# CHALLENGES OF THE STEEL INDUSTRY – LEAVING CARBON BEHIND


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SYNOPSIS:

Steel, with its high strength-to-weight ratio, recyclability, and relatively low production costs, will remain invaluable for various sectors for decades to come. Yet, as the realities of climate change around the globe bring heavy industries under increased scrutiny, the iron and steel industry is being pressed to transform based on changing legislation and regulations worldwide. While contributing nearly 10% of global carbon emissions and with market demand showing no signs of slowing down, the steel industry must face the challenges of climate change head-on as it leaves carbon behind.



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## THE CHALLENGE OF CLIMATE CHANGE

Since the Paris Climate Agreement in 2015, countries and governments worldwide have pledged their commitment to net-zero carbon emissions. As a result of the most recent UN Climate Change Conference, COP26 in Glasgow, United Kingdom, 90% of global emissions are now accounted for by net-zero commitments [1]. Although some critics have argued that progress has been slow, participants addressed crucial steps toward carbon neutrality at COP26, including phasing out coal, reducing methane emissions, and halting and reversing deforestation [1]. While the conference addressed immediate concerns facing the globe and climate change, its focus remained on coal consumption in the energy sector and setting realistic goals for countries reliant upon coal as an energy source. However, as pressures mount to reduce the use of coal in the energy sector, the steel industry will also experience pressures to reduce emissions and move away from fossil fuels, which currently still account for a 70% share of energy consumption per ton of steel [2].

According to the International Energy Agency (IEA) and the 'Iron and Steel Tracking report' from November 2021, steel demand has steadily increased by approximately 3% per year, excluding a brief plateau from 2013 to 2016 and a limited decline of 0.9% 2020 [2]. While McKinsey & Company predicted a slight increase of just 0.8% per year from 2016 to 2025, production from 2019 compared with 2021 still saw a 2% increase despite the decline in 2020 [3]. One thing is clear, no matter how volatile, steel demand will undoubtedly increase over the coming decades. Primetals Technologies' analysis forecasts steel demand of about 2,200 million tons in 2050. With steel demand set to rise, steel producers will have to track the fluctuating costs of raw materials and anticipate the price of carbon as well.

## THE COST OF CARBON

The European Green Deal from 2019/2020, which proposes mechanisms to cut greenhouse gas emissions by 55% by 2030 over 1990 and reach neutrality by 2050, is one of the more stringent pieces of legislation impacting all industry sectors in Europe. In July 2021, the Carbon Border Adjustment Mechanism (CBAM) was also proposed to prevent carbon leakage from at-risk industries and is likely to be launched by 2023. This mechanism is designed to allow EU importers to purchase carbon certificates corresponding to the carbon price that would have been paid had those products been produced in the EU. The mechanism also applies to exporters, who can demonstrate their payment for the carbon emitted during the production of the imported good, which can subsequently be deducted from the EU importer. Amongst the industry sectors chosen for the new mechanism is the iron and steel sector, which is labeled a high-risk sector for carbon leakage and increased carbon emissions.

The cost of these tax adjustments will continue to play a more decisive role for producers. In February 2022, we have already seen a sky-high price of more than 90 euros per ton of $CO_2$ as per the Emissions Trading System (ETS) (Figure 1). With an average of 1.4 tons of $CO_2$ produced for every ton of crude steel, according to the IEA, and integrated steel mills reaching between 1.7 and 2.2 tons, the price per ton of $CO_2$ will play a significant role for steel producers [2]. After the free allocation phase for carbon certificates ends, likely in 2035, ETS price levels for every million tons of steel produced will account for about 150 million euros each year. The rising price of EU carbon permits might be one of the critical motivators to invest in a green steel future. And while all signs point to a transition away from carbonintensive steel production, the question remains, how will the steel industry effectively move away from fossil fuel based steel production?


**Fig 1** EU Carbon Permit prices as per the EU Emissions Trading System

## BREAKTHROUGH TECHNOLOGIES

Several breakthrough technologies lead the way toward carbon neutrality for the steel industry, reducing carbon emissions, contributing to the circular economy and playing an integral role in the future of climate neutrality worldwide. Anticipating an increase in renewable energy infrastructure, the electrification of steel production, increased scrap-based steel production and increased use of direct reduction with natural gas and hydrogen, the steel industry will see a transition toward net-zero emissions over the coming decades. However, this transition will not happen overnight. Instead, the shift toward carbon neutrality for the steel industry will occur gradually and in phases. New technologies present the opportunity to act early and be prepared for the future.

The steel sector has already kicked off an initial transition phase with the potential to reduce its carbon footprint by up to 30%. The steel sector has implemented multiple improvement packages that focus on energy efficiency, yield improvement, new lightweight steel grades, circular economy and other process improvements. In these early transition phases toward carbon neutrality, the spotlight is on readily available technologies, including electric steelmaking using electric arc furnaces (EAF) and the incorporation of Endless Strip Production, such as Arvedi ESP. These technologies will help to immediately reduce carbon emissions by removing steps that emit increased amounts of CO2, including coke batteries, agglomeration plants, blast furnaces, basic oxygen furnaces (BOFs), and the fossil fuel fired reheating of slabs for downstream processing. Hybrid mills that operate both BF/BOF and EAFs will become a trend for steel producers transitioning to electric steelmaking. And as scrap usage and electric steelmaking expand, a closer look at supply chain management and the integration of Industry 4.0 strategies will be essential to increased sustainability in the steel industry.

## INDUSTRY 4.0 AND SUSTAINABILITY

While mini-mills will ensure improved energy efficiency and benefit the circular economy, the reality of the supply chain for input materials will become more and more relevant as time goes on. Incorporating Industry 4.0 into sustainability practices of steel producers and supply chain management may go a long way toward improving overall emissions. Studies have shown immediate sustainability improvements and performance improvements by integrating Industry 4.0 solutions [4]. In sustainable supply chains worldwide, assessing backward logistics integration, environmental indicators, CO2 emissions, and recycling and recovery will make Industry 4.0 technologies integral to a transition to sustainable steel production [5].

An essential aspect of incorporating Industry 4.0 technologies into the steel industry, especially concerning the supply chain, is the use of scrap. As previously mentioned, scrap recycling and reuse in electric arc furnaces allow for the lowest carbon footprint in steelmaking. However, several drawbacks impact the immediate value in use of scraps, making it part of mid-term goals for steel producers. Increased demand for steel means an increased demand for high-grade steel. Due to contaminants, such as copper, sulphur, and phosphorus, scrap cleaning is necessary and must be continuously improved to meet steel grade standards. Scrap cleaning, sorting and automatic identification to produce ‘designer scrap’ will be essential to increasing scrap's recyclability.

A fully automated scrap yard integrated into either an EAF, or BOF process control system would simultaneously increase efficiency and reduce emissions. Yet, scrap availability still poses the most significant problem to the feedstock. Studies report a global scrap availability of around 900 million tons per year in 2050, while demand will reach about 2,200 million tons of steel in the same year. Thus, the amount of steel unable to be produced by recycled scrap requires virgin iron ore feed. Fortunately, the potential to reduce CO2 emissions in this area is high.

## DIRECT REDUCTION: A CORNERSTONE TO ACHIEVING NET-ZERO EMISSIONS

To compensate for the limited amount of scrap available worldwide and allow for high grade steel production, increased use of Direct Reduced Iron (DRI) and Hot Briquetted Iron (HBI) will play a crucial role in decarbonizing the steel industry. More direct reduction facilities utilizing the MIDREX direct reduction process, or others based on natural gas will significantly decrease CO2 emissions. Direct reduction based on natural gas and EAFs powered mainly by renewables can reduce CO2 emissions by 65% compared with the BF/BOF route. However, the production of DRI is based on high grade pellet feed. As blast furnaces will gradually be blown down over the coming decades, the lower grade, blast furnace iron ore will have to find its way into direct reduction. While there is no immediate concern for the direct reduction process per se, higher gangue amounts persist in DRI/HBI and will generate vast quantities of slag, of 300 kilograms or more per ton of steel in an EAF. Maintaining an appropriate metal yield requires electrically heated smelter furnaces under a reducing atmosphere, which allow a vastly reduced slag with a low iron oxide content, likely suitable for use in the cement industry. Smelter furnaces are mainly heated by resistivity without any free arcing, maintaining a long refractory campaign lifetime. However, no one transition technology is enough to achieve net-zero ‘green steel’.

## HYDROGEN-BASED REDUCTION

Steel producers looking for the most environmentally friendly production route will turn from fossil fuel-based processes toward hydrogen based technologies to reach net zero emissions. For example, the MIDREX direct reduction process, which already reduces CO2 emissions by 65% using natural gas, can transition to operate partly, or entirely on hydrogen. And when combined with green hydrogen produced by renewable energy, steel producers have the most environmentally friendly production route. While the Hydrogen/EAF route still has slightly higher CO2 emissions than 100% scrap based EAF steelmaking powered by renewables, the virgin, high quality feed material can accommodate high end steel grades, a limitation with the scrap EAF route. However, this route faces its own set of challenges. By relying on high grade iron ore to produce high grade DRI, the limited availability of high grade iron ore will present a new challenge.

While shaft-based DR processes require pellet feed and additional pelletizing plant capacity and since not all ores are suitable for pelletizing, the challenge of low grade iron ore in the production route remains. Primetals Technologies is already addressing this challenge and has been developing the hydrogen based fine ore reduction, or HYFOR, technology (*Figure 2*).

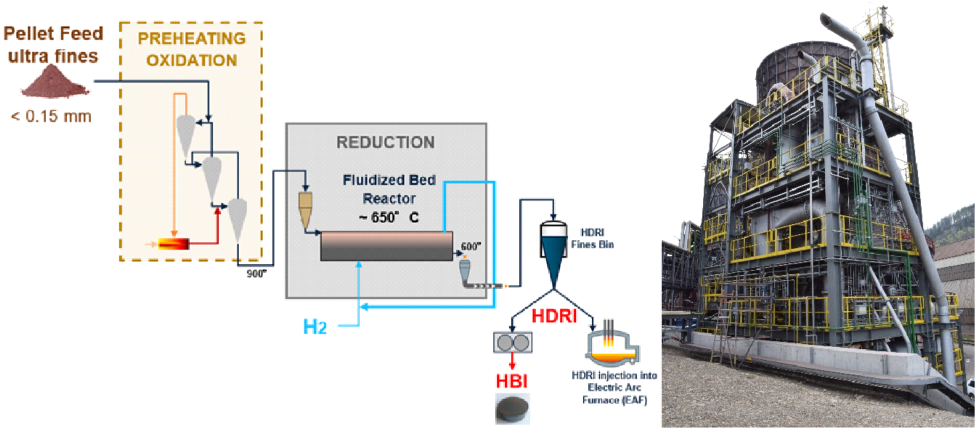


**Fig 2** HYFOR process flow sheet (L) and the pilot plant installation (R)

After several years of initial lab scale and simulation test work, a pilot plant at the voestalpine works in Donawitz, Austria, has been installed. HYFOR went into operation in June 2021. Since then, it has caught the attention of many in the industry for its innovative direct reduction process; the direct use of iron ore fines and pure hydrogen. It removes the necessity to invest in a pelletizing plant for steel producers, sparing crucial investment capital. Moreover, regions rich in low grade iron ore fines have an opportunity to put their natural resources to immediate use in the steelmaking process. While these solutions appear to demonstrate the steel industry's grip on the situation, the slow transitional phase has only just begun. Moreover, steel producers will reach carbon neutrality via diversified steel production in a more global and modular approach with mixtures of various technologies worldwide. According to Primetals Technologies own research, the steelmaking processes will see a significant shift toward DR/EAF/Smelter routes over the following decades, but no one process will dominate the industry (Figure 3).

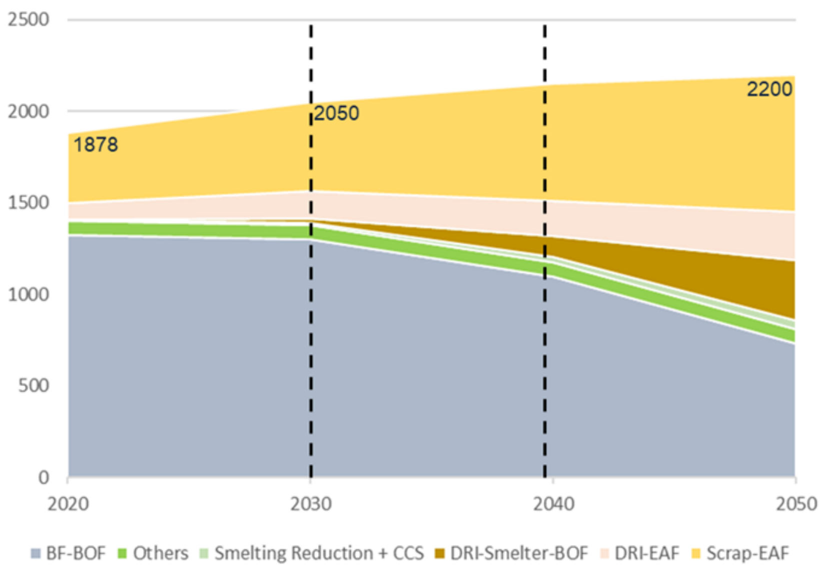

**Fig 3** Primetals Technologies forecast of the shift to DR, EAF and smelter routes

## VARIOUS CHALLENGES, A VARIETY OF SOLUTIONS

As the steel industry begins its transformation, the question of how each phase will impact each producer will vary across the globe, depending on natural resources, energy prices, and regional legislation. The speed and voracity of the transition will be determined by industry leaders motivating partners worldwide, to respond to the challenge presented by climate change. This transition will also depend on the adoption of multiple technologies, as there will be no one-size-fits-all solution for such a diverse industry. For example, within the next several decades there will be an increase of nearly 150 new direct reduction plants and 50% of them will operate on low grade iron ore by 2050. Additionally, HBI is traded only to a limited extent today. In the near term, direct reduction plants based on natural gas will gradually switch to hydrogen as soon as it is economically viable and at scale. To directly convert steel production and direct reduction plants to hydrogen would mean 72 million tons of hydrogen per year and 4000TWh of green renewable electricity per year.

Achieving net zero emissions and hydrogen production at scale will require large scale, stable renewable power grids to grow the electrification pathway, a developed green hydrogen economy, and the establishment of carbon capture utilization and storage (CCUS). As the electrical grid transforms and the hydrogen economy expands, what will begin as an increase in direct reduction and EAF steelmaking will mark a decline of BF/BOF steelmaking from 70% of the market share to 33% by 2050.

With an increase in CCUS technologies, the IEA anticipates that by 2050 CCUS will process approximately 400Mt of CO2 per year, meaning carbon intensive industries will, in part, reach their net zero goals via CCUS. As a part of the MHI Group, Primetals Technologies benefits from its full spectrum of decarbonizing solutions for the steel sector, including CCUS with their unique Kansai Mitsubishi Carbon Dioxide Recovery Process (KM CDR), shown in Figure 4, and H2 electrolysis, compression, distribution, and shipment technologies.

A recent study in 2020 explored the application of the KM CDR Process on a coal-fired power plant [6]. This study concluded that a 99.5% capture rate is technically feasible with the KM CDR process, including relatively normalized OPEX and a mere 6% increase in CAPEX to achieve 99.5% compared with the base case of 90% [6]. Yet, this study only examines the theoretical capture capabilities of KM CDR for CO2 from a coal fired power plant. The steel industry has several off gas treatment solutions and low carbon steelmaking solutions, meaning the steel sector is primed to act efficiently and economically to reduce CO2 emissions and incorporate CCUS. These technologies combined will form the basis for ‘green steel’.


**Fig 4** KM CDR Process Commercial Achievements worldwide. Courtesy of MHI.com and Mitsubishi Heavy Industries, Ltd.

## THE GREEN STEEL PHASE: LEAVING CARBON BEHIND

The Green Steel Phase is based on three pillars:

1. Electrification
2. Carbon Direct Avoidance (CDA)
3. Carbon Capture Utilization and Storage (CCUS)

### Electrification

Looking plainly at the steel industry and the increasing demands for steel production in the coming decades, means there is a massive increase needed in clean, renewable energy to match the demands of this energy intensive industry. First, to feed a significant number of electric furnaces and second to produce the green hydrogen required to replace carbon based reductants. Additionally, renewable energy, such as solar and wind energy, needs more steel per energy unit built than most fossil fuel powered plants. An increase in the adoption of renewable energy also means an increase in the amount of steel needed by the energy sector.

### CDA

The principal reduction process for iron ore is limited to three pathways: carbon based reduction, which has been a common practice to date, hydrogen based reduction, which is anticipated in the near future and direct electrolysis of steel, which is still in its infancy. The only realistic scenario today remains to establish a hydrogen economy. Recent large scale hydrogen projects address two main roadblocks: hydrogen production at scale and the feasibility of renewable based hydrogen production. A mid-term green hydrogen price of less than $2/kg suggests these roadblocks will diminish sooner, rather than later.

**CCUS**

Asset lifetime in the steel sector exceeds 40 years, and many upstream ironmaking facilities in India, China and other regions are still very young. Here, Carbon, Capture, Utilization, and Storage (CCUS) comes into play. CCUS captures CO2 with state-of-the-art processes, like Mitsubishi Heavy Industry's KM CDR amine scrubber based capturing system. After capture, the concentrated and pure CO2 can be compressed and safely stored underground. Alternatively, it can be used for Enhanced Oil Recovery purposes (EOR), or to produce base chemical products. For example, LanzaTech's proprietary microbial fermentation process ferments CO2, CO, and hydrogen into ethanol, or eFuels, and other base chemicals.

**CONCLUSION**

The ability of the steel industry to leave carbon behind rests not only with steel producers, but with several industries reliant upon one another to move forward toward carbon neutrality. New partnerships will gradually emerge worldwide as the availability of inexpensive renewable energy and raw materials will decide how and where industry leaders appear and may inform how current leaders adapt to maintain their position. The IEA names several vital research projects working toward net-zero emissions, which involve international cooperation, emphasizing climate change as a global challenge and signaling the interconnected nature of the steel industry. In this spirit, Mitsubishi Heavy Industries Group and Primetals Technologies joined the Heavy Industries Low-carbon Transition Cooperative Research Centre (HILT CRC) in Australia, dedicated to decarbonizing its heavy industries sector. Steel producers will soon feel the impact of these research efforts as energy costs, carbon border taxes, and raw material acquisition play a role in the steel industry's future.

Most importantly, the technologies available to reduce carbon emissions apply across the production chain from agglomeration to primary and secondary metallurgy to rolling. The path forward for the steel industry to net-zero emissions will be complex and winding, but innovations such as HYFOR and KM CDR help maintain optimism. With the realities of climate change set in, there is a call for steel producers to overcome these challenges, adopt future ready solutions, adapt to hydrogen based electric steelmaking and leave carbon behind.

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