Green Steel Production

Pathways for India

October 2024

INDIA GREEN STEEL COALITION

Confederation of Indian Industry

WWF

EY Parthenon
Building a better working world

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List of Common Abbreviations

BaU
Business as Usual

BF
Blast Furnace

BOF
Basic Oxygen Furnace

CCUS
Carbon Capture, Utilization, and Storage

DRI
Direct Reduced Iron

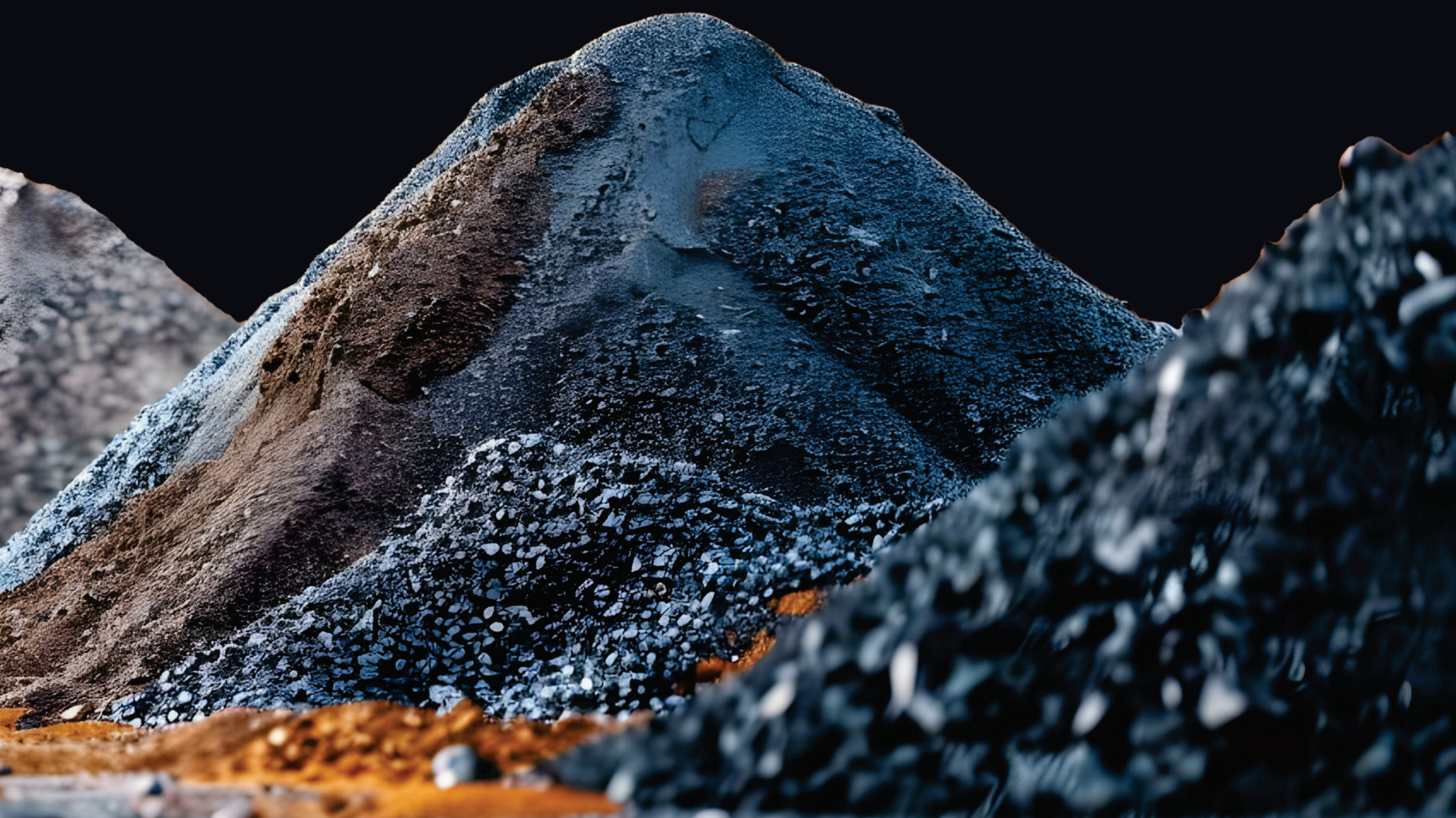
EAF
Electric Arc Furnace

FeMn
Ferromanganese

FeSi
Ferrosilicon

MMTPA
Million metric tons per annum

RE
Renewable Energy



01

Executive summary

The steel industry has been a cornerstone of economic development, with global production rising steadily due to industrialization and infrastructure growth. Despite a temporary plateau during the post-pandemic economic recovery, with a slight decline in demand in 2022 and 2023, the sector is poised for a resurgence. The World Steel Association predicts a robust increase in demand by 2024, particularly in India, where an 8% growth is expected over two years. China's dominance as the top producer and exporter is complemented by India's strong position as the second-largest steel producer. The traditional BF-BOF route, dependent on virgin iron and coking coal, remains the most carbon-intensive and widely used method, representing 71% of global steel production. In contrast, the EAF process, which utilizes steel scrap, presents a more sustainable alternative with a lower carbon footprint. The EAF's share is set to grow, driven by its flexibility, the steel industry's net-zero ambitions, the falling costs of renewable energy, and tightening environmental regulations.

India's steel production has been growing robustly, fueled by swift economic growth, government incentives for domestic manufacturing, and rapid urbanization. The Ministry of Steel's ambitious targets under the National Steel Policy aim for a capacity of 300 MTPA and a production level of 255 MTPA by 2030. The BF-BOF method accounts for ~43% of India's steel output, with Induction Furnace and Electric Arc Furnace contributing ~35% and ~22%, respectively. The majority of secondary steelmakers use coal-based DRI as the primary raw material, leading to significant CO_2 emissions. India's status as the top DRI producer, with a substantial portion derived from coal, underscores the need for a shift towards greener practices.

With the steel sector at a pivotal point, the urgency to reduce emissions is met with the high costs of adopting low-carbon technologies. India plans to maintain the BF-BOF route as the mainstay of production, which will result in a dramatic increase in CO_2e emissions. The expansion of steelmaking capacity through the BF-BOF route amplifies the need for decarbonization to mitigate the risks of market contraction and competitive disadvantages in environmentally conscious markets.

In the report, we performed an analysis of a steel company with a 15 MMTPA steel production using the BF-BOF method. The analysis showcases how renewable electricity, green hydrogen injection in blast furnace, and Carbon Capture can significantly reduce emissions in BF-BOF. Going forward, when the company decides to expand the production levels through green steel production pathway to reach 20 MMTPA production, the emission intensity potentially fall from 2.33 tCO_2/tsteel in FY24 to 0.22 tCO_2/tsteel by FY50. This highlights the possibility of continued brownfield BF-BOF decarbonized operations while also adapting green steel technologies as greenfield initiatives. This transition aligns with the Science Based Targets initiative's 1.5ºC Iron & Steel guidance.

The concept of green steel lacks a single definition, with various industry standards and initiatives setting different emissions targets and focusing on distinct aspects of production. Key standards suggest emissions intensity targets ranging from 0.05 to 0.4 tons of CO_2 per ton of steel.

Industry standards indicate that green steel can be produced with near-zero emissions using Green Hydrogen in Direct Reduced Iron (DRI) for primary production and scrap in Electric Arc Furnaces (EAF) for secondary production. These methods significantly reduce emission intensity compared to traditional steelmaking. Our analysis shows how the Natural Gas-based DRI, BF-BOF with Carbon Capture, and Scrap-based EAF cut emissions by 41%, 50%, and 71%, respectively, due to cleaner combustion, CO_2 capture, and the use of recycled materials. Renewable-powered EAFs and Green Hydrogen DRI processes can achieve up to 88% and 97% lower emissions, respectively. Under the projected Indian carbon pricing scenario, the production cost of green steel using the hydrogen-based direct reduced iron (H_2-DRI) method is expected to be $441 per ton of steel by FY35. This represents a 24% cost reduction compared to the $581 per ton of steel produced via the traditional blast furnace-basic oxygen furnace (BF-BOF) route.

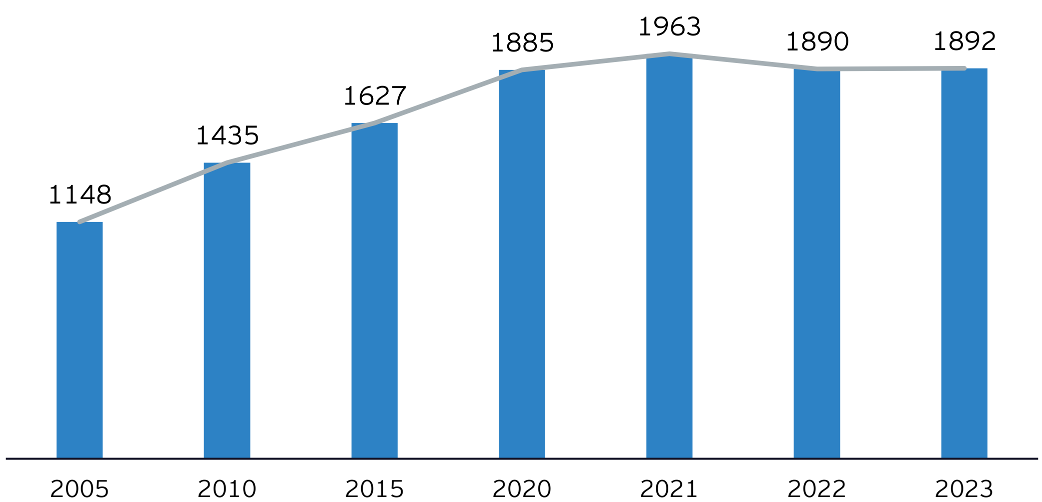
Adopting green steel production technologies is in line with worldwide environmental objectives and provides Indian steelmakers with a competitive edge in a market that is progressively prioritizing sustainability. This shift not only invites fresh investment and innovation in the sector but also prepares Indian manufacturers to take advantage of international trade policies that are increasingly biased towards low-carbon products. Indian steelmakers who actively minimize their emissions could enjoy favored entry into select markets. Additionally, the successful implementation of green steel methods will require the establishment of conducive policies, the enhancement of infrastructure, and the upskilling of the workforce to facilitate a seamless transition to these eco-friendly technologies.

02

Steel sector: global and Indian outlook

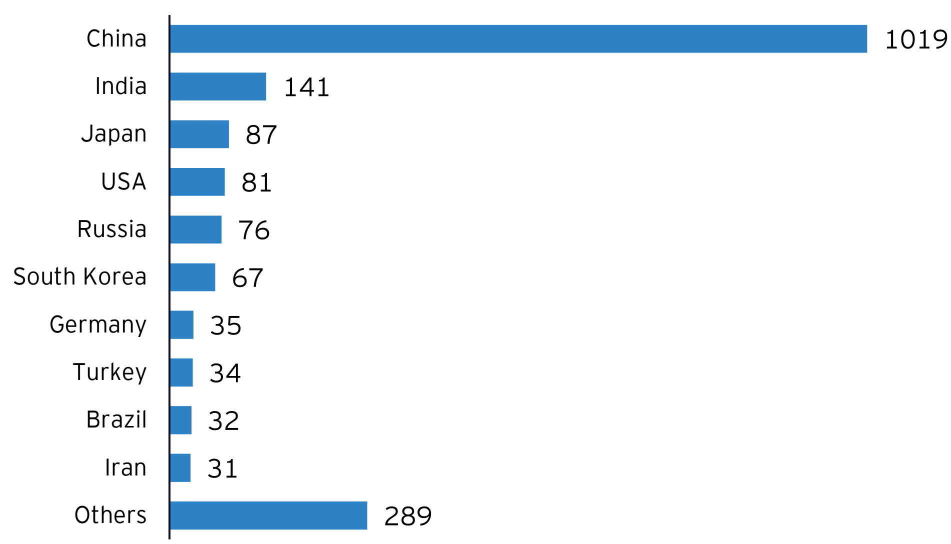
The global steel production has witnessed a steady rise over the past few decades, driven by rapid industrialization, urbanization, and infrastructure development in emerging economies. The crude steel production faced a stagnation period during post-pandemic economic recovery, following continuous decline in demand in 2022 and 2023. However, as per World Steel Association, the global demand is anticipated to resurgent in 2024, and continue to grow in 2025. This projection is primarily ascribed to India, where demand is expected to surge by 8% over the next two years.[1] China continues to dominate the sector as the world's largest producer and exporter of steel, whereas India has maintained its position of the 2nd largest steel producer.

Figure 1: Global crude steel production (million tons) over the years



Source: World Steel Association, World Steel in Figures 2024

Figure 2: Country wise crude steel production (million tons) in 2023



Source: World Steel Association, World Steel in Figures 2024

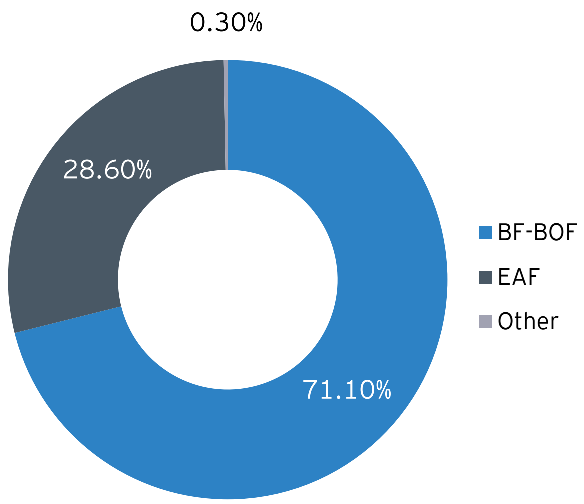
[1] World Steel Association, April 2024, worldsteel Short Range Outlook

The highly carbon intensive Blast Furnace – Basic Oxygen Furnace (BF-BOF) is the traditional route, which relies on virgin source of Iron and coking coal, has the highest rated installed capacity in terms of steel production. On the other hand, the Electric Arc Furnace (EAF) process, which primarily uses steel scrap as feedstock, offers lower carbon footprint. In 2023, around 71% of the global steel production was via BF-BOF route, complemented by 28% of steel production from EAF route. The relative share of the .

EAF route may evolve in times to come driven by factors such as:

- Flexibility in terms of utilizing diverse raw materials like Scrap, Direct Reduced Iron (DRI)
- Realizing steelmaker's net zero ambitions
- Declining costs of renewable energy
- Environmental regulations & mandates

Figure 3: Split of steelmaking routes in 2023



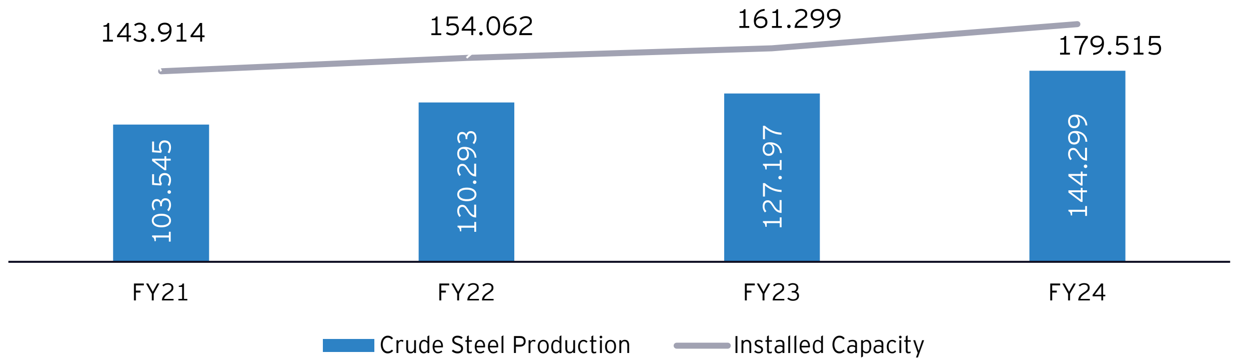
Source: World Steel Association, World Steel in Figures 2024

While the global crude steel production output remained flat, with a mere 0.1% rise in crude steel production levels in 2023 compared to 2022, India's production levels have ramped up significantly in recent years. India's swift economic growth, along with government's incentives for domestic manufacturing, investments in infrastructure and rapid urbanization are the key drivers bolstering the production to meet the required demand.[2] In response to the anticipated rise in demand, the Ministry of Steel has established a lofty goal within the framework of the National Steel Policy (NSP) to achieve a capacity of 300 million tons per annum and a production level of 255 MTPA by the year 2030.[3] Over the previous four years, India has experienced a substantial increase of approximately 45% in the consumption of finished steel, highlighting a significant uptick in the country's internal demand for this material.

[2] Joint Plant Committee, August 2024, Indian Steel Industry – A Trend Report

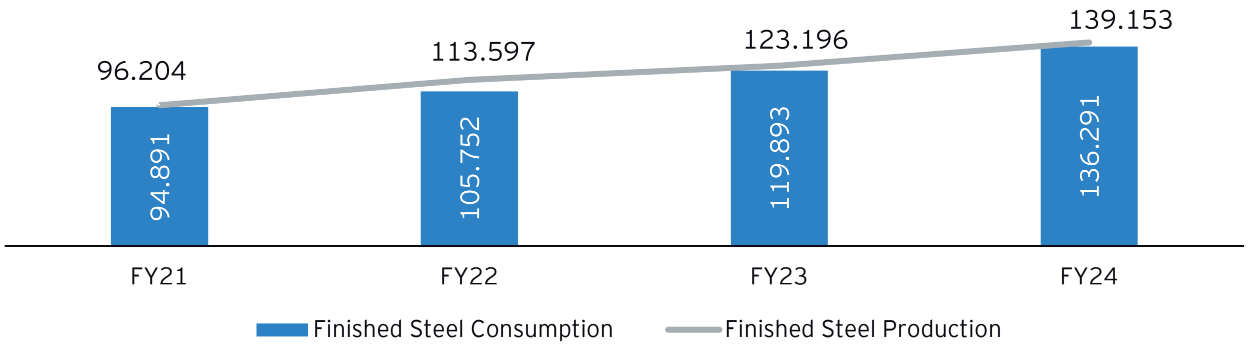
[3] Ministry of Steel, India, May 2017, National Steel Policy

Figure 4: India's crude steel production v/s installed capacity (million tons)



Source: Ministry of Steel, Annual Report 2023-24

Figure 5: India's finished steel production v/s finished steel consumption

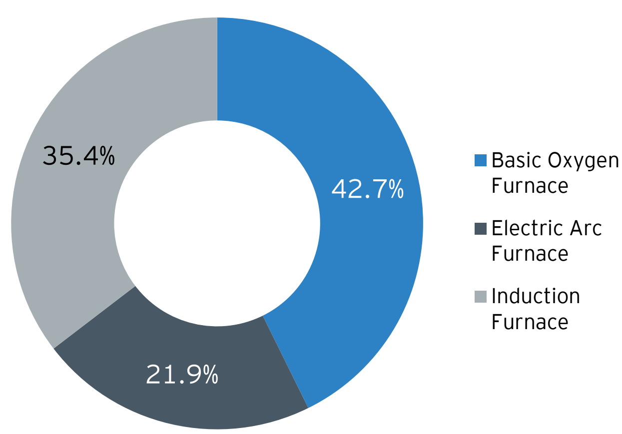


Source: Ministry of Steel, Annual Report 2023-24

In India's steel production landscape, the predominant pathway is the BF-BOF method, accounting for ~43% of the steel output. Meanwhile, ~35% of steel production is derived from Induction Furnaces (IF), and another ~22% from EAF. While few steelmakers utilize steel scrap as the main raw material in IFs & EAFs, in the majority case, Direct Reduced Iron (DRI) produced via coal based rotary kilns is utilized as the primary raw material. Like the BF-BOF process, coal based DRI-EAF / DRI-IF steelmaking is associated with high levels of CO2 emissions.

Notably, India continued to maintain its position as the top DRI producer in the world, with 49.3 million tons production in 2023, of which prodigious 39.9 million tons came from coal based DRI.[4]

Figure 6: Steel production routes in India



Source: Ministry of Steel, Annual Report 2023-24

[4] Midrex, September 2024, 2023 World Direct Reduction Statistics

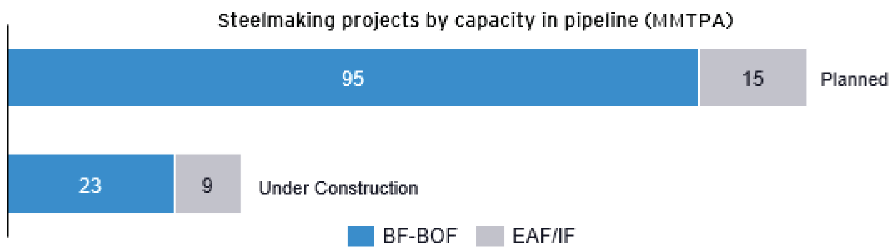
03

Indian steel sector: BF-BOF on rise

As the industry stands at a critical juncture with a dual challenge of urgent need of reducing the emission footprint, and high investment costs of low carbon technologies, India's steel sector plans to keep BF-BOF route as the main production pathway.

By the year 2032, it is anticipated that there will be an increase of at least 118 million tons in BF-BOF capacity, accompanied by an additional 24 million tons of steel produced through EAF and IF. It is crucial to note that the EAF/IF projects in pipeline is expected to utilize coal-based DRI as their primary feedstock. Only a minority of EAF projects shall adopt Scrap in the processes. Additionally, there are further ventures in the development stages without a set commissioning date, poised to introduce roughly 56 million tons of BF-BOF capacity.[5] This trend raises concerns, considering that the average lifespan of a Blast Furnace, including the time for relining, is 50 years[6], indicating that these installations will have a long-term presence in India, along with recently developed facilities.

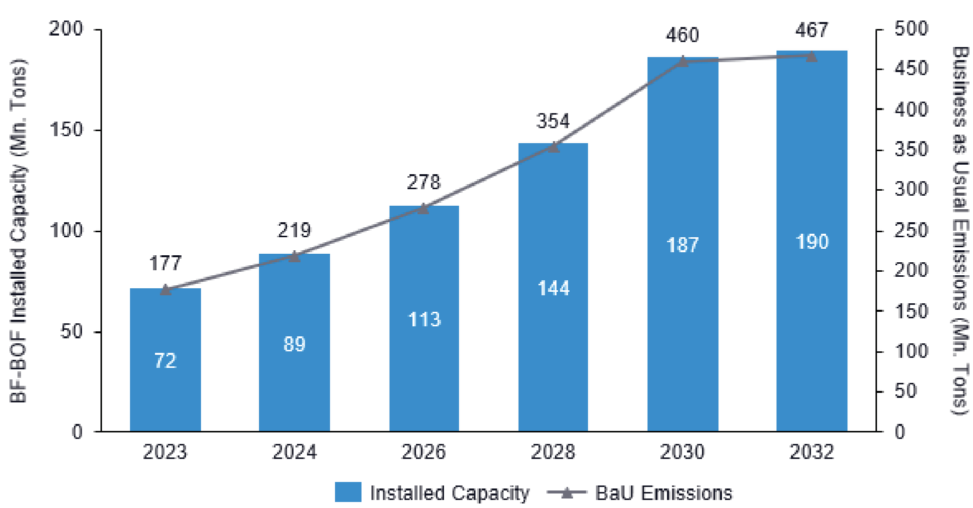
Figure 7: Announced capacity of steelmaking projects by year 2032 (million tons)



Source: Global Energy Monitor's Global Steel Plant Tracker (v1) release & EY Parthenon analysis

India is expected to have a minimum installed capacity of 190 million tons for BF-BOF steel production by 2032. Aforementioned, the figure excludes any BF-BOF projects that have yet to have a confirmed date of commissioning. Under typical operational scenarios for BF-BOF steel production, the CO2e emissions are projected to surge to over 2.5 times the current levels of emissions.

Figure 8: BaU emissions from Indian BF-BOF projects in pipeline by 2032



Source: Global Energy Monitor's Global Steel Plant Tracker (v1) release & EY Parthenon analysis

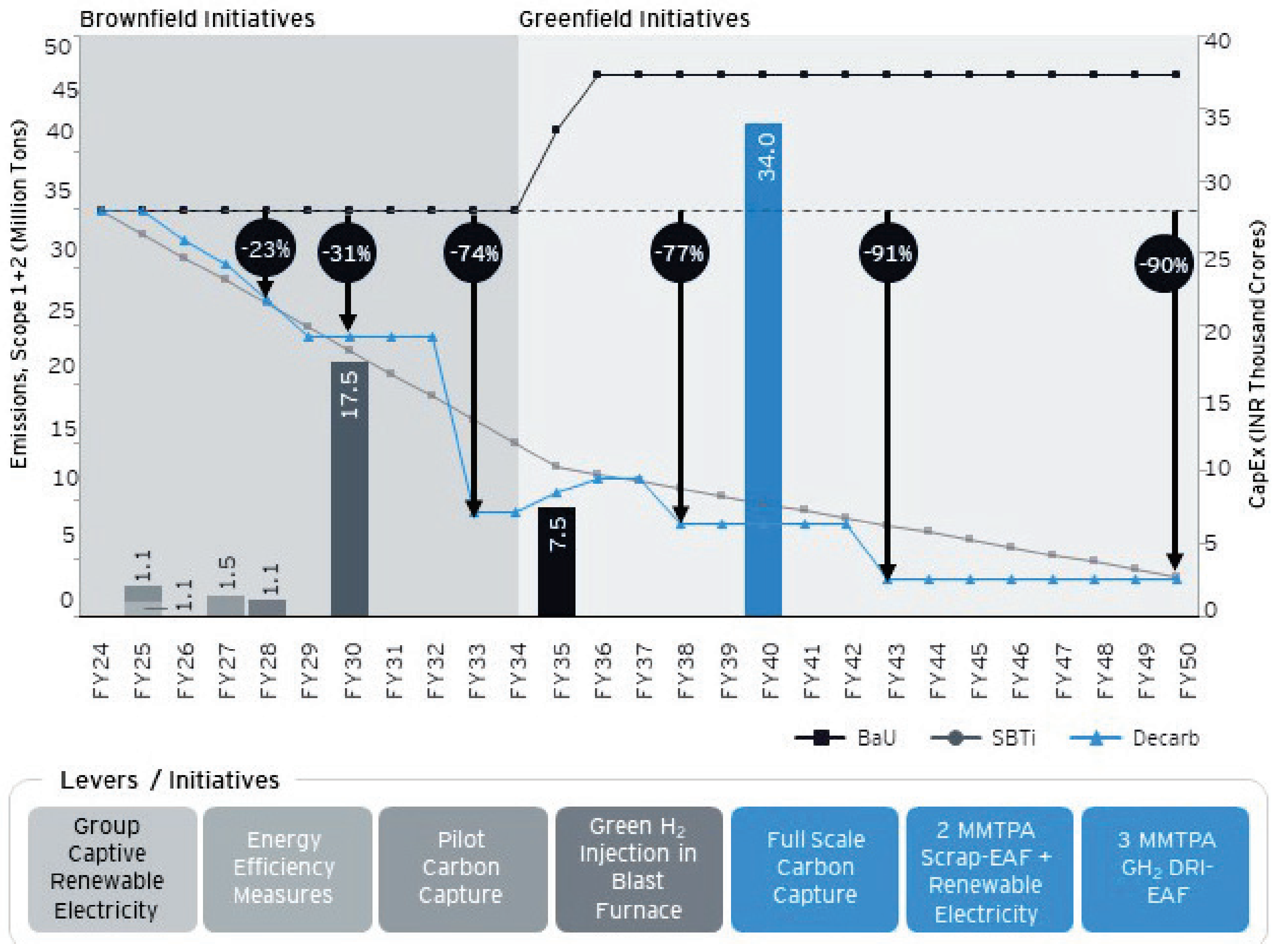
[5] Global Energy Monitor, April 2024, Global Steel Plant Tracker (v1) release

[6] Institute for Energy Economics and Financial Analysis, February 2024, India's technology path key to global steel decarbonisation

While the steelmaking capacity of India expands through BF-BOF route, the imperative to decarbonize the operations becomes critical. The consequences are not limited only to increased GHG emissions, but there is a tangible risk of market contraction in countries & regions with stringent environmental and regulatory norms. Additionally, there is pressure from clients focusing on sustainable supply chain, which could result in competitive disadvantages for Indian producers.

To address these challenges, we performed an analysis for a steel company with an annual production capacity of 15 million metric tons per annum (MMTPA) using the BF-BOF method. Our analysis hypothesized that the company aims to increase its capacity from the current 15 MMTPA to 20 MMTPA between FY34 and FY36. We identified four decarbonization ideas viz. Renewable Electricity, Energy Efficiency, Green Hydrogen Injection in Blast Furnace, and Carbon Capture (Cradle-to-gate, including pipeline transport; for all the analysis in the whitepaper) for decarbonizing the existing operations within the brownfield setup. Additionally, we proposed the introduction of a 2 MMTPA scrap-based electric arc furnace operating with renewable electricity and a 3 MMTPA green hydrogen-based DRI-EAF operation as technological advancements for producing green steel. This strategic analysis illustrates how the company's existing 15 MMTPA BF-BOF infrastructure can operate concurrently with the adoption of new technologies for 5 MMTPA of green steel production. The approach is designed to align with the Science Based Targets initiative (SBTi) guidance for Iron & Steel sector.

Figure 9: SBTi aligned roadmap for 15 MMTPA BF-BOF player expanding with 5 MMTPA green steel pathways



Source: EY Parthenon analysis

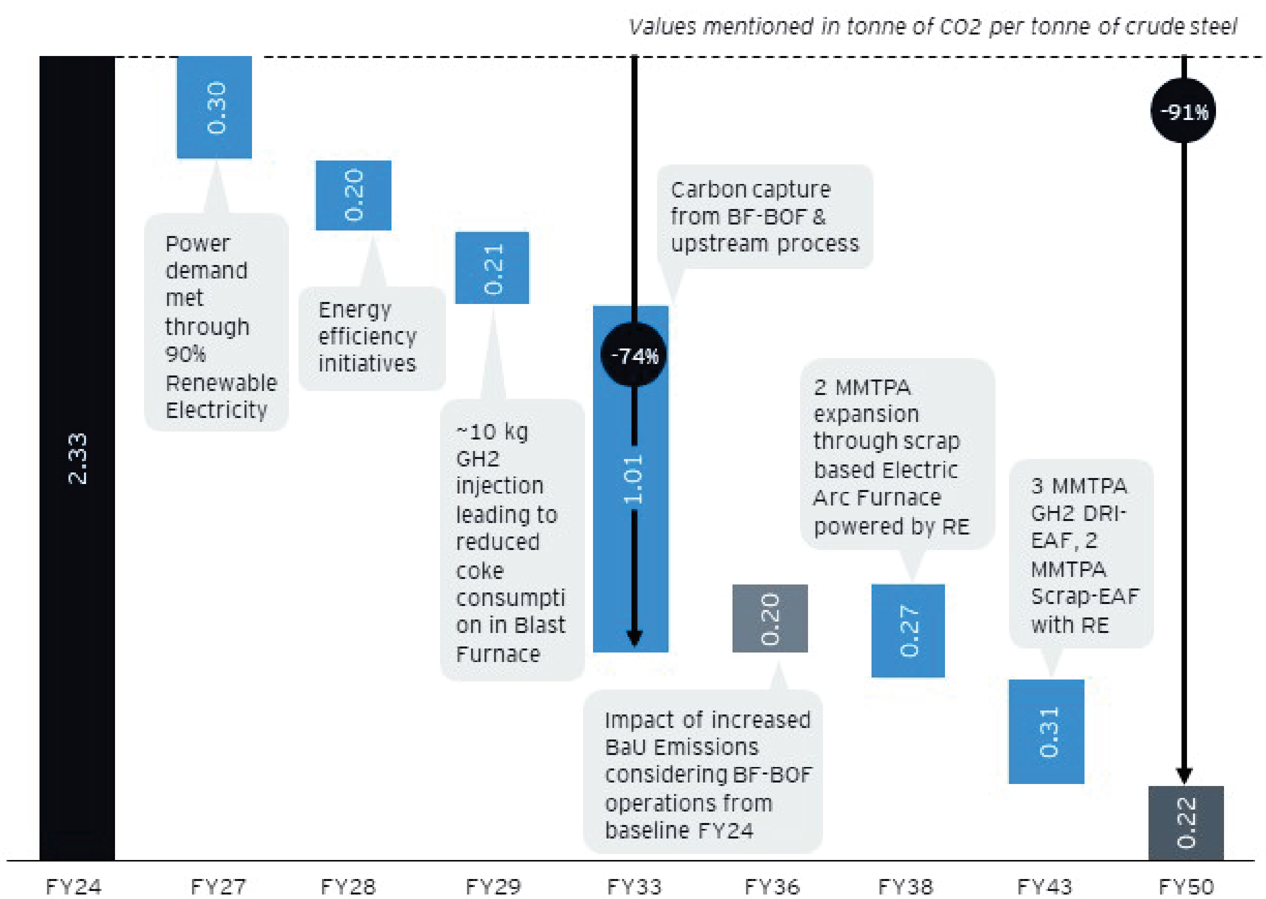
To reduce carbon emissions from current BF-BOF processes, the company may plan to implement energy efficiency strategies such as Waste Heat Recovery, Variable Frequency Drives (VFDs), Enhanced Sinter Burner Efficiency, Energy Monitoring Systems starting in FY25. Additionally, in the same fiscal year, the company may fulfill 90% of its electricity needs through group captive renewable energy sources. By FY27, the company may explore carbon capture at pilot level, and by FY28, it can introduce green hydrogen injection into the blast furnace. These initiatives are expected to result in a 31% reduction in emissions from the FY24 levels by FY30, with an estimated capital expenditure of INR4,800 crore.

A subsequent investment of approximately INR17,500 crore in FY30 for full scale carbon capture technology is projected to further decrease emissions by 74% by FY33, relative to the FY24 benchmark. This substantial reduction will be the cumulative effect of all the decarbonization measures implemented and the full-scale carbon capture.

For the expansion projects, the company may consider investing in a 2 MMTPA scrap-based electric arc furnace powered by renewable energy and a 3 MMTPA green hydrogen-based DRI facility in FY35 and FY40, respectively. The total capital expenditure for these greenfield projects is estimated at INR41,500 crore. These technologies are also the route for the production of green steel.

By integrating decarbonization efforts in existing BF-BOF operations and adopting new technologies in greenfield expansions, the company would be on track to achieve a 90% reduction in Scope 1 and 2 emissions by FY50, in comparison to the FY24 baseline.

Figure 10: Emission intensity reduction with decarb levers and green steel technologies integration



Source: EY Parthenon analysis

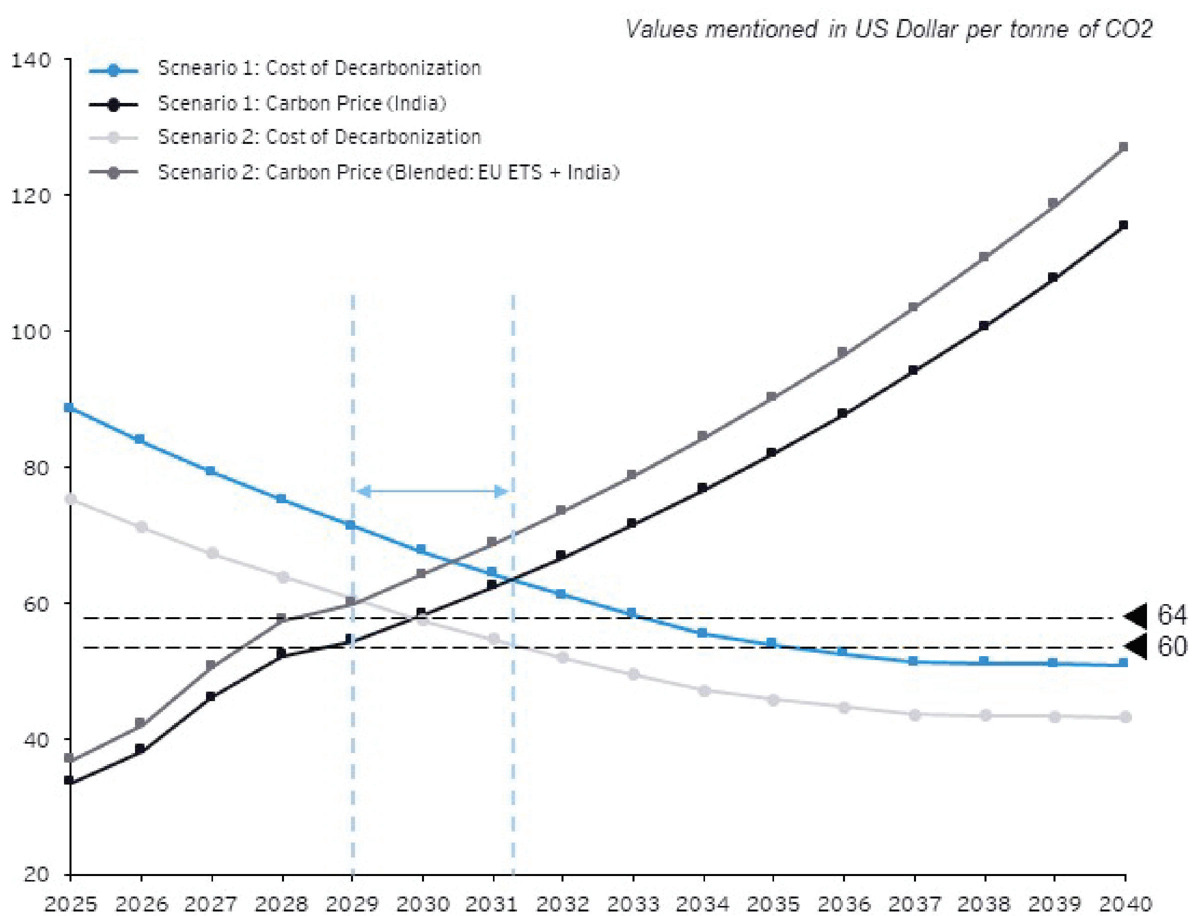
Our analysis reveals the significant potential of renewable electricity, energy efficiency measures, green H2 injection in BF, and carbon capture to reduce CO2e emissions by up to 74% from BF-BOF operations. Energy efficiency measures include Waste Heat Recovery, VFDs, Improved Sinter Burner Efficiency, Energy Monitoring System etc. As the plant undergoes expansion and progressively integrates Green Steel technologies, we observe a substantial decrease in scope 1 and 2 emission intensity. Specifically, the emission intensity is projected to drop from 2.33 tCO2/tsteel in FY24 to just 0.22 tCO2/tsteel by FY50. This highlights the critical impact and necessity of not only pursuing decarbonization strategies but also embracing the pathway of Green Steel technologies, which we will define in a subsequent section of this paper. Green steel definition and its pathways are defined in the subsequent sections of this paper.

Further, with reference to Figure 11, our assessment indicates between 2029-2031, BF-BOF steel producers in India are expected to start reaping the benefits of their investment in decarbonization technologiesThis move is expected to be economically motivated as carbon prices are projected to exceed the costs of abating CO2. The same decarbonization levers previously mentioned were considered in this analysis and upcoming carbon prices for India are projected based on evolution of carbon prices in other regions.

By abating CO2 emissions at a cost lower than the carbon price, BF-BOF steelmakers may realize significant cost savings by overcoming the higher expenses tied to carbon taxation or the need to purchase emissions allowances.

Moreover, this strategy provides a solid foundation for the continued operation of the newly established BF-BOF facilities. These decarbonization levers will play a crucial role during the transition period before the full adoption of green steel technologies becomes feasible and widespread.

Figure 11: Cost of abatement v/s carbon price (India) for BF-BOF



Source: EY Parthenon analysis

The evaluation presents two scenarios forecasting the future costs of decarbonization in relation to carbon pricing in India and potential exports to Europe.

In Scenario 1, it is projected that by the year 2031, the cost of decarbonization will drop below $64 per ton of CO2. Concurrently, carbon prices in India are expected to rise above $64 per ton of CO2.

Scenario 2 predicts that by 2029, the cost of decarbonization will remain above $60 per ton of CO2, while carbon prices will be lower than $60 per ton of CO2. This scenario takes into account an effective carbon price that combines the European Union Emissions Trading System (EU ETS) and Indian carbon prices, based on a steady export volume of 5 million metric tons per annum (MMTPA) of finished steel to Europe.

The decreasing trend in decarbonization costs in both scenarios is attributed to a significant reduction in the expenses associated with CO2 capture and the declining cost of green hydrogen. Moreover, in Scenario 2, the decarbonization costs are anticipated to be even lower than in Scenario 1, reflecting the potential for further cost reductions as the relevant technologies advance and scale up.

Key notes for the analysis:

- Levers considered: Energy Efficiency, Renewable Energy, Green Hydrogen injection in BF, and Carbon Capture
- Indian carbon prices are projected based on evolution of carbon prices in other regions

As highlighted earlier, carbon capture is crucial for decarbonizing BF-BOF operations. While carbon capture offers solutions for reducing emissions, several aspects of its deployment suggest a thoughtful stance and raises ambiguity. The absence of a dedicated carbon capture utilization and storage policy in India creates a regulatory uncertainty and potential investment risks. Moreover, the definite CO2 storage capacity in India is yet to be assessed along with downstream utilization market. While few pilot scale projects exist in India, the necessary infrastructure, including assessment of definite CO2 storage capacity is to be analyzed for full scale projects. Even if the conventional route of steelmaking deploys the identified levers, the dependence on coal as fuel will persist. As the global peers of Indian steel manufacturers are increasing their efforts to carb the emissions, Indian players may focus on transitioning from ‘Carbon Direct Use’ to ‘Carbon Direct Avoidance’.

04

What is green steel?

One particular definition of green steel does not exist. There are increasing number of standards, protocols, initiatives, and government policies, each focusing on different components of the industry. These measures can be categorized based on their focus on steel manufacturers, the demand side, or the finance and funding aspects.[7]

The definition of green steel requires the definition of system boundaries, which varies from standard to standard. For near-zero steel production, emissions intensity targets are defined by ResponsibleSteel and the IEA as ranging from 0.05 to 0.4 tons of CO2 per ton of steel, contingent on the scrap ratio used., Demand-side initiatives like IDDI, the First Movers Coalition, and SteelZero share this definition but set varying targets for steel procurement. Other initiatives specify time-bound emissions reduction goals, while some are dedicated to establishing frameworks for emissions accounting and reporting, such as GHG Protocols, ISO Standards, and The World Steel Association.

The diversity of the steel industry's global operations makes a single universal standard impractical. A more realistic approach might be to develop a few high-quality, mutually aligned standards and protocols. Harmonization could concentrate on emissions accounting boundaries, the types of GHGs included, and the criteria for zero-emission or near-zero-emission steel. Integrating the perspectives of major steel-producing emerging economies, especially China and India, into these decarbonization standards is critical. Effective communication and coordination among these standards and protocols are imperative to streamline requirements and alleviate the industry's compliance burden, thereby supporting the shift towards reduced emissions.

Standards and initiatives[8]	Description	Key players (non-exhaustive)
ResponsibleSteel standards & certification	► Sets emission intensity target based on scrap usage across 4 bands for 100 to 0% scrap usage: ▸ Level 1 – 0.50 to 2.8 tCO2/tcs ▸ Level 2 – 0.35 to 2.0 tCO2/tcs ▸ Level 3 – 0.20 to 1.2 tCO2/tcs ▸ Level 4 – 0.05 to 0.4 tCO2/tcs ► Level 1 is termed as Basic Threshold, whereas level 4 is Near Zero	aperam ArcelorMittal BlueScope
Science Based Targets – Driving ambitious corporate climate action	► The Science Based Targets Initiative (SBTi) developed the Steel Science-Based Target-Setting Guidance to help steel companies set climate targets that align with the Paris Agreement's 1.5°C goal	SSAB Swiss Steel Group
First Movers Coalition	► Sets emission intensity target based on scrap usage across between 0.05 (at 100% scrap usage) to 0.4 tCO2/tcs (at 0% scrap usage) ► It is envisaged that these targets shall be accomplished basis advanced green technologies like H2 DRI, CCUS, Electrowinning etc.	Ørsted ReNew Power VATTENFALL
Climate Bonds Initiative	► Emission intensity reduction in BF operations by 20%, if baseline is more or equal to 2 tCO2 per ton steel; 15% reduction if baseline less than 2 tCO2 per ton of steel ► Emission intensity target reduction by 20% & 40% for fossil gas based & coal based DRI respectively	Allianz Global Investors UBS citi

[7] Ali Hasanbeigi and Adam Sibal, January 2023, What is Green Steel? Definition and Scopes from Standards, Initiatives, and Policies around the world

[8] Standards and initiatives, Description, and Key players are publicly available information

Apart from various standards, protocols, and initiatives, companies are developing their own green steel definition and issuing corresponding certificates. Generally, these definitions focus on specific aspects of the steel production process, such as reduced carbon emissions, energy efficiency, or the use of renewable energy sources. The certificates serve as a valuable tool for companies to showcase their commitment to environmental responsibility and attract customers seeking sustainable products. However, the proliferation of different green steel definitions and certifications can create confusion amongst the buyers of green steel. To address this issue, corporates have assigned auditing protocols to verify their own claims of green or low carbon steel.

Companies[9]	Certificates	Description
ArcelorMittal	XCarb® Towards carbon neutral steel	▶ XCarb green steel certificates are issued by company's operation in Europe – Flat Products based on audit by Det Norske Veritas (DNV) on CO2 savings ▶ Two distinguished certificates are provided based on processes used: BF-BOF with reduced coal, and scrap based EAF with 100% renewable electricity
TATA STEEL #WeAlsoMakeTomorrow	Zeremis® Carbon Lite	▶ Carbon Lite solution offers a 30% reduction in CO2e intensity compared to the Tata Steel Nederland baseline Jan 2018 ▶ Carbon Savings are independently assured by Det Norske Veritas (DNV)
thyssenkrupp	bluemint® Steel High quality. Less CO_2.	▶ bluemint® recycled offers 0.75 tCO2e per ton of hot strip compared to 2.1 tCO2e per ton of conventional hot strip ▶ Follows DIN EN ISO/IEC 17029 and TUV SÜD VERIsteel Standard for bluemint® steel production ▶ This lower emissions product is certified by TÜV SÜD
SAARLOHA A KALYANI GROUP COMPANY	KALYANI FeRRESTA	▶ Offers two unique certificates under KALYANI FeRRESTA™, and KALYANI FeRRESTA™ PLUS ▶ KALYANI FeRRESTA™ has an emission intensity of less than 0.19 tCO2e per ton of crude steel or less than 0.35 tCO2e per ton of rolled steel ▶ KALYANI FeRRESTA™ PLUS offers net zero GHG emission intensity for both, crude & rolled steel. ▶ Both the certificates use GHG Protocol ISO 14404-2:2013 and ISO 14064-1 (2018) ▶ Certificates are jointly issued by DNV Business Assurance India Private Limited and Saarloha
JFE	JGreeX	▶ Follows mass-balance approach in accordance with Japan Iron and Steel Federation guidelines to reduce GHG emissions of diverse product portfolio ▶ Nippon Kaiji Kyokai assessed JFE's claims of GHG reductions and carbon footprint of JGreeX™ products

Focusing on the development and commercialization of low carbon emission steel products, rather than solely pursuing broad corporate-level decarbonization strategies, may be crucial for securing premium pricing during the transition phase. This product-centric approach allows for differentiation in the market, where the industries are increasingly willing to pay a premium for materials that contribute to their own sustainability goals. By positioning low carbon emission steel as a distinct, value-added product, companies can capture a competitive edge and drive industry-wide change, encouraging the adoption of greener practices throughout the supply chain.

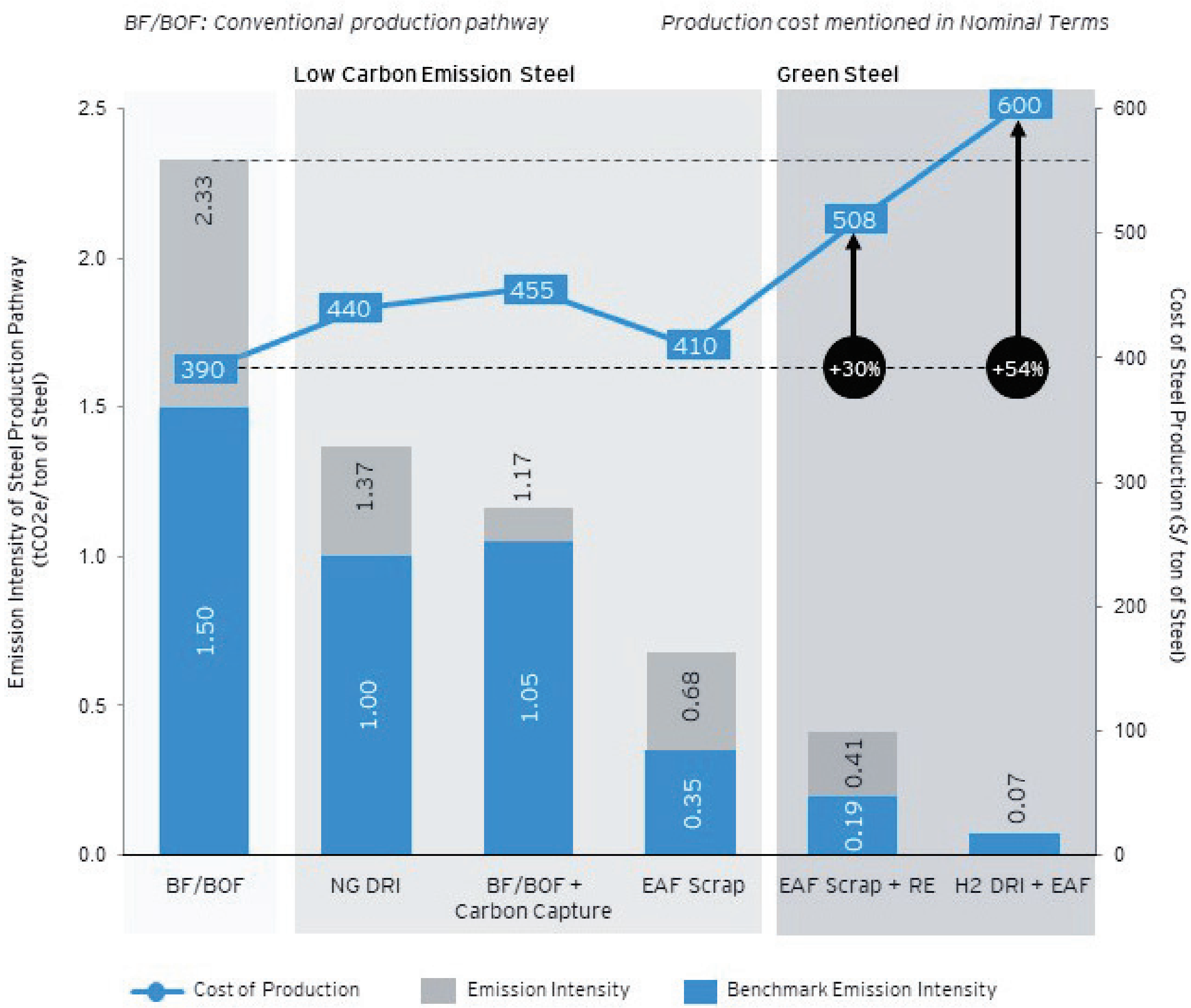
[9] Companies, Certificates, and Description are publicly available information on company's respective website

05

Cost of green steel

The preceding section threw light on the absence of a universally accepted benchmark for the carbon emission levels that qualify steel production as 'green.' Ideally, the closer the emissions approach zero, the greener the steel. For all practical purposes, steel production resulting in less than 0.5 tons of CO_2e emissions per ton of steel may be considered green. Current standards and industry consensus suggest that the production of green or near-zero emission steel is feasible using Green Hydrogen in Direct Reduced Iron processes for primary steel production, and through Scrap utilization in Electric Arc Furnaces powered by renewables for secondary producers. As these innovative technologies gain traction, it is imperative for Indian steel manufacturers to embark on a journey of decarbonization by adopting these methods.

Figure 12: Emission intensity and cost of steel production pathways (FY24)



Source: EY Parthenon analysis

The emission intensity of low carbon emissions steel production methods such as Natural Gas-Based Direct Reduced Iron (DRI), BF-BOF with Carbon Capture and Scrap-Based Electric Arc Furnace (EAF) is significantly lower than that of the traditional BF-BOF steelmaking route, by 41%, 50%, and 71%, respectively.

The key factors contributing to these reductions are:

1. The use of natural gas in the DRI process offers a cleaner combustion alternative to coke, which is the primary fuel in the BF-BOF method.

2. The implementation of carbon capture technology in the BF-BOF process enables the capture of CO2 emissions from the steelmaking workflow.

3. The Scrap-EAF method eliminates the need for coke as a fuel source and leverages recycled scrap metal, which bypasses the requirement for raw iron extraction, resulting in lower emissions throughout the production cycle.

Green steel production methods offer a substantial decrease in emission intensity. When renewable energy sources power a Scrap-Based Electric Arc Furnace, the emission intensity is 82% lower compared to the conventional Blast Furnace-Basic Oxygen Furnace (BF-BOF) method. Additionally, the Hydrogen-Based Direct Reduced Iron (H2-DRI) process achieves a remarkable 97% reduction in emissions relative to the BF-BOF approach. The underlying reasons for these significant reductions include:

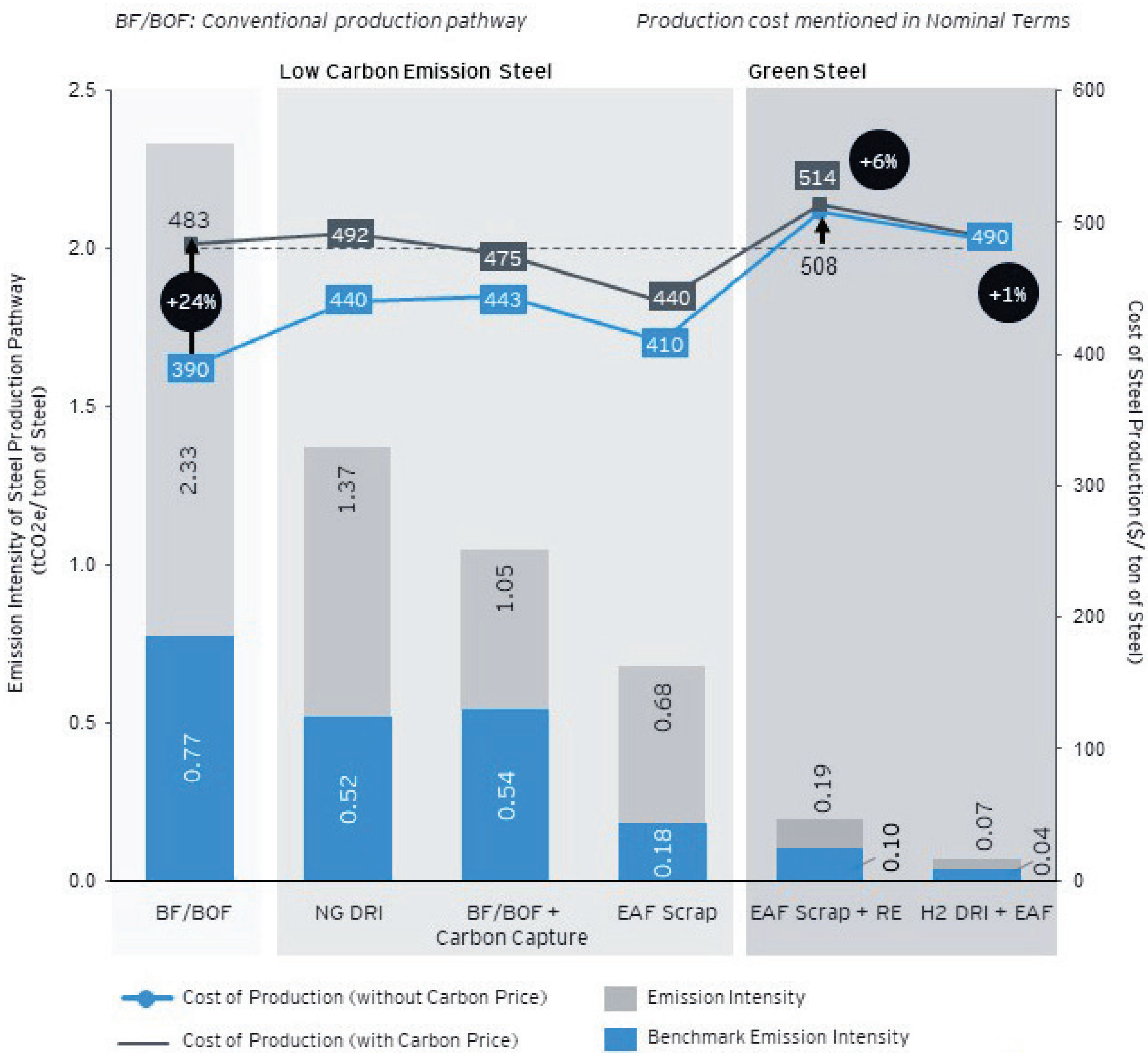
1. The integration of renewable energy into the Scrap-EAF process minimizes emissions related to electricity consumption, whether sourced from the grid or generated on-site.

2. Utilizing green hydrogen as a reducing agent in the DRI process results in a cleaner reaction, with water vapor being the only byproduct, thus dramatically lowering emissions during the iron ore reduction in the shaft furnace.

The production costs for steel with reduced carbon emissions are greater compared to the BF-BOF route: 13% more for natural gas based DRI, 27% more for BF-BOF with Carbon Capture, and 5% more for scrap-based electric arc furnace operations. In terms of environmentally friendly steel production methods, using an EAF powered by renewable energy sources incurs a 30% cost increase over conventional steel, while the green hydrogen direct reduced iron (Green H2 DRI) steelmaking route is 54% more expensive.

In fiscal year 2030, this trend is expected to change as technologies aimed at reducing emissions, such as Carbon Capture and Green Hydrogen, become more cost-effective and efficient when compared to FY24. Declining decarbonization costs are projected to reduce H2 DRI EAF production cost by 22% and BF-BOF with Carbon Capture production cost by 3%.

Figure 13: Emission intensity and cost of steel production pathways in FY30



Source: EY Parthenon analysis

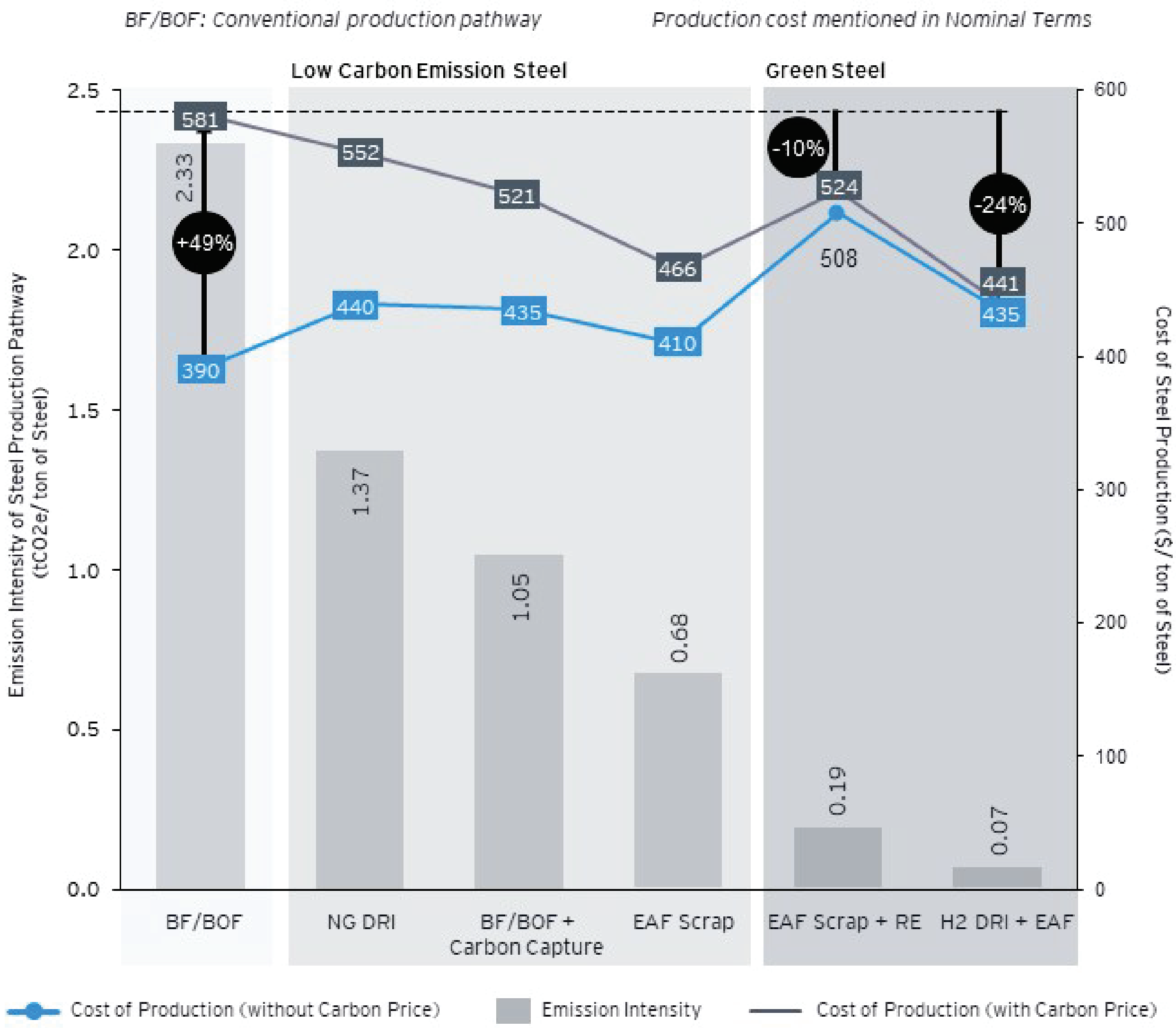
Under the carbon price scenario, it is anticipated that the production costs for low carbon steel methods will be reduced by 1% to 10% compared to traditional steel manufacturing. Conversely, the costs for producing green steel are expected to be 1% to 6% more than those of standard steel production. Meanwhile, the price of steel produced through conventional methods is projected to rise by 24% by the fiscal year 2030.

Key notes for the analysis:

- Carbon price in FY30 is projected to be 58.3$/tCO2
- Carbon Capture abatement price considered 53 $/tCO2e
- RE carbon abatement price considered 98$/tCO2e translating to 0.07$/kWh
- EAF RE benchmark considered with 90% renewable energy
- EAF RE emission intensity considered with 50% renewable energy
- Effective benchmark emission intensity reduction for Indian steel sector mirrors that of CBAM in EU
- For effective implementation of a CCTS scheme in India, grant and phasing out of free allowances is important

By the fiscal year 2035, the expense of producing green steel through the hydrogen direct reduction (H2 DRI) method is expected to decrease significantly, becoming 26% less costly than in FY24 (refer figure 12), owing to the anticipated reduction in the price of green hydrogen. In a scenario where carbon pricing is implemented, the estimated production costs for low carbon steel methods are forecasted to be 5% to 20% less than those of traditional steel manufacturing. Moreover, the costs for green steel production are projected to be 10% to 24% less than conventional steel methods. This trend suggests that green steel will become increasingly cost-effective in the future.

Figure 13: Emission intensity and cost of steel production pathways in FY35



Source: EY Parthenon analysis

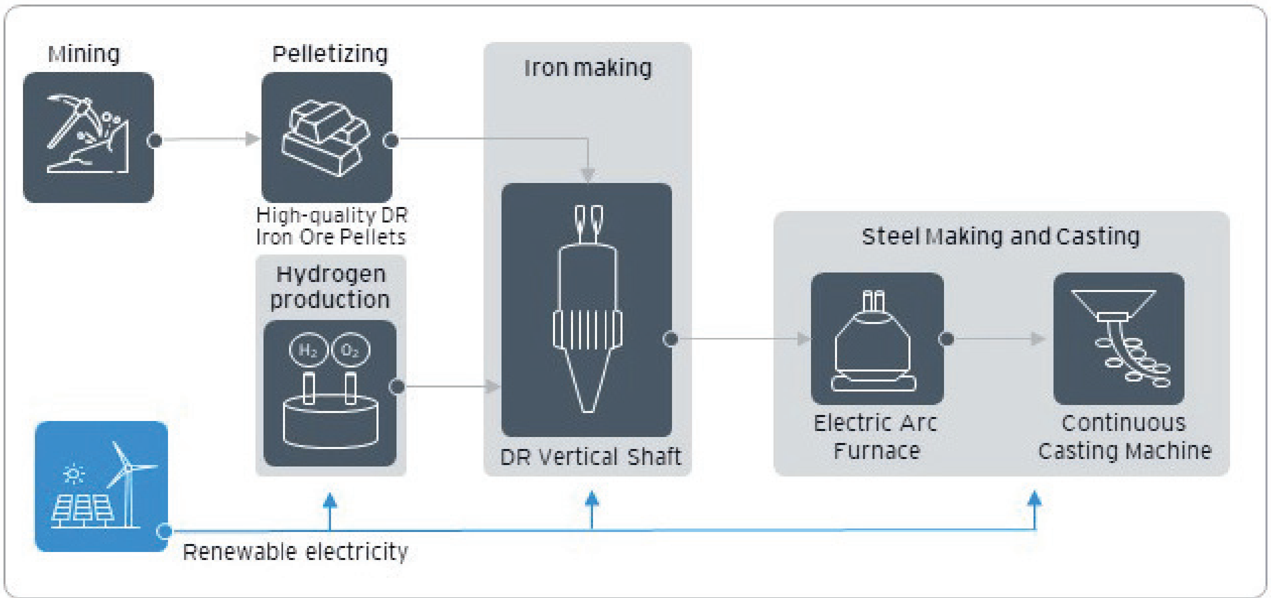
Key notes for the analysis:

- Carbon price in FY30 is projected to be 82$/tCO2
- Carbon Capture abatement price considered 45$/tCO2e
- RE carbon abatement price considered 98$/tCO2e translating to 0.07$/kWh
- EAF RE benchmark considered with 90% renewable energy
- EAF RE emission intensity considered with 50% renewable energy
- Effective benchmark emission intensity reduction for Indian steel sector mirrors that of CBAM in EU
- For effective implementation of a CCTS scheme in India, grant and phasing out of free allowances is important

As the steel industry moves towards a more sustainable future, the financial viability of green steel production becomes a pivotal factor for widespread adoption. The projected cost reductions for green steel, as outlined for FY30 & FY35, signal a transformative shift in the economics of steel manufacturing. This shift is not only driven by the decreasing costs of green hydrogen but also by the implementation of carbon pricing mechanisms that incentivize cleaner production methods. The anticipated affordability of green steel positions it as a compelling alternative to traditional steel, potentially accelerating the industry's transition towards environmentally friendly practices.

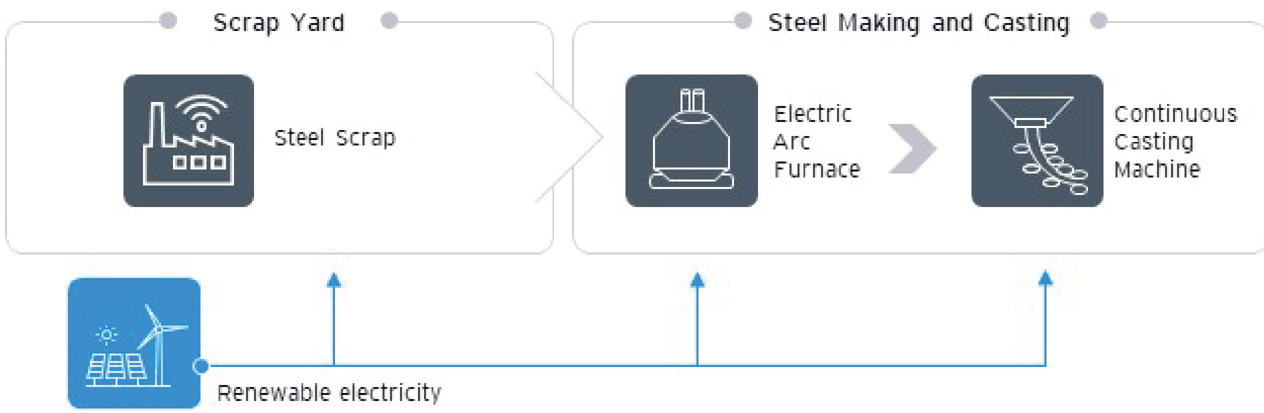
06

Production pathways of green steel



Key raw materials required	1. High grade iron ore (Fe > 67%) & lower impurities 2. Green Hydrogen as reducing gas in DR Shaft 3. Carbon injection and slag forming additives in EAF
Brief process description	The steelmaking process using green hydrogen begins with the electrolysis of water, powered by renewable electricity, to generate hydrogen. This green hydrogen acts as the reducing gas in the process. Iron ore pellets are fed from the top of a shaft furnace, while the green hydrogen is introduced from the bottom. This process results in the formation of Direct Reduced Iron and water vapor as a byproduct. The DRI is then fed into an Electric Arc Furnace for steelmaking. This step can be done either as cold charging or preferably hot charging of DRI, leading to potential energy savings and increased productivity during the steelmaking process. The liquid steel undergoes casting, followed by rolling and other downstream finishing processes.
Key challenges	1. Unavailability of high-grade iron ore can attract additional gangue 2. Increased slag volume in low grade iron ore 3. H_2-DRI based DRI has lower melting efficiency due to absence of carbon content 4. Nitrogen management during steelmaking process 5. High upfront capital costs (40% higher than conventional) 6. GH2 production & use is up to 80%-120% costlier than fossil fuels 7. Water intensive (10 ltr Distilled water for 1 kg hydrogen production)
Key technology players (non-exhaustive)[10]	MIDREX, tenova
Companies deploying GH2 DRI (non-exhaustive)	ArcelorMittal, BlueScope, SSAB, HBIS

[10] Key technology players and Companies deploying GH2-DRI are publicly available information on respective websites and press releases



Key raw materials required	1. Scrap is the primary raw material 2. Fluxes like Dolomite, Limestone etc. 3. Ferroalloys such as FeMn, FeSi etc
Brief process description	The steel production process begins with the formulation of a scrap recipe, which involves combining various types of scrap materials such as bushelling, shredded scrap, bundles etc. These materials vary in size and density and are assembled in scrap bucket according to the specific needs of the process. The recipe is then introduced into an electric arc furnace (EAF) for melting. Following the charging of the scrap, electric current is passed through electrodes to generate a high-intensity heat that melts the scrap. The subsequent stage involves refining the molten metal and forming slag, which is facilitated by the addition of specific additives. To achieve the desired steel grade, various alloying elements are incorporated. This high-energy process has the potential to achieve near-zero emissions when integrated with renewable energy sources, thereby enhancing the sustainability of this secondary steelmaking route.
Key challenges	1. Unavailability of substantial scrap in India and globally 2. Tramp elements like Cu in scrap 3. Scrap based EAF is energy intensive process, and switching to RE would be capital intensive
Key technology players (non-exhaustive)[11]	DANIELI, SMS group, PRIMETALS TECHNOLOGIES, tenova
Companies deploying Scrap-EAF + renewables (non - exhaustive)	ArcelorMittal, SAARLOHA A KALYANI GROUP COMPANY, outokumpu, AICHI STEEL

[11] Key technology players and Companies deploying Scrap-EAF + Renewables are publicly available information on respective websites and press releases

07

Select H2 DRI case studies

Case: HYBRIT collaborative mission by SSAB, LKAB, Vattenfall[12]

Summary:

Advancing towards a value chain free from fossil fuels, from extraction to steel production, by employing renewable electricity and hydrogen

Background:

The HYBRIT (Hydrogen Breakthrough Ironmaking Technology) project was initiated in 2016 as a joint venture between SSAB (steel producer), LKAB (iron ore supplier), and Vattenfall (electricity producer), aiming to decarbonize the steel industry. In response to rising climate change concerns and the global push for sustainable industrial processes, HYBRIT seeks to revolutionize steel manufacturing by replacing coal with green hydrogen, produced using renewable energy. This breakthrough technology has the potential to significantly reduce carbon emissions, making steel production fossil-free and contributing to the global transition towards a more sustainable economy.

Project financials:

- SSAB, LKAB, and Vattenfall invest a total of SEK 259 million in the hydrogen storage itself
- SSAB is investing €4.5 billion in a new mill that is expected to produce 2.5 million tonnes of fossil-free steel a year by 2029

Project timelines:

2016:	Project announced by SSAB, LKAB, Vattenfall for the fossil free steel making initiative
2017:	SSAB, LKAB, and Vattenfall formed the JV company, Hybrit Development AB
2020:	Project's pilot plant inaugurated for production of sponge iron in Sweden
2021:	First Hydrogen reduced sponge iron produced and finished steel delivered to the automobile customer. The customer produced 1st vehicle made from fossil free steel
2022:	The customer produced construction machinery from fossil free steel Underground Hydrogen gas storage of 100 m^3 is inaugurated in Sweden
2023:	Launched a fossil free product
2026:	Fossil free steel will be available in the market

Conclusion:

The project aims to revolutionize steel production by using green hydrogen, significantly reducing carbon emissions. Its success could set a new standard for sustainable industry and play a vital role in addressing climate change

[12] Information available on company's website and press releases

Case: ArcelorMittal Dofasco's transition to low-carbon steel production[13]

Summary:

ArcelorMittal Dofasco, a steel producer in Canada, has embarked on an ambitious project to significantly reduce its carbon footprint by transforming its steelmaking process. The company plans to cut three million tons of CO2 emissions by constructing a 2.5 million tons per annum hydrogen-ready direct reduced iron (DRI) facility. This initiative is a strategic move towards sustainable steel production, aligning with global efforts to combat climate change.

Background:

The proposed expansion involves the introduction of a vertical shaft DRI using natural gas, coupled with an electric arc furnace (EAF), while retaining the existing downstream facilities. The DRI shaft is designed to be adaptable for future integration with green hydrogen (H2) as a fuel source. This would further enhance the facility's capacity expansion potential using the H2 DRI-EAF method.

The rationale behind the project is the company's commitment to phasing out coal from its primary steelmaking operations, targeting a 60% reduction in emissions, leading to around 3 million tons of annual CO2 abatement. This move is not only environmentally responsible but also positions the company as a leader in the transition to green steel production.

Project financials:

The project is estimated to cost 1.8 billion Canadian dollars. It has secured significant funding from the government, with contributions of CAD$400 million and CAD$500 million from the Government of Canada and the Government of Ontario, respectively.

Project timelines:

2021:	Project announcement and formation of the project team. Completion of significant pre-front end engineering and design (pre-FEED).
2022:	Ground-breaking ceremony marking the start of the project.
2023:	Commencement of detailed engineering and demolition of the decommissioned Coke Plant-1, followed by the start of onsite construction work.
2024:	Foundation work is set to begin.
2026:	Construction of new assets, including the EAF, is expected to be completed.
2028:	The full transition from the active BF-BOF route to the DRI-EAF route is anticipated.

Conclusion:

The company's strategic shift to a hydrogen-ready DRI facility represents a significant step forward in the steel industry's journey towards decarbonization. The project not only demonstrates the company's leadership in adopting green technologies but also serves as a blueprint for other steel producers aiming to reduce their environmental impact. With the support of the Canadian government, this initiative sets a precedent for public-private collaboration in achieving sustainability goals within the industrial sector.

[13] Information is available on company's website and press releases

08 Recommendations

To advance the adoption and production of green steel in India, a multifaceted approach is essential. This approach should encompass technological advancements, policy interventions, ecosystem requirements, and strategic collaborations. The following recommendations outline the key areas of focus:

Green steel definition and mandate

To establish a robust framework for green steel, it is essential to implement Product Level Carbon Footprinting (PCF) for accurate emission tracking and reporting at the product or grade level. Policy interventions should include the development of standards and certification for green steel production, setting maximum carbon allowances and steel sector's plant level emission reduction targets are required. Additionally, there should be an adoption mandate requiring a specific percentage of green steel usage by domestic consumers, similar to Renewable Purchase Obligations (RPO). The ecosystem must support these initiatives through Green Steel Certification Programs, collaborating with industry and certification bodies to create audited low-emission certificates, and fostering a demand pool from consumers focused on their scope 3 reduction targets.

Adoption of green steel pathways

For the adoption of green steel pathways, existing BF-BOF steelmakers should invest in energy efficiency, renewables, alternate fuels and carbon capture technologies. Greenfield expansions should focus on pathways like Electric Arc Furnaces (EAF) with renewables and Green Hydrogen-Direct Reduced Iron (H2-DRI). A strong policy framework is required, offering tax incentives, capital subsidies, viability gap funding and grants for companies decarbonizing their current assets or adopting green steel technologies. The ecosystem should facilitate joint research and development programs to address specific challenges in green steel production, foster global technology collaborations and develop the necessary workforce and skillsets for implementation.

Renewable energy availability

Achieving the target of 90% renewable energy by 2027 necessitates advancements in solar, wind and energy storage technologies. Investments in power evacuation infrastructure, grid stability and managing load curve fluctuations are crucial. Policy interventions should focus on land availability and rebates for captive renewable energy plants, banking facilities, support for phasing out captive power plants (CPP) for existing assets, bringing steel hubs and states under interstate transmission, prioritization of RE demand to the sector, and funding support or tax exemptions under open access green energy policies. The ecosystem must encourage tie-ups with renewable energy developers, setting up group captive projects and innovative cooperative models that drive larger supply chain decarbonization.

Carbon capture utilization and storage

High Technology Readiness Level (TRL) carbon capture and separation technologies must be developed to achieve a cost of at least $35 per ton of CO2 captured by 2030, supporting emission reduction via the BF-BOF route. Policy interventions should mandate the utilization of captured CO2 from the steel industry in downstream applications, provide carbon credits for sequestration under Article 6.2/6.4, and establish Carbon Capture Utilization (CCU) hubs around industrial areas. The ecosystem should assess the downstream market for captured CO2 utilization like methanol, ethanol, polyurethane etc. production. An additional application to investigate is the potential for improved oil extraction by utilizing captured CO2 for injection into oil fields, thereby facilitating enhanced oil recovery. Further, the evaluation of definite CO2 storage capacity is required.

Scrap processing

To effectively integrate scrap into the formal sector, it is recommended to setup state-of-the-art scrap processing centres with advanced sorting and recycling technologies. An Extended Producer Responsibility (EPR) framework should be implemented to ensure manufacturers take back end-of-life products, complemented by incentives for companies investing in scrap infrastructure. The Government of India has established a vehicle scrappage policy. In a similar vein, the development of a policy dedicated to the aggregation and processing of scrap materials from infrastructure projects could be considered. These measures will formalize the scrap industry, contribute to the circular economy, and reduce the environmental footprint of steel production.

Beneficiation of low-grade iron ore and technology integration

The direct reduction process necessitates the use of high-grade iron ore for optimal performance. Using iron ore of a lower grade can lead to a host of issues, including lower process efficiency, gangue presence in the direct reduced iron, and increased energy demands. To counter these challenges, it may be beneficial to consider the beneficiation of the lower-grade iron ore to enhance its quality. Additionally, the adoption of technologies such as melters for DRI or the installation of submerged arc furnaces directly below the direct reduction shaft could be explored. These technologies have the capability to liquefy the direct reduced iron into molten hot metal. A significant benefit of this approach is the ability to integrate with existing basic oxygen furnace (BOF) infrastructure for the steelmaking process.

Carbon pricing and cost of abatement

The cost of decarbonizing technologies, particularly carbon capture and green hydrogen injection, must decline rapidly to reduce the overall cost of decarbonization. Policy interventions should introduce carbon pricing via carbon capture and storage (CCTS) for the domestic steel sector and provide guidelines for the impact of the carbon border adjustment mechanism (CBAM) on Indian players. The ecosystem must consider the implications of imposing a carbon tax on the steel value chain.

CBAM challenge

To navigate the CBAM challenge, it is recommended that India adopts a uniform mechanism for verifying and accounting for GHG emissions, supported by technological advancements for real-time verification. India should establish a national framework in line with international CBAM standards, while also formulating a protectionist, India-specific CBAM policy to safeguard domestic industries, including phased implementation and financial support for technological upgrades. Furthermore, an ecosystem fostering collaboration between government, industry, and environmental experts is essential, alongside sector-specific alliances to innovate and collectively align with CBAM regulations.

Conclusion:

In conclusion, the transition to green steel production requires a comprehensive approach encompassing technological advancements, robust policy frameworks, and a supportive ecosystem. By defining and mandating green steel standards, adopting innovative production pathways, ensuring renewable energy availability, advancing carbon capture technologies, and implementing effective carbon pricing, India can lead the way in sustainable steel production. These recommendations provide a strategic roadmap for achieving significant emission reductions and fostering a greener, more resilient steel industry.

Notes:

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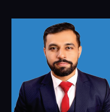

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About India Green Steel Coalition

To promote green steel manufacturing and consumption in India through enabling policies and demand alignment, India Green Steel Coalition (IGSC) has been constituted by WWF India and Confederation of Indian Industry (CII). IGSC has a vision towards ensuring optimal reduction in steel sector's emissions intensity by 2030.
IGSC will support the efforts of the government towards increasing domestic steel production and for creating an enabling environment for sustained reduction in emissions intensity of the sector. IGSC will work actively with the primary and secondary producers, demand side players to understand the challenges in this transition and advocacy for policy making on steel sector decarbonization.

About WWF India

WWF India is a science-based organization which addresses issues such as the conservation of species and its habitats, climate change, water and environmental education, among many others. Over the years, its perspective has broadened to reflect a more holistic understanding of the various conservation issues facing the country and seeks to proactively encourage environmental conservation by working with different stakeholders- Governments, NGOs, schools and colleges, corporates, students and other individuals.

About WWF Finland

WWF Finland is part of the extensive international WWF network that has offices in about 50 countries and operations in over one hundred countries. WWF, which was founded in 1961, has grown from a small organisation that focused on conserving endangered species to the most influential environmental organisation in the world. The operation in Finland has existed since 1972.

About CII- GBC

CII – Sohrabji Godrej Green Business Centre (CII – GBC) is CII's Developmental Institute on Green Practices & Businesses, aimed at offering world class advisory services on conservation of natural resources.
Fostering green practices and businesses through its services in energy management, green buildings, green companies, renewable energy, green product certification, waste management, and cleaner production processes, the Green Business Centre facilitate India's emergence as a global leader in green business by 2025.