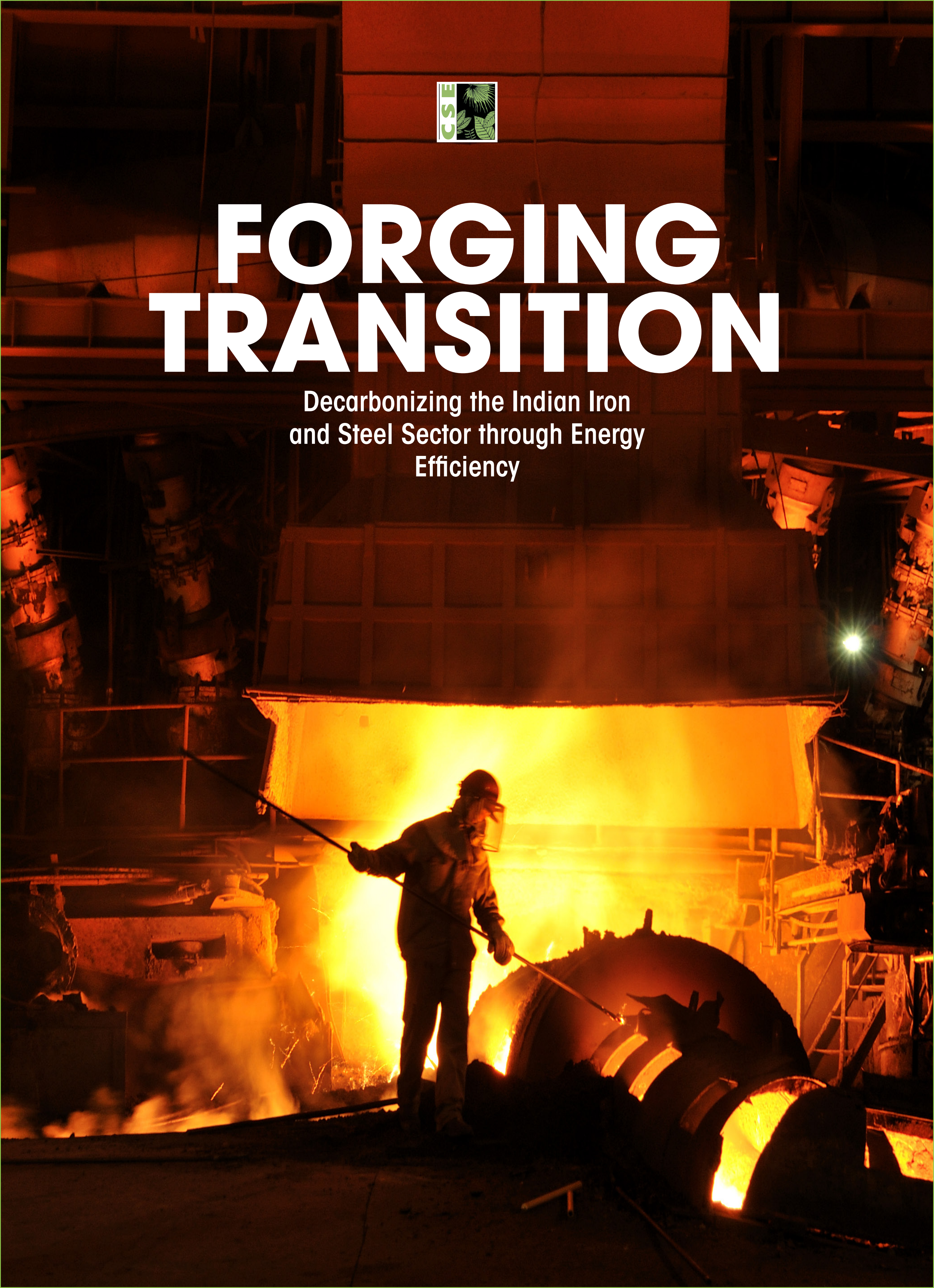
FORGING TRANSITION

Decarbonizing the Indian Iron and Steel Sector through Energy Efficiency



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Decarbonizing the Indian Iron and Steel Sector through Energy Efficiency

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LIST OF ABBREVIATIONS

AFR	Alternative fuels and raw material
BAU	Business as usual
BEE	Bureau of Energy Efficiency
BF-BOF	Blast furnace—basic oxygen furnace
CCC	Carbon Credit Certificate
CCTS	Carbon Credit Trading Scheme
CCUS	Carbon Capture, Utilization and Storage
CO	Carbon dioxide
DRI	Direct reduced iron
EAF	Electric arc furnace
EE	Energy efficiency
ESCert	Energy Savings Certificate
ESCO	Energy Service Company
GEI	Greenhouse Gas Emission Intensity
GHG	Greenhouse gas
HPGR	High pressure grinding roller
IF	Induction furnace
kg	Kilogram
MoEFCC	Ministry of Environment, Forest & Climate Change
MTOE	Million tonnes of oil equivalent
MTPA	Million tonnes per annum
PAT	Perform, Achieve and Trade
PCI	Pulverized coal injection
SEC	Specific energy consumption
SIDBI	Small Industries Development Bank of India
TPD	Tonnes per day
TRT	Top-pressure recovery turbine
UHP	Ultra-High Power
VFD	Variable Frequency Drive
WHR	Waste Heat Recovery
WHRS	Waste Heat Recovery System
YoY	Year-on-year

EXECUTIVE SUMMARY

India is the world's second largest producer of crude steel. In FY 2023–24, the country had a crude steel capacity of 179.5 million tonnes per annum (MTPA) and produced 144.3 million tonnes (MT) from an industry that contributes about 2 per cent of national GDP and provides direct and indirect employment to some 2.6 million people. Under the National Steel Policy 2017, the sector is expected to reach 300 MTPA of capacity by 2030, with per capita consumption rising from 98 kg to approximately 160 kg over the same period. The sector is also among the most carbon-intensive in the country, with an average emission intensity of 2.54 tonnes of CO_2 per tonne of crude steel.

Indian steel emitted approximately 366.52 million tonnes of CO_2 in FY 2023–24, which represents 10–12 per cent of the country's total CO_2 emissions. A major part of the emissions in Indian steelmaking are energy-related, arising from the combustion of coal and coke for heat and chemical reduction and from electricity use in furnaces, mills and auxiliaries. Emission intensity in this sector is therefore directly addressable through energy-efficiency measures.

Multiple decarbonization pathways are available for the sector, including increasing energy efficiency, increasing scrap use, renewable electricity integration, green hydrogen-based ironmaking, and carbon capture, utilization and storage (CCUS). For India to achieve net zero by 2070, efforts to widely adopt all these pathways will be required.

While most of these technologies will require more time to achieve technological maturity and economic viability, energy efficiency remains a distinct pathway. Energy-efficient technologies are commercially proven, and they can be deployed at the earliest. These measures reduce energy costs, thereby covering the cost of installation after a certain period of time. In the past, the Perform, Achieve and Trade scheme prompted large integrated producers to implement some energy-efficiency improvement measures, but there is still substantial scope for improvements. Benchmarking studies indicate a gap of 30–42 per cent between average Indian plant performance and global best practice.

Out of the several technologies available for energy efficiency, this study assesses 15 commercially available and emerging technologies based on their potential to reduce energy consumption and subsequent CO_2 emissions across the blast furnace and basic oxygen furnace route, the coal-based DRI route and electric arc and induction furnace steelmaking. For each, the report quantifies the further reduction available from extending the technology across capacity that does not have it. It finds that complete deployment to that remaining potential would reduce the sector's average emission intensity by 0.150–0.241 tCO_2 per tonne of crude steel, bringing it from 2.54 to approximately 2.30–2.39, and would reduce overall sectoral emissions by 21.58–34.75 MT, or 5.9–9.5 per cent of the country's average emission intensity for the sector. The potential is concentrated: blast furnace ironmaking and coal-based DRI together account for roughly 85 per cent of it, and five technologies carry about two-thirds. The study also sets out the indicative capital cost and payback period for each technology. These are tentative estimates and actual figures will vary case by case, but they show that the cost of 11 out of the 13 technologies (for which a payback figure is available) can be recovered within two years.

The findings indicate that the targets assigned to the sector under the Carbon Credit Trading Scheme can be met through the adoption of these technologies. The second draft notification for iron and steel greenhouse emission target, published in June 2026, covers 255 obligated entities and requires a 5.82 per cent reduction in greenhouse gas emission intensity by FY 2026–27 on average across the sector.

This study shows a reduction potential of 5.9–9.5 per cent through energy efficiency alone. The margin at the lower end of that range is narrow, and it is realized only by the sector that actually installs the equipment rather than the sector that could. This report demonstrates that the immediate compliance obligation can be met with energy-efficiency improvement technologies that are available today, without recourse to hydrogen, carbon capture or any change of feedstock or process route.

1. Introduction

Iron is a key element that has played a major role in the advancement of human civilization. Through the ages, it has contributed as the foundation for modernizing human society. Steel, an alloy of iron, is used extensively due to its strength and abundance in infrastructure, housing, transportation, capital goods, machinery, defence and space equipment. Its demand is closely tied to GDP growth. However, extraction of iron from its ore is energy intensive.

As countries around the world industrialize and urbanize, demand for steel will continue to rise through this century. For a country like India, extensive growth plans with new infrastructure and manufacturing industries will continue to drive the demand for iron and steel manufacturing in the coming years. The National Steel Policy (2017) suggests that based on current trends, steel consumption on a per capita basis will increase from approximately 90 kg to approximately 160 kg by 2030.[1] India's growth trajectory will clash directly with the emissions reduction commitments made under the Nationally Determined Contribution (NDC) goals of 47 per cent reduction in emissions intensity from 2005 levels by 2035 and achieving net zero emissions by 2070.[2] To meet these targets, decarbonizing hard-to-abate sectors will play a key role and iron and steel is an important industry that will require focus.

The iron and steel sector is structurally complex, especially since it encompasses multiple distinct production routes with fundamentally different emission profiles, energy inputs and efficiency improvement pathways. This report therefore explores energy-efficiency pathways route by route, treating the blast furnace (BF) ironmaking system, coal-based direct reduced iron (DRI) system, basic oxygen furnace (BOF) steelmaking system, electric arc furnace (EAF) and electric induction furnace (EIF) steelmaking system, and the common rolling and utilities systems as separate analytical units.

2. Sector profile

2.1 Production scale and structure

Iron and steel production is responsible for 7–9 per cent of total global greenhouse gas emissions (GHG) emissions.[3] India is the second-largest producer of crude steel in the world and therefore plays a significant role in shaping global industrial trends. The sector accounts for 2 per cent of India's GDP and provides direct and indirect employment to around 2.6 million people.[4] According to the Ministry of Steel, Government of India, as of Financial Year 2023–24, the country possesses a total crude steel production capacity of 179.5 MTPA and produced 144.299 MT.[5]

Despite the prowess, per capita steel consumption remains relatively low at 98 kg (FY 2025), and is expected to rise to 160 kg by 2030.[6] In 2017, the Government of India introduced the National Steel Policy to achieve a production target of 300 MTPA by 2030.[7] Since 2024, India has been a net importer of steel, with a steady increase in domestic demand. As the market grows, domestic steel companies will establish more production units.

The steel industry in India consists of both large integrated companies and smaller businesses. The distribution is highly heterogeneous, with over 1,091 crude steel-producing units and more than 1,200 re-rolling mills downstream.[8] The composition of crude steel production is broadly classified into blast furnace—basic oxygen furnace (BF-BOF) at approximately 42.7 per cent, electric induction furnaces (EIF) at approximately 35.4 per cent, and electric arc furnaces (EAF) routes at 21.9 per cent (see *Table 1*[9] for a broad distribution of the pathways).

Table 1: Product-wise production capacity, actual production and share of sector production

Sector	End product/type of industry	Capacity (MT)	Actual production FY 2023–24 (MT)	Share of sector production (%)
Iron	Blast furnace—hot metal	95.80	87.04	62.8
	Blast furnace—pig iron		7.36	5.3
	DRI/sponge iron producers—coal based	48.20	41.80	30.2
	DRI/sponge iron producers—gas based	12.30	9.80	7.1
	Sector total	156.30	138.64	–
Crude steel	Electric arc furnace (large and small)	39.50	31.61	21.9
	Induction furnace	68.80	51.08	35.4
	Basic oxygen furnace	71.20	61.61	42.7
	Sector total	179.50	144.30	–

Source: Greening the steel sector in India: Roadmap and action plan, Ministry of Steel, Government of India

While global DRI production is predominantly gas-based, India's DRI sector is highly dependent on coal, with a production capacity of approximately 52 MTPA. The sector sees extensive use of rotary kilns and typically has a capacity between 100 and 500 tonnes per day (TPD). This distribution adds up to India's steel emission profile and sets it apart from every other major steel-producing economy.

2.2 Specific energy consumption

Indian steelmaking is energy-intensive by international standards. According to the Ministry of Steel statement, '*energy consumption in most of the integrated steel plants in India is generally high at 6-6.5 giga calorie per tonne of crude steel as compared to 4.5-5.0 in steel plants abroad*'.[10] This implies that Indian plants, at an average, consume a quarter to a third more energy for the production of each tonne of steel as compared to their global competitors. Columbia University's Center on Global Energy Policy finds greenhouse gas emissions in the Indian steel industry are about 30 per cent higher than the global average.[11] This report aims to address the gap from the lens of energy efficiency.

2.3 Emissions

The steel sector is one of the most carbon-intensive industries. However, unlike cement, where 50–56 per cent of emissions arise from process emissions, most of the emissions in the steel sector, especially in the Indian industrial landscape, are energy-related. Processes such as combustion of coal and coke for heat and chemical reduction, along with electricity use in furnaces, mills and auxiliaries, constitute the largest share of the emissions. As a result, reduction in emission intensity is directly addressable through energy efficiency and fuel management measures.

Globally, the sector accounts for 7–9 per cent of the total GHG emissions.[12] In India, it contributes 10–12 per cent of the total CO_2 emissions[13] in the country. At 2.54 tCO_2/t, India's emission of crude steel is higher than the global average of 1.91 tCO_2/MT.[14] The high carbon footprint is primarily due to the heavy reliance on

Table 2: Route-wise average carbon emission intensity in India

Route	Average carbon emission (tCO_2/tcs)
BF-BOF	2.2–2.6
Coal-based DRI-EIF/EAF	2.7–3.1
Natural gas-based DRI-EAF	1.4–1.6
100 per cent scrap-based steel through EAF	0.55–0.65
Average emission intensity of steel production in India	2.54

Source: Greening the steel sector in India: Roadmap and action plan, Ministry of Steel, Government of India coking coal in blast furnaces and thermal coal in DRI rotary kilns. As of 2023–24, the cumulative emissions of the Indian iron and steel manufacturing sector are 366.52 million tonnes (MT) of CO_2. *Table 2*[15,16] demonstrates emission intensity of crude steel production from each route.

An energy benchmarking study report[17] by the Centre for Science Technology and Environmental Policy shows that average primary specific energy consumption of major Indian steel plants is at 27.3 gigajoule per tonne (GJ/t)of crude steel against global best-practice benchmarks of 16.4 GJ/tcs (BF-BOF), 19.1 GJ/tcs (coal-based DRI-EAF) and 15.9 GJ/tcs (gas-based DRI-EAF). This shows a gap of 30.04–41.76 per cent. This gap defines the magnitude of the efficiency opportunity assessed in this report.

3. Decarbonization pathways

3.1 Overview of pathways

Decarbonization roadmaps target net zero by 2070 through multiple pathways. To achieve this goal, India's steel sector will have to go through a multi-pathway approach. The following are the pathways:

Energy efficiency (EE): This is the most readily available route that can be implemented within the shortest time frame. Energy-efficiency measures are low-hanging fruit for decarbonizing the Indian steel sector by reducing thermal and electrical specific energy consumption per unit of output, achieved through improving equipment efficiency and performance across all production routes.

Increased scrap use: The Steel Scrap Recycling Policy aims to introduce circularity in domestic iron and steel use in India. By raising the share of scrap-based steelmaking, both Scope 1 and Scope 2 emissions can be significantly reduced by reducing the need for primary iron production.

Renewable electricity integration: The EAF and IF routes together account for 57.3 per cent of crude steel production in the country, which runs on electricity. Sourcing this electricity from renewable sources will help reduce the sector's Scope 2 emissions. The Ministry of Steel targets a substantial increase in the use of renewable energy in the iron and steel sector by 2030.[18]

Carbon Capture, Utilization and Storage (CCUS): Even after switching fuel and implementing energy efficiency measures, emissions are produced from blast furnaces due to process emissions. CCUS is an advanced technology under development, which addresses this issue by capturing emissions at source, converting and/or storing them in the form of their chemical components. As outlined by the Department of Science and Technology (DST),[19] for India, CCUS in steel is a long-term (2035–50) option rather than a near-term solution.

Green hydrogen: Hydrogen can replace fossil-based reducing agents in direct-reduction processes, enabling low-carbon ironmaking. Hydrogen injection into blast furnaces can also reduce fossil fuel consumption, reducing emission. This is especially effective for plants operating blast furnaces. India defines green hydrogen as 'hydrogen produced using renewable energy, such as solar or wind power, instead of fossil fuels', with total emissions from the process not exceeding 2 kg of CO_2 equivalent per kg of hydrogen produced.[20]

3.2 Role of energy-efficient technologies for decarbonizing the iron and steel sector in India

The energy-efficiency pathway of decarbonizing the iron and steel sector provides two important benefits. It mitigates energy-related emissions and saves production costs in an industry where energy represents 20–40 per cent of total production cost[21] (coking coal for integrated producers; electricity for EAF/EIF producers).

The Indian steel industry has seen a reduction in Specific Energy Consumption (SEC) over the last two decades. The change is also driven by regulatory mandates from the Perform Achieve and Trade (PAT) scheme, which pushed the large integrated manufacturers to modernize their production technologies. Despite these advances, significant savings potential remains. The 30.03–41.76 per cent (approx.) gap between average Indian plant performance and global best practice, discussed earlier, shows that energy efficiency measures are not widely adopted by iron and steel manufacturing units in the country. For example, a typical 500-TPD coal-based DRI plant has been found to operate at a process efficiency of only about 51 per cent, with waste gas losses alone accounting for 43.5 per cent of total heat input.[22] In other words, these plants are wasting about half of their energy input, part of which can be captured and rerouted for utilization in plant processes or generation of electricity through steam generation. The coal DRI-based secondary steel manufacturing pathway with an emission intensity of 2.7–3.1 tCO_2/tcs presents a strong opportunity in which energy-efficiency measures can achieve substantial reduction of emissions as well as energy cost.

While the PAT cycle has achieved some targets, especially in large integrated plants, the new Greenhouse Gases Emission Intensity Target Rules (2025) mandate obligated entities to meet specific CO_2-equivalent reduction targets and introduce a carbon credit system to achieve these targets. As a result, manufacturers failing to achieve their targets will bear more cost.

4. Methodology

This report expresses thermal savings in gigajoules per tonne (GJ/t) of route product and electrical savings in kilowatt hours per tonne (KWh/t) of route product. For each technology, the reduction in carbon dioxide intensity per tonne of route product is calculated as the energy savings multiplied by the emission factor.

The thermal emission factor used is 0.0946 tCO_2/GJ,[23] a standard factor for coal-dominated process heat. The electrical emission factor used is 0.962 kg of carbon dioxide per kilowatt hour, equivalent to 0.000962 t/KWh.[24]

Secondary data was collected from published sources including Government of India reports, international reports, benchmarking studies, BEE's ADEETIE list of energy-efficient technologies, and peer-reviewed articles to calculate potential reductions in emissions due to improvements in thermal and electrical energy usage. The data was cross-referenced by Industry experts. Since the steel sector comprises multiple distinct production routes, technologies are organized by the following production pathways: blast furnace (BF) ironmaking, coal-based direct reduced iron (DRI), basic oxygen furnace (BOF) steelmaking and electric arc furnace (EAF)/induction furnace (IF) steelmaking. The sector-wide reduction potential of each technology is calculated only over the respective production route.

For each technology, sector-wide CO_2 reduction scope is calculated as:

(**CO_2 reduction scope per tonne of crude steel**) × (**production base of the applicable route**) × (**adoption potential***)

*adoption potential is 1 minus the mean of the current adoption rate.

This report assumes current technologies that are commercially available and have documented performance in Indian plants, and emerging technologies that are at the pre-commercial or early demonstration stage and are not yet widely implemented in India.

4.1 Key assumptions

All savings figures are expressed as ranges rather than point estimates, reflecting variation across plant configurations, feedstock qualities and operating practices. The ranges are taken from the source literature.

Table 3: Key assumptions for calculation

Parameter	Value
Sector annual production	144.3 Mt crude steel[25]
Average emission intensity	2.54 tCO_2/tcs[26]
Baseline sectorial emission	366.52 MTPA[27]
Route shares of production	BF-BOF 42.7% (61.61 Mt); IF 35.4% (51.08 Mt); EAF 21.9% (31.61 Mt)[28]
Coal-based DRI	41.80 Mt[29]
Electrical emission factor (coal-based power generation)	0.000962 t/KWh[30]
Thermal emission factor	0.0946 t CO_2/GJ (3.96×10^{-7} tCO_2/kcal)[31]

Sources:

1. Greening the steel sector in India: Roadmap and action plan, Ministry of Steel, Government of India
2. Central Electricity Authority (CEA). Report
3. IPCC Guidelines for National Greenhouse Gas Inventories (2026)

4.2 Limitations

- The analysis assumes that the savings from each technology are independent and additive. In practice, a plant deploying several measures simultaneously may see interaction effects in either direction: waste heat recovery and feed preheating compete for the same heat, reducing the combined benefit, while improved process control may increase the effectiveness of physical upgrades. No interaction adjustment has been applied, and the totals should be read as indicative of the scale of the opportunity rather than as a prediction of what any individual plant would achieve.
- Equipment capital costs are tentative. Actual figures may vary depending on factors including the age of the manufacturing unit, exchange rates and market conditions.
- Adoption rates are approximate. As route-wise adoption is not uniformly reported in published sources, the adoption rate is estimated with stakeholder consultation.

5. Energy-efficiency technologies

This chapter focuses on the assessment of 15 commercially available energy efficiency technologies across the BF-BOF route, coal-based DRI route, IF/EAF route. For each technology, the sector-wide CO_2 reduction scope shown is the further reduction available from extending the technology across the remaining unequipped capacity of the route to which it applies. It is calculated, following the methodology in Chapter 4, as 'per-tonne reduction scope' (tCO_2/tcs) multiplied by the route's production base and the adoption potential. Electrical savings are valued at the coal-based power emission factor of 0.962 tCO_2/MWh and thermal savings at the thermal emission factor of 0.0946 tCO_2/GJ. The technologies are organized by production route, and a consolidated summary with indicative capital costs and adoption rates is discussed.

5.1 Integrated BF-BOF route technologies

India's primary production is dominated by blast furnace and basic oxygen furnace integrated units. The blast furnace is the single largest contributor to emissions in this route, accounting for approximately 68 per cent of process emissions.[32] The total share of emissions from the sector stands at 148 Mt. The average blast furnace in India consumes about 20–30 per cent more energy than the most efficient plants globally. This is due to the use of high-ash coking coal, suboptimal operating practices at some plants, and uneven technology adoption.[33] The basic oxygen furnace step that follows is exothermic and relatively energy-efficient. Its primary opportunity lies in recovering energy-rich converter gas. The technologies mentioned in the following section include the ironmaking (BF) and steelmaking (BOF) stages of the integrated route.

5.1.1 Pulverized coal injection (PCI) optimization

Energy savings: 1.0–1.5 GJ/t | Sector-wide CO_2 reduction scope: 2.88–4.32 Mt | Emission intensity reduction scope: 0.020–0.030 tCO_2/tcs

Pulverized coal injection optimization introduces fine coal directly into the blast furnace through the tuyeres (specialized nozzles, pipes or tubes that inject a blast of pressurized air, oxygen or gases into a furnace or forge) as a partial replacement for metallurgical coke. Production of metallurgical coke is itself an energy-intensive process and is therefore one of the most energy-intensive inputs for ironmaking. While Indian furnaces work at a consumption rate of 565 to 572 kg/t,[34] modern furnaces achieve coke consumption as low as 286–320 kg/t globally.[35] Almost every large integrated producer in India operates PCI systems, but achievable injection rates are constrained by the high ash content of available coals, which reduces burnout efficiency in the raceway. Optimization remains uneven across the fleet at around 60–70 per cent. Optimizing injection rates together with oxygen enrichment of the blast is the key lever where the basic infrastructure already exists. Complete optimization of PCI in India will further help reduce 2.88–4.32 Mt CO_2 from the sector.

5.1.2 Top gas recovery turbine (TRT)

Energy savings: 30-40 kWh/t | Sector-wide CO_2 reduction scope: 1.38-1.84 Mt | Emission intensity Reduction scope: 0.010-0.013 tCO_2/tcs

Blast furnace gas exits the furnace top at a pressure of 2-3 bar. Without recovery, this pressure energy is throttled away in the gas cleaning system. A top gas recovery turbine expands the gas through a turbine connected to a generator, producing 30 to 40 kWh[36] of electricity per tonne of hot metal from what would otherwise be waste. TRT is standard at large modern blast furnaces globally and at India's larger integrated plants, with adoption of around 40 to 50 per cent across the fleet, but it is not universal. Capital cost is in the range of Rs 30 to 60 crore per turbine. Complete adaptation of TRT in India will help reduce 1.38–1.84 Mt CO_2 from the sector.

5.1.3 Hot stove heat optimization

Energy savings: 0.4-0.8 GJ/t | Sector-wide CO_2 reduction scope: 2.14-4.28 Mt | Emission intensity Reduction scope: 0.015-0.030 tCO_2/tcs

Hot blast stoves preheat the air blown into the blast furnace, typically operating three or four to a furnace on a cyclic regenerative basis in which each stove is alternately fired and then blasted. Stove efficiency governs blast temperature, and blast temperature governs coke rate: each 100°C increase in blast temperature reduces coke consumption by roughly 0.4–0.8 GJ/t.[37] Indian stoves commonly deliver blast at 1050–1150°C against 1200–1250°C at internationally competitive operations, with losses arising from excessive flue gas exit temperature, air ingress through burner and valve seals, uncontrolled combustion air excess, deteriorated dome insulation and fouled checker brickwork. The remedies are automated combustion control, waste heat recovery from stove flue gas to preheat combustion air and fuel gas, dome and shell reinsulation, and ceramic burner upgrades. Adoption of a full optimization stands at only 30–40 per cent, and because the measures are modular they can be implemented progressively without a furnace outage. Sector-wide, stove optimization offers further 2.14–4.28 Mt CO_2 of annual reduction.

5.1.4 Bell-less top charging and burden distribution optimization

Energy savings: 0.2-0.5 GJ/t | Sector-wide CO_2 reduction scope: 0.49-1.24 Mt | Emission intensity reduction scope: 0.003-0.009 tCO_2/tcs

Iron-bearing material (pellet, sinter or ore), coke and fluxes are added from the top of the furnace and are known as 'burden'. On the other hand, hot gas flows from the bottom of the furnace to the top. The efficiency of heat transfer in the blast furnace is dependent on the distribution of burden (flowing top to bottom), and it determines how the gas flows from bottom to top. Bell-less top charging systems uses rotating chutes that allow precise programmatic control of burden distribution and enable more uniform gas utilization. This in turn lowers coke consumption, typically by 0.2–0.5 GJ/t[38] as compared to plants currently using older double-bell systems. Several large Indian furnaces have been retrofitted, but older and smaller furnaces often retain outdated charging systems. Adoption of this technology is around 60–80 per cent. A complete adoption of this technology will help achieve 0.49–1.24 Mt CO_2 from the sector.

5.1.5 AI and machine learning-based process control (blast furnace)

Energy savings: 0.3-0.5 GJ/t | Sector-wide CO_2 reduction scope: 2.10-3.50 Mt | Emission intensity reduction scope: 0.015-0.024 tCO_2/tcs

The blast furnace is a complex, multi-variable system with slow, non-linear fluid dynamics. Between the input and output, there is a time lag of several hours. Conventionally, the system is controlled using Proportional-Integral-Derivative (PID). In recent years, developments in AI and machine learning-based control systems have improved the prediction capability of fluid mechanics. The system can be trained on historical operating data and continuously updated sensor feeds to anticipate process deviations and make preemptive adjustments. This helps in optimizing operations. Case studies have reported that AI and ML integration can achieve coke rate reductions of 10–20 KG/t,[39] translating to energy savings of 0.3–0.5 GJ/t. As in other process steps, these savings are achieved without plant outage or major hardware replacement. Current adoption is around 10–20 per cent in the industry. Complete adaptation of this technology can help further achieve 2.10–3.50 Mt reduction of CO_2 from the sector.

5.1.6 Converter gas recovery (OG system)

Energy savings: 0.50-0.79 GJ/t liquid steel | Sector-wide CO_2 reduction scope: 1.02-1.61 Mt | Emission intensity reduction scope: 0.007-0.011 tCO_2/tcs

Oxygen blowing in the basic oxygen furnace decarburizes the hot metal charge and evolves a gas stream at 1600–1700°C containing 60–80 per cent carbon monoxide.

An oxygen converter gas recovery system captures this stream through a suppressed-combustion hood, cools it, cleans it by wet or dry dedusting and stores it in a gas holder for use as plant fuel, in place of flaring it to atmosphere. Recovery is typically 60–90 Nm^3 per tonne of liquid steel at a calorific value of 8.4–8.8 MJ/Nm^3,[40] equivalent to roughly 2,000 $kcal/Nm^3$, giving a potential energy saving of 0.50–0.79 GJ per tonne. Most Indian integrated plants have an OG system installed, and adoption stands at 60–70 per cent, but recovered volumes vary widely, and some plants continue to flare a material fraction because gas holder capacity, downstream demand or blowing-cycle scheduling do not permit full capture. The remaining opportunity therefore lies as much in raising recovery rates at existing installations as in new capital projects. Sector-wide potential is 1.02–1.61 Mt CO_2 per year.

5.2 Coal-based DRI (rotary kiln) technologies

India is the largest manufacturer of coal-based DRI in the world. It is one of the least energy-efficient industries in India. With a low setup cost and access to cheap local coal, a large number of DRI units are present throughout the country. Sponge iron, the end product from this route is used as metallic charge by IF and EAF plants alongside scrap. While IF and EAF routes have low emission intensity, the embedded intensity remains high for finished steel utilizing coal-based sponge iron. Indian DRI plants employ kilns with production capacity as low as 100 tonnes per day (TPD), which limits the economic viability of the larger waste heat recovery systems. As a result, a very small percentage of plants currently have installed WRHS. The technologies in this section apply to the coal-based DRI production base of 41.80 Mt.

5.2.1 Waste heat recovery boiler (WHRB) for power generation

Energy savings: 60-90 kWh/t DRI | Sector-wide CO_2 reduction scope: 2.11-3.17 Mt | Emission intensity reduction scope: 0.015-0.022 tCO_2/tcs

Waste gas from a coal-based rotary kiln leaves the after-burner chamber at 900–1000°C, carrying a large fraction of the energy originally supplied as coal. A waste heat recovery boiler raises steam from this stream to drive a turbo-generator, converting an otherwise wholly wasted flow into electricity that displaces grid or captive coal-fired supply. Recovery of 60–90 kWh[41] per tonne of sponge iron is achievable. Adoption is only 5–20 per cent, the lowest of any measure examined in this report other than kiln control, and is concentrated almost entirely in larger units. The obstacle is capital rather than technology. Secondary technical constraints are heavy dust loading and alkali-bearing deposits that foul boiler surfaces, requiring careful design and disciplined cleaning. Full deployment would deliver 2.11–3.17 Mt CO_2 of annual reduction.

5.2.2 Kiln shell heat loss reduction and refractory improvement

Energy savings: 0.021-0.042 GJ/t DRI | Sector-wide CO_2 reduction scope: 0.06-0.12 Mt | Emission intensity reduction scope: 0.000-0.001 tCO_2/tcs

Heat radiated and convected from the shell of a rotary kiln is a continuous loss proportional to shell temperature and exposed area. Upgrading the lining to mullite-based or low-cement high-alumina castables, with ceramic fibre backup insulation, can lower shell temperature from a typical 300–350°C to 200–250°C, saving 5–10 kcal per kg of sponge iron produced.[42] At an indicative capital cost below Rs 1 crore, this is the cheapest measure in the catalogue, and it requires no process modification, no change in operating practice and no shutdown beyond the relining interval that the kiln already observes. Adoption is nevertheless only 20–30 per cent, which reflects the measure's low visibility rather than any barrier: refractory specification is treated as a maintenance decision driven by campaign life rather than as an energy investment, and the two objectives are not always aligned. The individual contribution is at 0.06–0.12 Mt CO_2 per year.

5.2.3 Kiln feed preheating and process integration

Energy savings: 1.52-1.90 GJ/t DRI | Sector-wide CO_2 reduction scope: 4.96-6.20 Mt | Emission intensity reduction scope: 0.034-0.043 tCO_2/tcs

A substantial share of the coal charged to a rotary kiln is consumed simply in bringing the iron ore and coal to reaction temperature. Preheating the charge using kiln exhaust gas before it enters the kiln addresses this loss directly, reducing coal consumption by 8–10 per cent against a reference specific energy consumption of 19.0 GJ per tonne of sponge iron and yielding 1.52–1.90 GJ/t.[43] Adoption is only 15–20 per cent at an indicative capital cost of Rs 5–15 crore. The barriers are physical rather than financial. Retrofitting a preheater requires space at the kiln inlet that many existing layouts do not provide, and the dust-laden exhaust demands robust materials handling. A further consideration is that preheating and waste heat recovery draw on the same exhaust stream, so a unit deploying both will realize less than the sum of the two individually assessed savings. The sequencing decision between them should be made on plant-specific grounds. On the calculation presented in this report, kiln feed preheating is the single largest contributor to the sector-wide total at the low end of the range, offering 4.96–6.20 Mt CO_2 of annual reduction.

5.2.4 AI and sensor-based kiln control

Energy savings: 0.57-0.95 GJ/t DRI | Sector-wide CO_2 reduction scope: 2.20-3.66 Mt | Emission intensity reduction scope: 0.015-0.025 tCO_2/tcs

A coal-based rotary kiln is fired through six to eleven air injection points distributed along its length, and the resulting temperature profile determines both metallization and coal consumption. In most Indian units these injection points are adjusted manually on the basis of periodic sampling and operator judgement, with the consequence that the kiln operates well away from its optimal profile for much of the campaign. Continuous instrumentation such as shell-mounted thermocouples, infrared pyrometry and exhaust gas analysis coupled to a model-based controller allows coal split and air distribution to be optimized in real time, reducing coal consumption by 3–5 per cent, potentially saving 0.57–0.95 GJ/t.[44] Adoption is below 5 per cent, so virtually the entire potential remains available, and at an indicative cost of Rs 0.5–1 crore. The capital requirement is negligible compared to the energy-saving potential. This is the most cost-effective measure identified in this report, offering 2.20–3.66 Mt CO_2 of annual reduction.

5.3 EAF and EIF steelmaking technologies

Electric arc furnaces in India are typically fed with a mix of scrap and coal-based DRI on coal-dominated grid power, reporting specific electricity consumption of 400–600 kWh per tonne of liquid steel depending on charge mix, furnace age and practice. The induction furnace segment, accounting for around 35 per cent of crude steel production, is characterized by small furnaces and a large base of MSME operators. EAF-specific technologies below apply to the EAF production base of 31.61 Mt; variable frequency drives and ladle practice apply across the combined EAF and induction furnace base of 82.69 Mt.

5.3.1 Scrap preheating

Energy savings: 50-100 kWh/t liquid steel | Sector-wide CO_2 reduction scope: 1.29-2.58 Mt | Emission intensity reduction scope: 0.009-0.018 tCO_2/tcs

Electric arc furnace off-gas leaves the fourth hole at 1200–1600°C and carries 15–20 per cent of the total energy input to the furnace. Scrap preheating recovers part of this by passing the off-gas through the incoming charge. Savings of 50–100 kWh per tonne is achievable.[45] The principal technical constraint is the formation of dioxins and furans as the off-gas passes through the 250–450°C window in the presence of organic contamination on the scrap, which requires either rapid quenching downstream or strict control of charge cleanliness. Adoption in India is 10–20 per cent at an indicative Rs 30–60 crore. Beyond capital, the barriers are the variable and often contaminated quality of domestically available scrap and the space required to retrofit a shaft or conveyor into an existing melt shop. Full deployment offers 1.29–2.58 Mt CO_2 of annual reduction.

5.3.2 Ultra-High Power (UHP) transformer upgrades

Energy savings: 20-40 kWh/t liquid steel | Sector-wide CO_2 reduction scope: 0.40-0.79 Mt | Emission intensity reduction scope: 0.003-0.005 tCO_2/tcs

Electric arc furnaces are classified by the transformer power available per tonne of furnace capacity: regular power below 400 kVA/t, high power at 400–500 kVA/t, and ultra-high power above 500 kVA/t. Higher power delivery shortens the tap-to-tap cycle. As heat loss occurs through the furnace shell, roof and off-gas proceeds continuously, a shorter cycle reduces the total energy lost per tonne produced. Upgrading to ultra-high power, together with optimization of secondary voltage and circuit reactance, typically saves 20–40 kWh per tonne.[46] Adoption stands at 30–40 per cent at an indicative Rs 5–15 crore. The constraint is rarely the transformer itself but the electrical connection: an ultra-high-power furnace imposes a substantial and highly variable load, and compliance with grid flicker limits may require static Volt-Ampere Reactive (VAR) compensation, adding materially to project cost. The remaining potential is 0.40–0.79 Mt CO_2 per year.

5.3.3 Electrode management and arc control systems

Energy savings: 10-20 kWh/t liquid steel | Sector-wide CO_2 reduction scope: 0.17-0.33 Mt | Emission intensity reduction scope: 0.001-0.002 tCO_2/tcs

The graphite electrodes of an arc furnace are positioned by hydraulic regulators that respond continuously to changes in arc impedance as the scrap charge collapses and melts beneath them. The speed and stability of that regulation determine how much of the delivered electrical energy reaches the bath rather than being lost due to arc instability, radiation to the water-cooled panels, or electrode breakage. Modern adaptive regulation systems, which adjust their control parameters according to the melting phase, deliver 10–20 kWh per tonne of saving relative to conventional impedance-based control, and their benefit compounds with foamy slag practice, in which the arc is submerged in a slag layer that both shields the sidewalls from radiation and improves heat transfer to the bath. Adoption is comparatively high at 40–50 per cent, reflecting a well-established technology, a short payback and an indicative capital cost of only Rs 1–3 crore. The remaining potential for carbon reduction is 0.17–0.33 Mt CO_2 per year with the remaining adoption of this technology.

5.4 Shared auxiliaries in electric arc and induction furnace plants

Two of the fifteen technologies assessed in this report act not on the melting process itself but on the auxiliary systems that support it, and are therefore common to both electric arc and induction furnace operations. Variable frequency drives govern the fans, pumps, blowers and compressors that serve any melt shop irrespective of its furnace type, and ladle preheating and insulating lids address the handling of liquid steel after tapping, which is likewise route-agnostic. Because neither measure depends on the melting technology, both are assessed against the combined electric arc and induction furnace production base of 82.69 Mt, comprising 31.61 Mt of electric arc furnace crude steel and 51.08 Mt of induction furnace output.

5.4.1 Variable Frequency Drives (VFDs)

Energy savings: 2-5 kWh/t crude steel | Sector-wide CO_2 reduction scope: 0.08-0.20 Mt | Emission intensity reduction scope: 0.001-0.001 tCO_2/tcs

Fans, pumps, blowers and compressors in a steel plant are conventionally driven by fixed-speed motors, with output regulated by dampers or throttling valves, a practice that dissipates excess as pressure drops. Because the power absorbed by a centrifugal machine varies with the cube of its speed, matching motor speed to actual demand via a variable frequency drive typically reduces consumption on the driven load by 20–50 per cent, which across a plant's auxiliary population amounts to 2–5 kWh per tonne of crude steel.[47] Adoption stands at 40–60 per cent, with an indicative capital cost of Rs 0.1–1 crore, the lowest of any measure assessed. The remaining barriers are largely matters of awareness and specification rather than economics: harmonic distortion introduced by drives requires filtering on weaker networks, and older motors may need insulation upgrades to withstand the switching waveform. Although the per-tonne saving is the smallest in this catalogue and the sector-wide contribution correspondingly modest at 0.08–0.20 Mt CO_2 per year, the measure's low cost, universal applicability and short payback make it the natural entry point for a small producer beginning an efficiency programme.

5.4.2 Ladle preheating and insulating lids

Energy savings: 5-15 kWh/t crude steel | Sector-wide CO_2 reduction scope: 0.30-0.89 Mt | Emission intensity reduction scope: 0.002-0.006 tCO_2/tcs

A steel ladle must be brought to 1000–1200°C before receiving liquid steel, and any shortfall in that temperature is made up by superheating the melt in the furnace, where each additional 10°C of superheat costs roughly 4–5 kWh per tonne. Conventional open-flame ladle preheating operates at 30–40 per cent thermal efficiency. Recuperative and regenerative burner systems reach 60–70 per cent, while insulating lids fitted during preheating, transit and idle periods substantially reduce radiation loss from the ladle mouth. Together these measures save 5–15 kWh per tonne of crude steel, partly in preheating fuel and partly in indirectly through reduced furnace superheat.[48] Adoption is 20–30 per cent at an indicative Rs 2–5 crore. Sector-wide potential is 0.30 –0.89 Mt CO_2 per year.

Table 4: Energy efficiency technologies in the Indian iron and steel sector: Energy savings, indicative cost, current adoption and CO_2 reduction potential

S. no	Technology	Production route	Energy savings	Indicative CapEx (₹₹ crore)	Current adoption (%)	CO_2 reduction potential (tCO_2/tcs)	Sector reduction (Mt CO_2)
1	Pulverized coal injection (PCI) optimization	BF ironmaking	1.0–1.5 GJ/t	50–100 per BF	60–70	0.020–0.030	2.88–4.32
2	Top gas recovery turbine (TRT)	BF ironmaking	30–40 kWh/t	30–60	40–50	0.010–0.013	1.38–1.84
3	Hot stove heat optimization	BF ironmaking	0.4–0.8 GJ/t	15–30	30–40	0.015–0.030	2.14–4.28
4	Bell-less top charging	BF ironmaking	0.2–0.5 GJ/t	20–40	60–80	0.003–0.009	0.49–1.24
5	AI/ML process control	BF ironmaking	0.3–0.5 GJ/t	2–5	10–20	0.015–0.024	2.10–3.50
6	Converter gas recovery (OG system)	BOF steelmaking	0.50–0.79 GJ/t †	60–100	60–70	0.007–0.011	1.02–1.61
7	Waste heat recovery boiler	Coal-based DRI	60–90 kWh/t	30–60	5–20	0.015–0.022	2.11–3.17
8	Kiln shell and refractory improvement	Coal-based DRI	0.021–0.042 GJ/t †	<1	20–30	0.000–0.001	0.06–0.12
9	Kiln feed preheating and integration	Coal-based DRI	1.52–1.90 GJ/t ‡	5–15	15–20	0.034–0.043	4.96–6.20
10	AI and sensor-based kiln control	Coal-based DRI	0.57–0.95 GJ/t ‡	0.5–1	<5	0.015–0.025	2.20–3.66
11	Scrap preheating	EAF steelmaking	50–100 kWh/t	30–60	10–20	0.009–0.018	1.29–2.58
12	Ultra-high-power transformer	EAF steelmaking	20–40 kWh/t	5–15	30–40	0.003–0.005	0.40–0.79
13	Electrode and arc control	EAF steelmaking	10–20 kWh/t	1–3	40–50	0.001–0.002	0.17–0.33
14	Variable frequency drives	EAF/IF auxiliaries	2–5 kWh/t	0.1–1	40–60	0.001–0.001	0.08–0.20
15	Ladle preheating and insulating lids	EAF/IF steelmaking	5–15 kWh/t	2–5	20–30	0.002–0.006	0.30–0.89
	TOTAL					**0.150–0.241**	**21.58–34.75**

Sources: Multiple sources (see references 32–48)

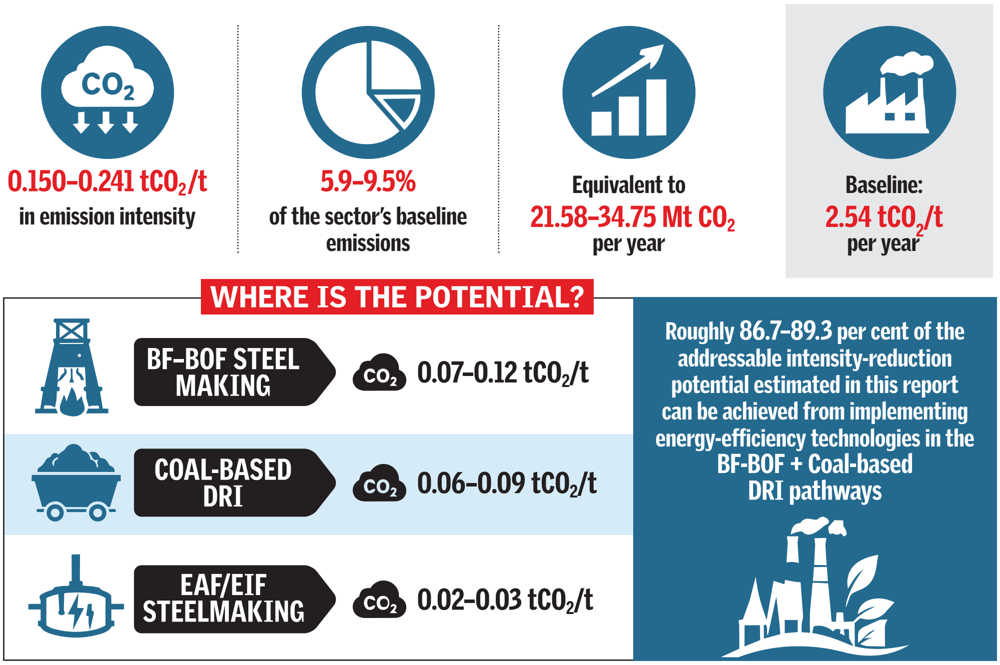
6. Sector-wide reduction potential

Complete deployment of the adoption potential available on each technology would reduce Indian steel sector emissions by between 0.150–0.241 tCO_2/t. This is equivalent to 21.58–34.75 Mt CO_2 per year, or 5.9–9.5 per cent of the 366.52 Mt baseline.

The reduction potential is distributed unevenly across different pathways. Across the total estimated scope of emission reduction, BF–BOF iron making has a reduction scope of 0.07–0.12 tCO_2/t of the sector's overall intensity reduction, the single largest share. Coal-based DRI has a reduction scope of 0.06–0.09 tCO_2/t, and EAF/EIF steelmaking has a reduction scope of 0.02–0.03 tCO_2/t. Therefore, energy efficiency technologies discussed above for the BF–BOF and coal-based DRI pathways together have the potential to deliver roughly 86.7–89.3 per cent of the total emission reduction estimated in this report.

EMISSION REDUCTION POTENTIAL IN INDIA'S STEEL SECTOR

Complete deployment of the adoption potential available on each technology would reduce



Source: CSE analysis

Note: Figures may not add up exactly due to rounding

7. Policy context and implications: CCTS and GEI targets for the Indian iron and steel sector

India's principal market-based efficiency instrument to date has been the Perform, Achieve and Trade (PAT) scheme, administered by the Bureau of Energy Efficiency since 2012. The scheme assigned specific energy consumption reduction targets to designated consumers above a sectoral threshold and issued tradable energy saving certificates to those that over-performed.

The scheme's limitations are now widely acknowledged. Targets were often set at levels well below demonstrated technical potential, certificates were over-supplied, resulting in collapsed prices, and enforcement was weak. Studies of the integrated steel segment found that producers had the technical potential to reduce energy intensity by up to 20 per cent while the scheme set targets of about 4.31 per cent to 2024–25.[49]

The Carbon Credit Trading Scheme, notified in June 2023, is the successor instrument. It shifts the basis of regulation from energy consumption to greenhouse gas emission intensity, measured in tonnes of carbon dioxide equivalent per tonne of product. The Bureau of Energy Efficiency administers the scheme, the Central Electricity Regulatory Commission regulates it, the Grid Controller of India operates the registry, and carbon credit certificates are traded through the power exchanges. The scheme explicitly provides for the transition of PAT-designated consumers into the compliance segment, converting specific energy consumption targets into emission intensity targets, and building on the measurement, reporting and verification infrastructure the earlier scheme established.

The CCTS marks a genuine change of metric, not merely a rebranding of PAT. Where PAT set an energy-efficiency goal, the CCTS sets a greenhouse-gas emission intensity (GEI) goal in tonnes of CO_2-equivalent per unit of product, capturing fuel switching, feedstock change and process emissions, not just energy intensity, and covering non-CO_2 gases. Each Carbon Credit Certificate (CCC) represents 1 tCO_2 equivalent reduced, removed or avoided. The scheme is an intensity-based baseline-and-credit system, not an absolute cap-and-trade: obligated entities receive a GEI target relative to a financial year (FY) 2023–24 baseline, earn CCCs if they meet it, and must purchase CCCs (or pay compensation) if they miss the target.

The institutional architecture is deliberately distributed. The National Steering Committee for the Indian Carbon Market (NSCICM) is co-chaired by the Secretaries of the Ministry of Power and the Ministry of Environment, Forest and Climate Change (MoEFCC) for oversight of the framework. BEE is the administrator, setting trajectories and issuing CCCs, as it did for PAT. The Ministry of Environment, Forest and Climate Change (MoEF&CC) notifies the legally binding intensity targets under the Environment (Protection) Act, 1986. The Central Electricity Regulatory Commission (CERC) is the market regulator. In March 2026 it notified the CERC (Terms and Conditions for Purchase and Sale of Carbon Credit Certificates) Regulations, 2026. Grid Controller of India Ltd operates the ICM registry, and trading takes place on the power exchanges.

Key market parameters are yet to be published. However, in June 2026, the revised (2^{nd}) draft targets for CCTS for the iron and steel sector were published. The baseline average GHG intensity reduction target according to this draft document is 5.82 per cent for the targeted FY 2026–27 from the baseline.

With an average year-on-year (YoY) growth of 2.9 per cent,[50] production is estimated to reach 157.2 MTPA as of 2026–27. A business-as-usual (BAU) scenario with no change in emission intensity as compared to the baseline with emission intensity at 2.54 tCO_2/t production will bring the total emission at 399.34 Mt. Implementing the CCTS target of an average reduction of 5.82 per cent in emission intensity, total emissions would fall to approximately 376.10 Mt, a reduction of 23.24 Mt per annum. This target can be achieved by implementing the specified 15 energy efficiency technologies alone across various routes of the sector, with a total sectorial reduction potential at 21.58–34.75 tCO_2 (5.9–9.5 per cent from the overall sectoral emissions in the country).

For the sector as a whole, proven energy efficiency technology is therefore more than sufficient to meet the first compliance cycle. For future cycles and targets (if ambitious), the recourse to green hydrogen, carbon capture, or any change in feedstock or process route will become significant.

The secondary sector

The secondary steel sector accounts for the largest share of untapped potential and faces the sharpest challenges. These include high upfront capital costs relative to balance sheet size, limited access to affordable finance, onerous collateral requirements, low levels of automation and digital readiness, retrofit complexity in plants never designed for the equipment, and a degree of informality that limits both institutional finance and policy visibility.

The Carbon Credit Trading Scheme covers 255 obligated entities in the iron and steel sector. The secondary sector comprises many thousands of units, most below any plausible obligation threshold, and they collectively hold a majority of the potential quantified in this report. A compliance mechanism alone will not reach them. What is required is a parallel programme of targeted finance, technical assistance and demonstration for units the compliance mechanism does not reach, funded in part by the revenues the compliance mechanism generates.

Energy efficiency is the among the most effective decarbonization levers available to the Indian iron and steel sector in the near term. The 15 technologies discussed earlier can abate 21.58–34.75 Mt CO_2 per year, and the analysis below finds that the large majority of that potential is available at negative net cost (energy-cost savings exceed the annualized capital outlay). Yet it remains unrealized because of financing and structural barriers concentrated in the coal-based DRI and secondary segments.

This report focuses on monetization of energy savings using current Indian energy prices, computes plant-level paybacks and a marginal-abatement-cost ranking, examines why economically attractive measures are deferred, and maps the financing mechanisms available against the technologies and producer segments that actually need them.

8. Cost analysis and financing opportunities

The principal benefit of energy efficiency investment in an Indian steel plant is the reduction in operating cost it delivers, in an industry where energy accounts for 20–40 per cent of total production cost.[51] Reducing specific energy consumption therefore delivers both a direct financial return and emission reductions, and the two arrive together. Most of the technologies assessed in this report have been commercially available for years and carry relatively low technical risk because their performance is well documented across a large installed base. This distinguishes them from breakthrough pathways such as hydrogen-based reduction, carbon capture and electrolytic ironmaking.

Capital requirements across the 15 technologies span three orders of magnitude, from under Rs 1 crore to Rs 100 crore, depending on the scale of the intervention, the age of the plant and its capacity to accommodate a retrofit. Converter gas recovery and pulverized coal injection optimization sit at the upper end and represent a large share of the total investment required at an integrated plant. Waste heat recovery in coal-based DRI is similarly capital-intensive at power-generation scale.

At the other end, process control systems, variable frequency drives, refractory improvements and ladle insulation require modest capital and repay it quickly, making them the natural entry point for producers beginning an efficiency programme and the measures most readily financed from working capital.

The economic case for each technology is best assessed through its payback period, which varies considerably across the fifteen measures.

8.1 Payback period and economic viability

Short payback (one to two years)

Eleven of the 13 technologies for which a payback figure is available have payback periods of two years or less, which is the central finding of the cost analysis. Process control systems repay fastest: AI and machine learning control on the blast furnace, and sensor-based control on the DRI kiln, both recover their cost within eight to ten months and require the least capital in the catalogue. Variable frequency drives repay over the same period. Refractory and shell improvements on DRI kilns, and

Table 5: Cost and payback period of major energy efficiency technologies in the Indian iron and steel industry

Technology	CapEx range (Rs crore)	Payback period (months)	Adoption level
Pulverized coal injection optimization	50–100 per BF	12–15	High
Top gas recovery turbine	30–60	15–18	Medium
Hot stove heat optimization	15–30	12–14	Medium
Bell-less top charging	20–40	Not listed	–
AI/ML process control (BF)	2–5	8–10	Low
Converter gas recovery (OG)	60–100	Not listed	–
WHR boiler—process heat	30–60	54–60	Low
Kiln shell and refractory	Below 1	11–12	Low
Kiln feed preheating	5–15	12–14	Low
AI and sensor-based kiln control	0.5–1	8–10	Low
Scrap preheating	30–60	26–48	Low
Ultra-high-power transformer	5–15	12	Medium
Electrode and arc control	1–3	21–24	Medium
Variable frequency drives	0.1–1	8–10	Medium
Ladle preheating and lids	2–5	11–12	Low

Source: BEE List of Energy Efficient Technologies and stakeholder discussion; CapEx and adoption from Table 4

ladle preheating with insulating lids, repay in eleven to twelve months. Ultra-high-power transformer upgrades in electric arc furnaces repay in twelve months.

Three larger interventions also fall within this band. Hot stove optimization and kiln feed preheating both repay in 12–14 months, and pulverized coal injection optimization in 12–15 months despite requiring Rs 50–100 crore per furnace, because the volume of coke displaced is large and coke is costly. Top gas recovery turbines follow at 15–18 months, and electrode and arc control at 21–24.

Medium payback (two to four years)

Scrap preheating in electric arc furnaces repays over 26–48 months. The wide range reflects strong dependence on charge composition and on the configuration installed, from a simple bucket preheater to a continuous shaft system. The measure requires ₹30–60 crore and its economics are correspondingly sensitive to furnace utilization.

Long payback (four years and above)

Waste heat recovery in coal-based DRI repays over 54–60 months, the longest in the catalogue. This is the exception to the pattern above. It is a large untapped opportunity. The adoption stands at only 5–20 per cent, but it is the one measure in the DRI group whose payback extends beyond four years.

Technologies without a listed payback

Bell-less top charging and converter gas recovery do not carry a payback figure in this report. In both cases, the measure is best undertaken during scheduled work. The relevant comparison for both is the incremental cost of installation during planned work rather than the full cost of a dedicated project, and this should be assessed on a plant-by-plant basis.

The payback periods above rest principally on Bureau of Energy Efficiency estimates. They were assessed against prevailing energy prices and make no allowance for carbon value. Once rising fuel and electricity costs are taken into account, and once the compliance value of avoided emissions under the Carbon Credit Trading Scheme is recognized, the effective payback for every measure reduces. In the future, when more stringent emission reduction targets are set for obligated entities, to avoid the penalty alone will justify measures that appear marginal on energy savings.

8.2 Barriers to investment

The principal barriers to investment are:

- High initial capital requirement for major upgrades, particularly waste heat recovery and scrap preheating, relative to the balance sheet size of the units concerned;
- Limited access to affordable finance for smaller producers;
- Downtime during retrofit;
- Limited information on technology availability, vendor selection, suitability for particular plant configurations, and uncertainty about realized savings;
- Absence of sub-metering and energy accounting in many secondary units, which prevents savings from being measured and therefore defeats performance-based financing; and
- Competition for internal capital against capacity expansion, which carries higher headline returns and greater strategic priority in board-level allocation.

8.3 Major financing mechanisms for adoption of energy-efficient technologies

The financing landscape for industrial energy efficiency in India has developed considerably over the past decade. Large integrated producers have been early movers and can generally fund upgrades internally or through capital markets. Smaller producers frequently lack the credit history, collateral, technical data and institutional capacity to access mainstream finance. Closing this gap is as much of a policy issue as a financial challenge. The technologies are commercially proven and economically viable. What is required is a structured and accessible financing ecosystem that directs capital to where the abatement potential is greatest.

Internal funding

Producers with strong operating cash flow and sound credit standing generally fund efficiency investments from retained earnings, the simplest and cheapest route. Large integrated producers have financed process control, waste heat recovery and auxiliary upgrades this way. Internal funding is far less available to smaller producers operating on thin margins with little retained surplus. Even where funds exist, efficiency investment competes with capacity expansion, which is generally accorded higher strategic priority, so internal capital allocation may deprioritize efficiency absent a strong regulatory or carbon price signal. This structural barrier persists even in well-capitalized firms, and it is why policy signaling matters to board-level decisions.

Government and regulatory schemes

The PAT scheme established India's first market-based mechanism for monetizing energy savings through Energy Saving Certificates. Its successor CCTS extends this by allowing entities that outperform their emission intensity target to earn tradable carbon credit certificates, creating a direct revenue stream as the carbon price matures. The Assistance in Deploying Energy Efficient Technologies in Industries & Establishments (ADEETIE) scheme, launched by the Ministry of Power through BEE in July 2025 with a Rs 1,000 crore outlay, provides interest subvention of 5 per cent for micro and small enterprises and 3 per cent for medium enterprises on efficiency loans. It also provides support for investment-grade energy audits. The Small Industries Development Bank of India (SIDBI) operates the most developed set of MSME instruments, offering loans of Rs 10 lakh to Rs 5 crore at concessional rates, with a bundled energy audit, a green finance line up to Rs 20 crore, and the Partial Risk Sharing Facility providing risk cover for energy performance contracts. The Partial Risk Guarantee Fund for Energy Efficiency offers lenders cover of 50 per cent of the loan or Rs 10 crore, whichever is lower, and is well suited to the low-collateral waste heat recovery problem if deployed at scale. The Credit Guarantee Fund Trust for Micro and Small Enterprises provides collateral-free guarantee cover. It is applicable to secondary-sector efficiency investment.

Commercial bank and NBFC lending

Equipment loans from commercial banks typically carry interest of 8–12 per cent with repayment over three to seven years, and some lenders offer lease-to-own structures. Bank finance is in principle the most suitable route for mid-sized producers. However, it also has its own challenges. Most lenders assess collateral and balance sheet strength rather than projected energy savings, and efficiency equipment provides weak security. Loan officers may lack the technical background to assess energy efficiency project risk accurately. This may at times lead to conservative underwriting and rejection of proposals.

Green bonds and sustainability-linked instruments

Large producers can access sustainability-linked loans and bonds, where pricing is tied to emission intensity or renewable energy targets. JSW Steel issued the global steel industry's first dollar-denominated sustainability-linked bond in 2021. These instruments suit a portfolio of efficiency measures at investment-grade producers but are effectively closed to smaller firms. The process for issuing the bond is costly and time-consuming, and includes third-party certification, legal documentation and continuous impact reporting.

Multilateral and bilateral development finance

The World Bank, Asian Development Bank and International Finance Corporation provide concessional finance and credit guarantees for large capital projects. The World Bank's Clean Technology Fund, the Global Environment Facility, KfW and JICA provide bilateral concessional lines for industrial clean technology. These sources supply the concessional and risk-bearing tranches that make MSME efficiency lending viable. However, access to these financial instruments has limitations. The application and compliance with environmental and social safeguard frameworks impose preparation costs and documentation burdens that smaller producers struggle to meet without assistance.

Equipment leasing and energy service companies (ESCO)

Leasing allows a producer to use equipment owned by a lessor in exchange for periodic payments, often with maintenance and servicing included, reducing both capital outlay and operational risk. It suits firms willing to adopt a technology but unwilling to commit capital before proving it, and is particularly relevant to the longer-payback measures. The leasing market for heavy industrial machinery in India is however considerably less developed than for logistics or construction equipment, and lessors are cautious about specialized steel plant equipment for which no ready secondary market exists. The energy service company model, in which a third party finances and installs equipment and is repaid from verified savings, addresses the capital constraint directly. However, this remains underdeveloped in India due to limited measurement and verification capability at host plants.

9. Conclusion

The iron and steel industry in India is at a critical point. In line with the National Steel Policy's target of 300 MTPA by 2030, the sector's capacity is expected to expand substantially over the coming years. An expansion of this scale will have major consequences for India's emissions trajectory and its national climate change commitments. There is an array of energy-efficient technologies available for the iron and steel sector. This report attempts to identify the most impactful and commercially available options across the BF-BOF, coal-based DRI, and EAF/EIF routes that can be leveraged to achieve emission reductions through energy efficiency in the near future. The study shows that full deployment of the 15 assessed technologies to their remaining adoption potential could reduce emissions by 0.150–0.241 tCO_2/t crude steel, equivalent to 21.58–34.75 MTPA CO_2 from the sector. This would translate into a reduction of 5.9–9.5 per cent in the current average emission intensity of the sector, bringing it down from 2.54 to approximately 2.30–2.39 tCO_2/t. These outcomes are achievable using technologies whose performance has already been established. It is important to note that the potential for energy efficiency will likely differ from plant to plant depending on parameters such as age, current technologies etc. The largest untapped opportunity is concentrated in the coal-based DRI sector.

There is a need for policy interventions to provide easier access to finance, information and technological understanding, especially for smaller and older units that lack the balance sheet strength or credit history to access mainstream finance. With the commencement of the CCTS, energy efficiency will play a crucial role in enabling the sector to achieve its targets for the upcoming compliance cycle and beyond. The sector faces a tentative compliance target of a 5.82 per cent reduction in emission intensity by FY 2026–27 (still in the draft stage), which is equivalent to roughly 23.24 Mt of absolute emissions reduction against a business-as-usual scenario. The energy efficiency technologies evaluated in this report can deliver this required target, demonstrating that energy efficiency measures alone are sufficient to enable steel plants to meet their regulatory compliance obligations in the near term. Achieving deeper decarbonization beyond this will require clear strategies, targets and investments in pathways such as increasing scrap-based steelmaking, renewable electricity integration for electric arc and induction furnace operations, green hydrogen-based ironmaking, and CCUS for residual process.

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India is the second-largest manufacturer of crude steel in the world. In FY 2023–24, the sector produced 144.3 million tonnes of crude steel at an average intensity of 2.54 tCO_2 per tonne, releasing 366.52 million tonnes of CO_2. A major part of that emission comes from energy-related sources. The average Indian steel plant still consumes 30–42 per cent more energy per tonne as compared to global best plants.

***Forging Transition* argues that this gap is the opportunity. This report assesses 15 commercially proven energy-efficiency technologies across the blast furnace, coal-based DRI and electric furnace routes, quantifying the emissions that can be reduced from the existing capacity. Complete deployment would cut sectoral emissions by 21.6–34.8 million tonnes, or 5.9–9.5 per cent, with most technologies paying for themselves within two years. This could also be a major contributor in achieving the upcoming Carbon Credit Trading Scheme (CCTS) targets.**

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