITH GREEN
HYDROGEN?**

Deep
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HYDROGEN DRI FOR STEEL IN A RESOURCE-CONSTRAINED EUROPE: HOW MUCH RENEWABLE ELECTRICITY IS NEEDED TO DECARBONISE THE SECTOR WITH GREEN HYDROGEN?

The European Union (EU) is the world's second largest steel producer after China, with an annual production capacity of about 150 million metric tons in 2021 and home to over 500 steel production sites in 22 member states¹. The sector is a vital component of the EU's economy, directly providing jobs for around 310.000 people and many more in downstream sectors of the steel value chain, such as construction or the automotive industry. It contributes some €125 billion to the EU's GDP annually². Importantly, steel is an indispensable material for various parts of the energy transition, such as wind turbines, solar power plants, electricity transmission and distribution infrastructure and energy storage systems.

At the same time, the steel industry is also a major environmental concern causing an astounding ~190 million tonnes of CO₂eq or in relative terms about 5 % of greenhouse gas (GHG) emissions in the EU³. To meet European emission reduction targets, steel production must become CO₂-neutral by 2050. The conventional coal-based blast furnace route for primary steel production is already an energetically optimised process that offers little potential for further increases in efficiency and emission reductions. Consequently, business as usual does not present a viable path to a climate-neutral future, necessitating far-reaching restructuring and rethinking of the entire value chain.

Decarbonising the steel industry requires a multifaceted approach. No solution can single-handedly address this immense challenge. Instead, a compendium of solutions is needed, encompassing demand reduction through the optimisation of the use of steel, increased recycling rates and technological solutions for primary production such as hydrogen direct reduced iron (DRI) and carbon capture and storage (CCS). These decarbonisation pathways must be deployed collectively and in a synergistic manner.

EUROPEAN STEELMAKERS EMBRACE HYDROGEN DRI PLANTS FOR DECARBONISATION

Hydrogen DRI plants have seemingly emerged as the preferred decarbonisation route for primary steel production in Europe, with multiple large steelmakers announcing plans to switch at least parts of their production to DRI. In many cases, these plants could initially run on fossil gas until hydrogen is available at a sufficient scale and competitive price. At least 19 steel mills operated by big players such as ArcelorMittal, ThyssenKrupp, or Tata Steel will see a DRI plant added to their portfolio until 2030⁴. Growing political interest in hydrogen, the adoption of binding targets for hydrogen use in industry, and the allocation of public money to support its production and the deployment of relevant infrastructure can be expected to further increase attention towards and plans for "greening" steel production through electrolytic hydrogen produced with

1 Eurofer, 2022 (<https://www.eurofer.eu/assets/publications/brochures-booklets-and-factsheets/europe-an-steel-in-figures-2022/European-Steel-in-Figures-2022-v2.pdf>).

2 Eurofer, 2022 (<https://www.eurofer.eu/assets/publications/brochures-booklets-and-factsheets/europe-an-steel-in-figures-2022/European-Steel-in-Figures-2022-v2.pdf>).

3 Joint Research Centre – European Commission, 2022 (https://joint-research-centre.ec.europa.eu/jrc-news/eu-climate-targets-how-decarbonise-steel-industry-2022-06-15_en#:~:text=The%20steel%20industry%20is%20responsible,with%20the%20EU's%20climate%20targets).

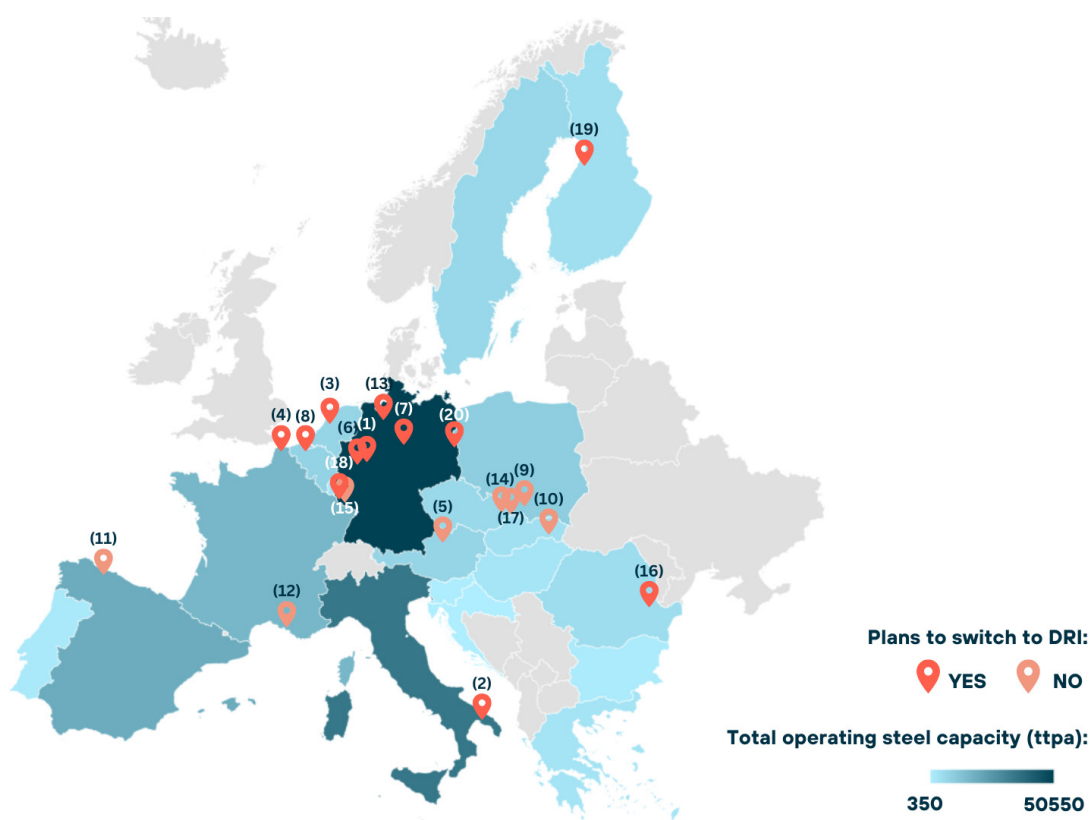
4 Bellona, 2021 (<https://bellona.org/news/eu/2021-05-hydrogen-in-steel-production-what-is-happening-in-europe-part-two>) and Somers, 2022 (<https://publications.jrc.ec.europa.eu/repository/handle/JRC127468>).

renewable electricity.

Switching to DRI and using renewable hydrogen to reduce iron ore for primary steel production can indeed significantly reduce greenhouse gas emissions by up to 95 %⁵ compared to the conventional blast furnace route, which emits around [1.85 tonnes CO₂/t steel](#). DRI processes produce sponge iron in a shaft furnace. The iron is then further processed to steel in an electric arc furnace (EAF). The blast furnace route is the currently dominant process and mostly relies on coke, made from coal, as a reducing agent. By eventually replacing fossil fuels with hydrogen, the industry can achieve significant strides towards decarbonisation and contribute to the achievement of net-zero emission targets. However, such a shift is not done with only a change of fuel but also requires investments in entirely new production facilities.

We zoomed in on the twenty largest steel plants in the EU out of which twelve pledged to undergo a switch to hydrogen DRI in the upcoming years.

TOTAL OPERATING STEEL CAPACITY PER COUNTRY AND LOCATION OF 20 LARGEST STEEL PLANTS IN THE EU



Note: Shown are the 20 largest steel plants in the EU in terms of their production capacity. Data sourced from Global Energy Monitor, 2023 (https://www.gem.wiki/Category:Steel_plants_in_Europe)

1) Integriertes Hüttenwerk Duisburg, ThyssenKrupp

(8) ArcelorMittal Gent steel plant

(15) Saarstahl Völklingen Steelmaking Plant

(2) Acciaierie d'Italia Taranto steel plant, ArcelorMittal

(9) Dąbrowa Górnicza steel plant, ArcelorMittal

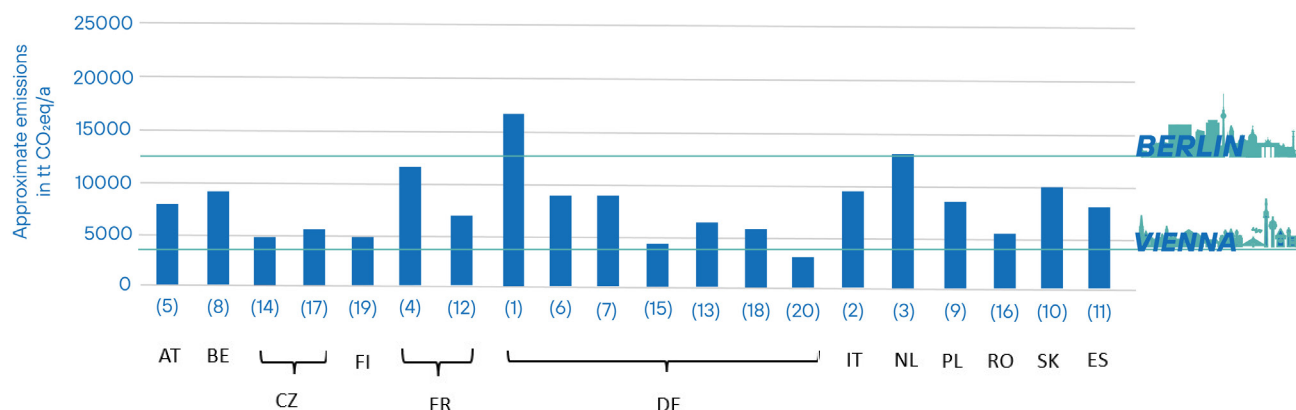
(16) GFG Liberty Galati steel plant

(3) Tata Steel IJmuiden steel plant	(10) U. S. Steel Košice steel plant	(17) TZMS Třinecké železářny Trinec steel plant
(4) Dunkerque steel plant, ArcelorMittal	(11) ArcelorMittal Olaberria-Bergara (Olaberria) steel plant, ArcelorMittal	(18) AG der Dillinger Hüttenwerke Dillingen steel plant
(5) Voestalpine Stahl Linz steel plant	(12) Fos-sur-Mer steel plant, Arcelor-Mittal	(19) SSAB Raahe steel plant
(6) Hüttenwerke Krupp Mannesmann (HKM) steel plant	(13) ArcelorMittal Bremen steel plant	(20) ArcelorMittal Eisenhüttenstadt steel plant
(7) Glocke Salzgitter steel plant, Salzgitter Flachstahl	(14) GFG Liberty Ostrava steel plant	

If those twenty largest steel plants' entire crude steel production of 2021 was to be replaced by DRI plants powered with low-carbon hydrogen, approximately 146 million tonnes of CO₂eq of emissions, accounting for roughly 77 % of the emissions of the entire European steel sector in that same year⁶, could be largely abated. Decarbonising the biggest steel plant in Europe (Duisburg) alone would well cut the equivalent of the total emissions of the city of Berlin.

EMISSIONS OF THE 20 LARGEST STEEL PLANTS IN THE EU – SCALE OF THE DECARBONISATION CHALLENGE

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Note: Own calculation based on crude steel production from Global Energy Monitor, 2023 (https://www.gem.wiki/Category:Steel_plants_in_Europe) and average emissions data sourced from <https://www.frompollutiontosolution.org/casestudy-h2insteel>.

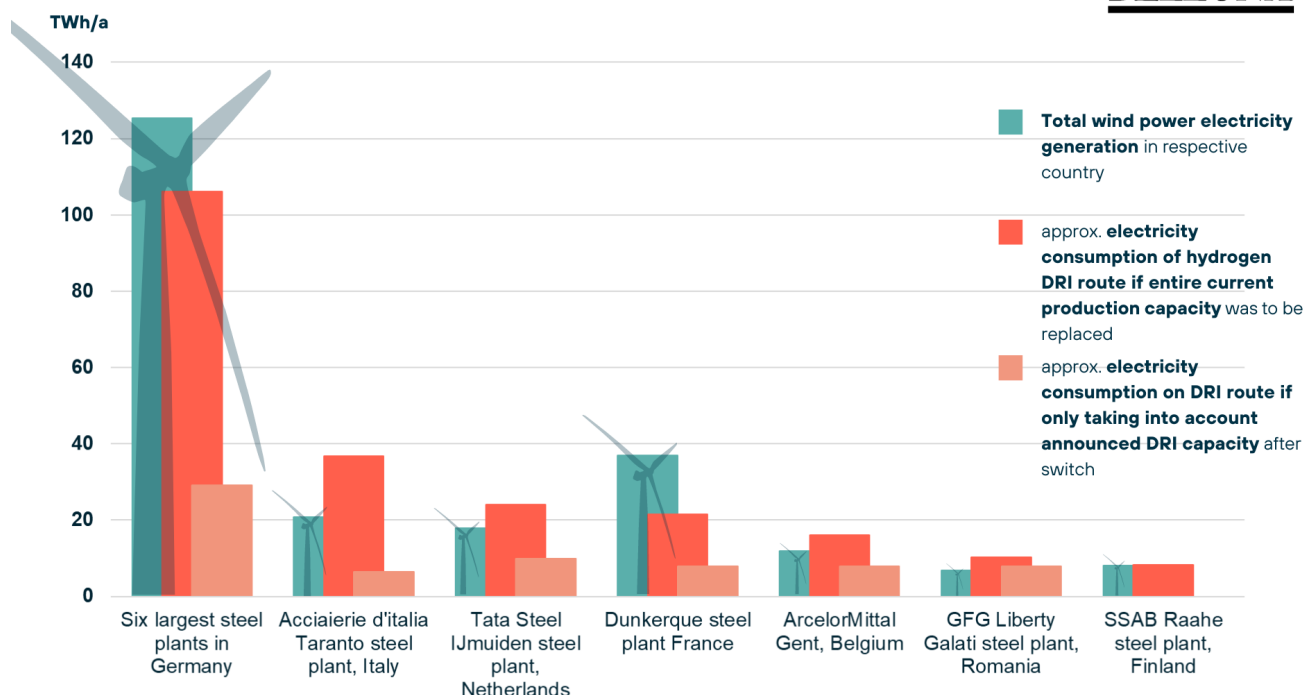
Yet, those promising prospects are but one side of the coin. To achieve far-reaching emission cuts, DRI plants need to ideally be fuelled with green hydrogen.

Hydrogen's significant potential to decarbonise the European steel industry is evident, but achieving this goal requires a rapid scale-up of renewable electricity capacities to enable the production of green hydrogen.

If the aforementioned twelve steel mills with announced plans to convert to hydrogen DRI were to replace their entire current production capacity with hydrogen DRI, each steel plant would require a vast amount of the currently available wind power. In Italy, the Netherlands, Belgium, Romania and Finland each steel plant would even require more wind electricity than is currently generated in their country.

⁶ 146 million tons account for roughly 77 % of the emissions of the entire European steel sector (~190 million tons of CO₂eq) and over 4 % of the EU's greenhouse gas emissions which totaled about 3.242 million tons of CO₂eq in that same year, see European Environment Agency, 2023 (<https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer>)

RENEWABLE WIND CAPACITIES THEORETICALLY CANNIBALISED BY HYDROGEN DRI STEEL PLANTS IN THEIR RESPECTIVE COUNTRIES

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Note: Current production capacities and indicated DRI capacities sourced from Global Energy Monitor, 2023 (https://www.gem.wiki/Category:Steel_plants_in_Europe); data on DRI capacity missing for Hüttenwerke Krupp Mannesmann and ArcelorMittal Eisenhüttenstadt steel plants in Germany and SSAB Raahe steel plant in Finland.

DUE TO SIGNIFICANT RESOURCE REQUIREMENTS FOR ITS PRODUCTION, HYDROGEN IS NOT A SILVER BULLET AND SHOULD NOT BE TREATED AS SUCH EVEN IN THE STEEL INDUSTRY

Hydrogen has been touted as a promising solution for decarbonising the steel sector, but it should be coupled with other solutions for emission reductions. There are three main alternative routes to decarbonise steel production: optimising steel use, increasing the recycling rates and using Carbon Capture and Storage (CCS).

(1) Optimising steel use involves reducing the total demand for steel through efficiency and sufficiency measures. For example, moving from private to public mobility with massive deployment of public transport and shared mobility solutions, could lead to a decreasing amount of private vehicles and thus a decline in the production of new passenger cars. Studies suggest that the deployment of car sharing systems in urban areas can lead to a reduction in car ownership, indicating that for every shared car added to the fleet five to 15 private cars could be replaced⁷. Considering that each vehicle requires on average 900kg of steel⁸ an increase in public transport and shared mobility solutions could reduce the overall demand for steel in Europe.

In addition, a partial substitution of steel with more energy-efficient and sustainable materials, for instance in the built environment, could likewise reduce the total demand for steel.

(2) Steel has exceptional circularity credentials. It is one of the world's most recycled materials and can be

7 Transport & Environment, 2017 (<https://www.transportenvironment.org/wp-content/uploads/2021/07/Does-sharing-cars-really-reduce-car-use-June%202017.pdf>); Namazu and Dowlatabadi, 2018 (<https://doi.org/10.1016/j.tranpol.2017.11.001>).

8 World Steel Association, 2023 (<https://worldsteel.org/steel-topics/steel-markets/automotive/>).

fully recycled repeatedly. Secondary steel production via the electric arc furnace route, i.e., the **recycling of steel**, which currently accounts for 56 % of European steel production⁹, is much less CO₂ intensive than primary steel production. Regardless of the energy source, the processing of secondary steel is always more energy-efficient than primary steel production. Hence, increasing the recycling rate as such is an impactful lever to decrease emissions from steel making, especially so if powered with renewable electricity.

This could, for instance, be achieved by enhancing urban mining efforts or reducing exports of scrap metals to countries, such as Turkey, and instead recirculating them to steel mills within the EU. Such an approach might, however, carry the risk of increasing emissions from enhanced steel production in those countries currently importing European steel scrap, as they might be forced to increase their primary steel production to satisfy demand.

Besides, the available amount of scrap steel is finite, aligning with circular economy thinking that prioritises extended product lifetimes and repair over recycling. Steel has an average life expectancy of 35 years, with steel in construction reaching a life time of more than 50 years while simple metal products usually have a lifespan of around eleven years¹⁰. Consequently, despite high recycling rates, the substantial demand for steel is unlikely to be satisfied solely through recycled resources, necessitating the continued production of primary steel.

Beyond that, [impurities persist](#) in the recycling process and accumulate with every recycling iteration. Primary steel production is, therefore, still required, especially for sectors where high grades of steel are indispensable, such as for the manufacturing of cars and wind turbines.

(3) Carbon Capture and Storage (CCS) represents another alternative to decarbonise steel production, provided access to a CO₂ transport- and storage infrastructure is available. However, the separate CO₂ point sources within the current blast and basic oxygen furnace route limit the effectiveness and economics of CCS, further aggravated by low concentrations of CO₂ in the flue gases. The effective application of CCS with a blast furnace steel production route requires the rebuilding of the plant into a Hisarna plant or a top-gas recycling plant.

CCS could also be applied to a DRI steel mill that is running on fossil gas. This is the case, for some of the DRI plant technologies currently deployed¹¹. In this case, the single flue gas stream and higher CO₂ concentration makes CCS more viable than on a blast furnace. However, there is currently only one fossil gas based DRI steel mill in operation in Europe (Bremen). Applying CCS on one of the planned H₂ DRI steel mills, which utilise a blend of fossil gas and hydrogen due to the abovementioned availability and cost constraints surrounding hydrogen, needs to be weighed against the cost of the production and use of hydrogen from fossil gas with CCS, so-called blue hydrogen. This could enable a 100% hydrogen use from the start, which is relevant as a DRI plant using a fossil gas-hydrogen blend might need further refurbishment to switch to 100% hydrogen in a second stage.

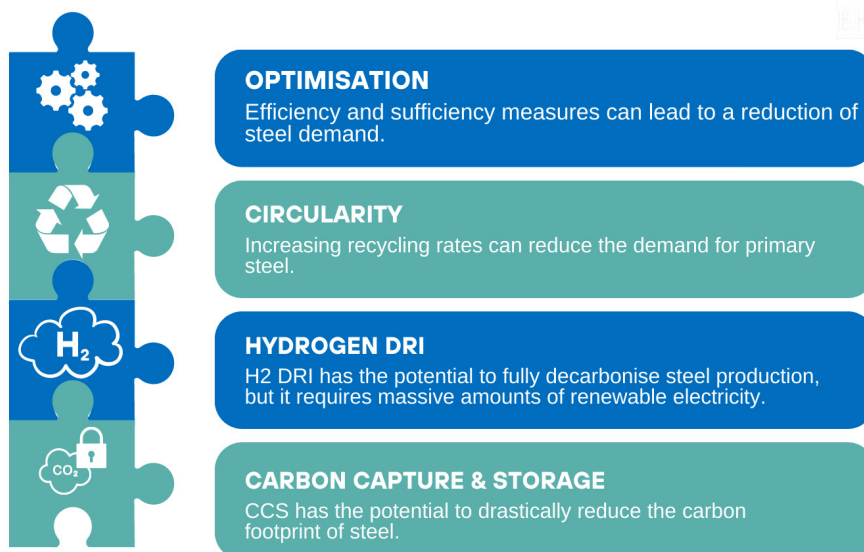
It is imperative to consider all these decarbonisation options collectively, especially given the importance of steel as a key material for the energy transition.

9 Eurofer, 2023 (<https://www.eurofer.eu/issues/environment/circular-economy/#:~:text=56%25%20of%20EU%20steel%20is, truly%20circular%20economy%20in%20Europe>).

10 Cooper et al., 2014 (<https://doi.org/10.1016/j.resconrec.2013.11.014>).

11 Tenova, n. d. (<https://tenova.com/node/339>).

SEVERAL STEEL DECARBONISATION OPTIONS ARE NEEDED

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Steel is a crucial material for the energy transition – the construction of wind turbines being a prime example. A windfarm with 1 GW capacity requires roughly 120 tonnes of steel. To produce this amount of steel through DRI one would need around 384 MWh of renewable electricity¹².

If we were to build enough windmills to produce the hydrogen needed to supply the twelve steel plants we analysed here¹³, one would need around 85 GW of new installed wind capacity¹⁴ equivalent to 31 % of what RePowerEU seeks to deploy between now and 2030¹⁵.

These windmills would require around 10.200 tonnes of steel. Consequently, an average wind turbine would have to run approximately 50 months¹⁶ just to generate the electricity needed for the hydrogen that one would require to produce the steel to build those windmills in the first place. Instead, this wind turbine could provide around 8.800 average European households¹⁷ with the means to decarbonise their electricity consumption.

Whichever way one looks at it, an exorbitantly high renewable electricity demand is the number one bottleneck to drastically reduce emissions and reach climate neutrality in the steel industry. The speedy deployment of such renewables is key to ensure a future for the European steel sector. However, given the size of the challenge, decarbonisation pathways relying on CCS for primary steel production need to be considered as a complementary decarbonisation route.

¹² Assuming a needed electricity input of 3,2 MWh per tonne of steel produced with green hydrogen DRI, see Bellona, 2020 (<https://www.frompollutiontosolution.org/casestudy-h2insteel>).

¹³ Assuming a full substitution of the entire production capacity. Only taking into account the announced DRI production capacity after the switch would result in around 26,5 GW of new installed wind capacity equivalent to 10% of what RePowerEU seeks to deploy between now and 2030.

¹⁴ Assuming a capacity factor of 30 % as a reasonable average between capacities of installed windfarms and expected capacities of new installations, see WindEurope, 2023 (<https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2022-statistics-and-the-outlook-for-2023-2027/>).

¹⁵ For context, through the measures adopted in the RepowerEU package, the EU aims to expand their total on- and offshore wind capacity from a currently installed 204 GW to 480 GW by 2030.

¹⁶ Assuming an average wind turbine of 3MW with a capacity factor of 30% would have to generate 13.440 MWh of renewable electricity to produce hydrogen for steel making.

¹⁷ An average European household consumes 3.7 MWh of electricity per year, see Odyssee-Mure, 2021 (<https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/electricity-consumption-dwelling.html>).

APPENDIX

	STEEL PLANT	COUNTRY	NOMINAL CRUDE STEEL CAPACITY (TTPA)*	CRUDE STEEL PRODUCTION 2021 (TTPA)*	CURRENT EMISSIONS (TT CO ₂ EQ/A)**
1	Integriertes Hüttenwerk Duisburg, Thyssenkrupp Steel Europe AG	Germany	13.000	11.560****	16.200*****
2	Acciaierie d'Italia Taranto steel plant, Arcelor-Mittal	Italy	11.500	4.100	7.585
3	Tata Steel IJmuiden steel plant	Netherlands	7.500	6.450	11.932
4	Dunkerque steel plant, Arcelor-Mittal	France	6.750	5.900	10.915
5	Voestalpine Stahl Linz steel plant	Austria	6.000	4.000****	7.400****
6	Hüttenwerke Krupp Mannesmann (HKM) steel plant	Germany	6.000	4.000***	7.100*****
7	Glocke Salzgitter, Salzgitter Flachstahl	Germany	5.200	4.300	7.200*****
8	ArcelorMittal Gent	Belgium	5.000	4.550	8.417
9	Dąbrowa Górnicza steel plant, ArcelorMittal	Poland	5.000	4.000	7.400
10	U. S. Steel Košice steel plant	Slovakia	4.500	4.473	8.275
11	ArcelorMittal Olaberria-Ber-gara (Olaberria) steel plant	Spain	4200	3421	6.328
12	Fos sur Mer steel plant	France	4000	3400	6.290
13	ArcelorMittal Bremen steel plant	Germany	3800	3300	6.400*****

14	GFG Liberty Ostrava steel plant	Czech Republic	3600	2280	4.218
15	Saarstahl Völklingen Steelmaking Plant	Germany	3540	unknown	4.200****
16	GFG Liberty Galati steel plant	Romania	3200	2300	4.255
17	TZMS Třinecké železářny Trinec steel plant	Czech Republic	2800	2400	4.440
18	AG der Dillinger Hüttenwerke Dillingen steel plant	Germany	2760	2281	6.000*****
19	SSAB Raahе steel plant	Finland	2600	unknown	3.700****
20	ArcelorMittal Eisenhüttenstadt steel plant	Germany	2400	1900	3.100*****

* according to Global Steel Tracker raw data (updated 2023) available at https://www.gem.wiki/Category:Steel_plants_in_Europe.

** Own calculation based on crude steel production from Global Energy Monitor, 2023 (https://www.gem.wiki/Category:Steel_plants_in_Europe) and average emissions data sourced from <https://www.frompollutiontosolution.org/casestudy-h2insteel>.

*** year 2020, no data for 2021.

**** own approximation due to lack of data.

***** sourced from WWF, 2023 (<https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Klima/WWF-DirtyThirty-Emissionen-Industrie.pdf>).



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