CCS in Steel
Kickstarting Europe's Steel Industry Decarbonisation
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European steel production alone is responsible for 5% of the CO₂ emissions in Europe. At the same time the steel industry direct and indirectly employs about 1.850,000 people, generates more than a 100 billion Euros of gross value added and is the base material for several important industrial sectors within the EU. It is of the utmost importance that steel in Europe is produced using low-emission processes, so that it can comply with net zero in 2050. In the IEA Net Zero Scenario, steel production emissions will need to decrease to 1 ton of CO₂ per ton of steel by 2030 to reach net-zero in 2050.

Direct reduction using renewable or green hydrogen can reduce emissions in steel production with almost 95% and is therefore the most promising way to decarbonise the steel sector. However, vast amounts of green electricity are required for the electrolysis of water to produce green hydrogen. This forms a significant bottleneck for hydrogen in the decarbonisation of steel. The scarcity of green hydrogen will mean that most steelmakers that do switch to Direct Reduced Ironmaking (DRI) as a mode of production in the short-term will be using fossil gas on their furnaces.

Furthermore, the conventional steel making route using coal of Blast Furnace–Basic Oxygen Furnace (BF/BOF) accounts for around 60% of the EU steel production. Such steel plants have a typical life of about 40 years, with the need for additional investment after 25 years. According to the IEA several of the existing blast furnaces in Europe are almost 25 years old and would be great candidates for investments in cleaner modes of production rather than BF/BOF. At the same time, several of Europe’s steelmaking capacity has recently undergone refurbishing works and other investments, this reduces the economic willingness and potentially feasibility for these steelmakers to switch technologies due to sunk costs.

This makes the use of Carbon Capture and Storage (CCS) in steel an option to cut emissions quickly in the following ways:

- The capture and storage of emissions from conventional blast furnaces in the short term.
- The capture and storage of emissions from DRI furnaces on fossil gas in the short to medium term.
- The creation of blue hydrogen for direct hydrogen reduction furnaces by capturing and storing CO₂ emissions from existing hydrogen production through CH₄ in the short to medium term.
- The capture of remaining emissions from metallurgic processes and off-gasses of electric arc furnaces even with direct hydrogen reduction with green hydrogen in the long term.

The case for CCS in steel is more compelling and necessary for 2030, with its relevance as a decarbonisation pathway diminishing in 2050 in favour of other technologies such as green hydrogen. As different decarbonisation options become available such as direct hydrogen reduction with green hydrogen scale up, the need for CCS in the steel sector will decrease over time. But ultimately, to fully decarbonise steel production, CCS remains necessary to tackle emissions that from the steelmaking process that cannot be otherwise decarbonised.
Introduction

The steel sector in Europe directly employs more than 300,000 people and indirectly employs 1.550.000 people. The industry directly and indirectly generates more than a 100 billion Euros of gross value added\(^1\) and steel is the base material for several important industrial sectors within the EU. Steel is also an important input for several technologies crucial to decarbonise Europe, such as wind turbines and solar panels. The demand for steel is expected to rise in the short- and long-term.

The global demand for steel is expected to increase by 11% from 1.8 billion tonnes in 2020 to 2 billion tonnes by 2030\(^2\). This trend will continue as the global steel demand is projected to rise by 30% in 2050\(^3\) compared to 2019, mostly fuelled by a rising demand in emerging economies. Steel demand is also set to rise in Europe’s main sales markets, namely Western Europe, Eastern Europe and Northern America. 95% of all steel produced in Europe is sold in these regions. The demand for steel in Western-Europe, Eastern-Europe and North America is set to rise by 11% by 2030, compared to 2021\(^4\). The demand in Western Europe will mostly remain stagnant with the most growth coming from Eastern-Europe and Northern-America. However, these future projections do not take into account potential effects the rebuilding of Ukraine after the Russian invasion could have on the general steel demand in Europe. According to the forecast by Bronk & Company the Ukraine war is one-time exogenous shock that cannot be predicted.

Due to heavy reliance on fossil fuels in the steel-making process, the iron and steelmaking industry is responsible for 5% of EU CO\(_2\) emissions\(^5\). In order to meet current and future demand in a net-zero world, steel must be produced using low-emission processes.

Setting the scene – Steel in Europe

Crude steel production in the EU27 amounted to around 136 million tonnes in 2022. This makes the EU the second largest steel-producer in the world, just behind China - producing 3 times as much steel as the EU. Nearly two thirds of crude steel production (both primary and secondary combined) within the EU comes from just four member states, namely: Germany, Italy, France and Spain. More than half of the steel produced comes from Germany.\(^6\)

The conventional steel making route of Blast Furnace–Basic Oxygen Furnace (BF/BOF) accounts for 90% of the world’s steel production according to the IEA, and around 60% of the EU steel production according to EUROFER. The blast furnace route mostly relies on coke, made from coal. This coal is used as a reducing agent, meaning that the coal creates a chemical reaction that extracts iron from iron ore (raw material) and adds the carbon content needed in order to make steel. The European steel primary production is made up of a fleet consisting of 25 plants. The remaining 43.3% is via electric arc furnace (EAF), mostly used for secondary steel. According to the IEA the emission intensity of secondary steel production with EAF is significantly lower than the BF/BOF route with only about 0.3 tonnes of CO\(_2\) per tonne of steel in direct and indirect emissions. In 2022, the volume of steel made via BF/BOF in Europe was 77 million tonnes. The BF/BOF route results in a large amount of emissions, in fact the average

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emissions intensity of the route according to the IEA is 2.2 tonnes of CO₂ per tonne of steel, this includes both direct and indirect emissions. This means that in 2022 169.4 million tonnes of CO₂ were emitted through steel production alone.

In the IEA Net Zero Scenario, steel production emissions will need to decrease to 1 ton of CO₂ per ton of steel by 2030 to reach net-zero in 2050. Within the EU, there are numerous “low-carbon” alternatives of producing steel being developed to be in line with climate neutrality by 2050 and the 55% reduction by 2030 (as compared to 1990). A map of low CO₂ emissions projects, meaning projects that aim to abate emissions in the steelmaking process by EUROFER, the European steel industry, shows that a majority of companies are considering green hydrogen for reduction as a pathway to net-zero, and only two Carbon Capture and Storage (CCS) projects are shown on the map at the time of publication.

**CCS in Steel – How would it work?**

Direct reduction using renewable hydrogen is hailed as the main solution for the steel production in a net zero world. Direct reduction with hydrogen produces steel using hydrogen to reduce iron instead of coking coal. Hydrogen is used as the main reduction agent in the process of making sponge iron through the direct reduction of iron ore in a shaft furnace. The resulting sponge iron is then used in the production of steel in an electric arc furnace (see figure 1). This reduces more than 95% of the emissions related to the steelmaking process. Switching to DRI (Direct Reduced Ironmaking) compared to the conventional blast furnace route.

![Figure 1: Hydrogen use in Industry. Source: From Pollution to Solution (Bellona Europa, 2020).](https://www.eurofer.eu/issues/climate-and-energy/maps-of-key-low-carbon-steel-projects)

Vast amounts of green electricity are required for the electrolysis of water to produce hydrogen. This forms a significant bottleneck for hydrogen in the decarbonisation of steel.

In the REPowerEU Package, the EU sets to wean itself off from Russian gas, by betting big on hydrogen. In the package, the EU hopes to produce 10 Mt of hydrogen at home and to import 10 Mt hydrogen. For

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the currently projected 10 Mt of hydrogen in the EU, nearly 500 TWh would be needed to produce it via electrolysis. This volume of electricity is more than the yearly electricity consumption of France.9

At the same time most blast furnaces in Europe are still BF/BOF furnaces. According to the IEA's Iron and Steel Technology Roadmap,10 the typical life of such steel plants is about 40 years, however after 25 years a blast furnace would need additional investment to have its internal refractory lining replaced. This is an opportune moment to invest in new technologies that would decarbonise the whole process. According to the IEA several of the existing blast furnaces in Europe are almost 25 years old and would be great candidates for investments in cleaner modes of production rather than BF/BOF. At the same time, several of Europe's steelmaking capacity has recently undergone refurbishing works and other investments, this reduces the economic willingness and potentially feasibility for these steelmakers to switch technologies due to sunk costs. Decarbonisation of these plants will be crucial to keep EU in line with its climate targets.

When it comes to the role of CCS in decarbonising the steel industry, there are several aspects to consider. On the one hand, steel production facilities tend to be located in industrial clusters near other industries that also need to decarbonise, as outlined in Bellona's CCS ladder. This presents an opportunity for proximity to future CCS and hydrogen infrastructure. On the other hand, there are limitations of carbon capture within a blast furnace stemming from the existence of multiple streams of flue gases, meaning multiple points of emissions. Across the steelmaking process, there are several points where CO2 can be captured. The largest source of emissions comes from the blast furnace itself, around 70% of the entire process.11 With a capture rate of 90%, this results in 63% of emissions from the full production process captured. When this CO2 is permanently stored, these emissions are hindered from reaching the atmosphere and contributing to further climate change - they are thus so-called abated emissions. By including flue gas streams from other sources within the steel making process (coke oven, sintering and blast oxygen furnace) a further 27% of emissions can be captured, resulting in 87% of total emissions from the full production process captured, and if stored subsequently abated emissions. Top gas recycling, which cycles the CO and H2 from the output of the blast furnace back into it, increases the overall efficiency of the combustion process and produces a purer stream of CO2, which can then be captured. This process of producing a purer CO2 stream and the general accumulation of flue gas streams from different point sources adds to the cost and complexity of CCS in steel. Furthermore, at the moment steel mills use part of their flue gasses for energy production, this means that capturing these gasses and storing them permanently could add to the energy requirement of a steel plant.

Furthermore, the resource constraint surrounding green hydrogen because of its huge demand of renewable electricity creates a huge bottleneck for European steelmakers looking to switch technologies from BF/BOF to DRI. The scarcity of green hydrogen will mean that most steelmakers that do switch to DRI as a mode of production in the short-term will be using fossil gas on their furnaces. There is however some discussion on how big the emission reduction is when switching from traditional BF/BOF to DRI with fossil gas. According to the IEA the CO2 intensity of the direct and indirect emissions of the classic BF/BOF route is 2.2 tCO2/t compared to 1.4 tCO2/t with a fossil gas based DRI-EAF. This means that the switch to fossil based DRI would cut emissions by 36%. Yet other sources assert that the gains can be even higher, citing a 72% reduction of CO212 when switching from conventional coal-based blast furnaces to fossil gas DRI. This emission reduction be it 36% or 72%, or an emission intensity of 1.4 tCO2 /t is not in line with the action needed from the steel sector to ensure net zero by 2050. As

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9 Yearly electricity consumption of France in 2023 was 464.19 TWh: https://ember-climate.org/countries-and-regions/countries/france/
10 https://www.iea.org/reports/iron-and-steel-technology-roadmap
12 Conde et al (2021) DOI: https://doi.org/10.1051/mattech/2022002
mentioned before according to the IEA Net Zero Scenario, steel production emissions will need to decrease to 1 ton of CO₂ per ton of steel by 2030 to reach net-zero in 2050.

CCS can play a role here by capturing CO₂ emissions from the fossil gas based DRI plant and by permanently storing these emissions, abating the emissions that arise from the use of fossil gas. This would bring steel production closer to net zero. There is already real-life example of steel being produced in this way. In 2016 the world’s first commercial DRI plant with CCS was commissioned in Abu Dabi; the Al Reyadah project13.

CCS can play a role when it comes to hydrogen direct reduction as well. Currently, hydrogen is mostly produced via steam methane reformation (SMR). The emissions from this process can be captured and permanently stored. This form of hydrogen production, tagged as blue hydrogen, can supply the needs for steel production in the short to medium term. CCS in hydrogen production via fossil methane can play an interim role until renewable electricity production can scale up to meet the additional needs of hydrogen for steel production.

Furthermore, even with enough hydrogen to produce steel in this way, there’s still some CO₂ being emitted through the burn-off of carbon electrodes in electric arc furnaces used in the production of both primary and secondary steel. The metallurgic process of making steel also requires some carbon to enrich the iron ore. This carbon can either be sourced through scrap, through fossil coal or gas or through biomass. In either case, a small amount of CO₂ will still be emitted if it’s not captured and stored permanently. In the case of sustainably sourced biomass, the CO₂ captured and stored could be counted as a carbon removal. In short, CCS will still be necessary in a scenario where all steel is being produced through direct reduction with green hydrogen for the residual emissions.

**Zoom-in Top 10 Steel producers in Europe**

Taking a deeper dive into the top 10 producers of steel in the EU it is clear that green hydrogen DRI with green hydrogen takes a leading role. Of the ten, seven steel plants have hydrogen projects for direct reduction of iron in both the mid and long term. With 50 kg of hydrogen required for 1 tonne of steel14, the cumulative demand of hydrogen for these 7 plants (49.5 t of steel) is 0.90 Mt resulting an electricity demand of 49.5 to 54 MWh.

The current investment strategies and plans of these plants, as researched by Bellona, does not make it financially likely that that such conversions of all blast furnaces will be completed by 2030. The fact that the cumulative demand of only 7 steel plants in Europe would almost need 1/10th of the total projected hydrogen production in Europe by 2030, illustrates how constrained green hydrogen is as a resource.

The overwhelming choice for hydrogen by the EU’s top 10 steel producers would allow them to cut emission drastically. At the same time, if these producers with plans to convert to hydrogen DRI were to replace their entire current production capacity with hydrogen direct reduction, each steel plant would require a vast amount of the currently available renewable electricity. For direct reduction with green hydrogen to truly be green, the hydrogen used needs to be produced by additional green electricity, or else hydrogen stands to cannibalise the renewables meant to decarbonise our electricity grids.

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13 [https://fossil.energy.gov/archives/csf/Projects/AlReyadah.html](https://fossil.energy.gov/archives/csf/Projects/AlReyadah.html)
Because of the resource constraints surrounding green hydrogen, this solution should be coupled with other solutions for emission reductions. To decarbonise steel production we need different complimentary emission reduction strategies such as: optimising steel use, increasing the recycling rates, shifting towards more use of secondary steel and the re-use of steel products as well as Carbon Capture and Storage (CCS).\(^\text{15}\)

<table>
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<tr>
<th>Steel Plant</th>
<th>Country</th>
<th>Nominal Capacity (tpa)</th>
<th>Emissions - Endra 2022 (Mt)</th>
<th>Hydrogen plans</th>
<th>CCS plans</th>
<th>Other plans</th>
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</table>

**Climate value of CCS applications in Steel**

In a nutshell, CCS could play a role in dramatically reducing emissions in European steel manufacturing in the following ways:

1. The capture and storage of emissions from conventional blast furnaces
2. The capture and storage of emissions from DRI furnaces on fossil gas
3. The creation of blue hydrogen for direct hydrogen reduction furnaces by capturing and storing CO\(_2\) emissions from existing hydrogen production through CH\(_4\)
4. The capture of remaining emissions from metallurgic processes and off-gasses of electric arc furnaces even with direct hydrogen reduction with green hydrogen

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In the CCS ladder, a publication by Bellona, E3G and independent authors, we assess the climate value of different CCS applications in Europe, including different steel production methods.

In the short-term (2030) Bellona’s CCS ladder prioritises public support for CCS applications in the case of fossil Gas DRI-EAF (electric arc furnace) steel and Hisarna steel. The mitigation potential for both modes of production is high and in the short term there are not many alternatives. In the case of fossil Gas DRI-EAF there is the possibility of switching to green hydrogen once available. On top of that the modes of production have centralised plants making it fairly easy to capture the CO₂. However, because the source of the CO₂ is from a fossil origin, by 2050 once green hydrogen is more readily available, that is the preferred option for the highest climate value.

When it comes to CCS projects on BF/BOF steel, Bellona asserts that the financial burden should be on the emitter. Wherever possible, phasing out of conventional blast furnaces running on coal and opting for steel production via direct reduction is a preferable move to cut down emissions. Just switching to fossil gas from coal will not get us to net-zero since as stated before the emission reduction varies from 36% to 72%. Beyond this, stating that unabated fossil gas is an interim solution until green hydrogen is available at scale for the sector, is a delay of climate action. CCS on fossil gas can be a viable emissions reduction strategy for the short to medium term.

In conclusion, based on this analysis the case for CCS in steel is more compelling and necessary for 2030, with its relevance as a decarbonisation pathway diminishing in 2050 in favour of other technologies such as green hydrogen. This is because, as outlined, that BF/BOF furnaces operating on coal have several potential CO₂ capture points and require some investments and other complexities to purify and accumulate the different CO₂ streams. This makes CCS, though needed to abate these emissions, expensive. But at the same time, as different decarbonisation options become available such as direct hydrogen reduction with green hydrogen scale up, the need for CCS in the steel sector will decrease over time. But ultimately, CCS remains necessary to do away with the residual emissions that stem from the steelmaking process and to fully decarbonise steel production.