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Low-Carbon Steel Sector

Perspectives on Interventions & Challenges

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Founded in 2008, the **Environment Conservation Society** (ECS), also known as SwitchON Foundation, actively offers **sustainable solutions** for the vulnerable Indian population. With a commitment to **clean and renewable energy**, climate-resilient agriculture, and **sustainable cities**, ECS is working towards creating opportunities for 10 million people by 2030, promoting equitable growth through innovative business models and technologies.

Recognizing the crucial role of the steel industry in India's green transition, ECS is dedicated to fostering sustainable steel production and consumption. Our work focuses on integrating renewable energy solutions, resource efficiency, and circular economy principles into steel manufacturing. By engaging with industry leaders, policymakers, and research institutions, we aim to drive innovation, reduce emissions, and promote responsible sourcing of raw materials.

Through **evidence-based research** and stakeholder engagement, ECS advocates for policies that encourage low-carbon steel production and responsible mining practices. Our efforts also include capacity-building initiatives to ensure that industries, workers, and communities are equipped to participate in this transition towards sustainable industrialization.

ECS's commitment to sustainability extends to fostering collaborations for green infrastructure and decarbonizing hard-to-abate sectors. This report, ***"Low-Carbon Steel Sector: Perspectives on Interventions and Challenges"*** *was releaed on August 22, 2025 in the Jharkhand Symposium,* captures key discussions on the current green steel landscape in India and Jharkhand, highlighting challenges and opportunities for aligning the sector with national and global climate goals.

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List of Abbreviations:

Abbreviation	Full Form
AI	Artificial Intelligence
BF	Blast Furnace
BF–BOF	Blast Furnace–Basic Oxygen Furnace
BEE	Bureau of Energy Efficiency
CBAM	Carbon Border Adjustment Mechanism
CCUS	Carbon Capture, Utilisation, and Storage
CEA	Central Electricity Authority
CCTS	Carbon Credit Trading Scheme
CO_2	Carbon Dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
ELV	End-of-Life Vehicle
EPR	Extended Producer Responsibility
ESG	Environmental, Social, and Governance
ESCert	Energy Saving Certificate
ETS	Emissions Trading System
EU ETS	European Union Emissions Trading System
EV	Electric Vehicle
Gcal	Giga Calorie
GHG	Greenhouse Gas
GW	Gigawatt
KM	Kilometre

MCal	Million Calories
MNRE	Ministry of New and Renewable Energy
MoS	Ministry of Steel
MTOE	Million Tonnes of Oil Equivalent
MSME	Micro, Small, and Medium Enterprises
Mt	Million tonnes
$MtCO_2$ / $MtCO_2e$	Million tonnes of carbon dioxide equivalent
MW	Megawatt
NGHM	National Green Hydrogen Mission
NITI Aayog	National Institution for Transforming India
PLI	Production-Linked Incentive
PAT	Perform, Achieve & Trade
PPA	Power Purchase Agreement
PPF	Project Preparation Facility
RE	Renewable Energy
Rs / ₹	Indian Rupee
SAIL	Steel Authority of India Limited
SRTMI	Steel Research & Technology Mission of India
t/mt	tonne/metric tonne
TWh	Terawatt-hour
USD	United States Dollar
VERRA	Verified Carbon Standard (Verra)

Executive Summary :

India's steel sector stands at a critical intersection of industrial growth and climate responsibility. As the world's second-largest producer, with 144 million tonnes of crude steel in 2024 and an ambitious target of 300 million tonnes by 2030, it remains a pillar of economic development but also a significant source of greenhouse gas emissions—responsible for 12% of national CO_2 emissions and ranking as the largest industrial energy consumer. Heavy reliance on coal-based blast furnace–basic oxygen furnace routes has resulted in high emissions intensity, while the country's net-zero by 2070 commitment and tightening global trade rules, notably the EU's Carbon Border Adjustment Mechanism (CBAM), demand urgent transformation. Without decisive action, CBAM could put up to US$2 billion of annual steel export revenue at risk. At the same time, the sector faces a historic opportunity: domestic and global demand for green steel is projected to grow from negligible levels today to 4.49 million tonnes by 2030 and 179 million tonnes by 2050, driven by construction, infrastructure, and automotive sectors

This report identifies six priority decarbonisation pathways with the potential to deliver substantial emissions reductions and improve competitiveness. Energy efficiency measures—such as reheating furnace recuperators, high-efficiency motors, and smart controls—can cut energy use by 15–30% and lower baseline carbon intensity. Integrating renewable energy into steelmaking can reduce Scope 2 emissions by 25–35%, while also stabilising electricity costs, especially when coupled with process electrification and green hydrogen production. Expanding the use of scrap steel can cut emissions by up to 58% per tonne and conserve water along with critical raw materials like iron ore and coking coal. Shifting to green hydrogen in direct reduced iron (DRI) processes could achieve up to a 90% reduction in route-specific emissions, offering a near-zero-carbon production pathway. Carbon Capture, Utilisation, and Storage (CCUS) can abate up to 56% of blast furnace process emissions, bridging the gap where emissions cannot yet be eliminated. Supplementary interventions—including circular economy measures such as biomass-derived biochar and advanced material efficiency—further enhance decarbonisation impact.

A robust and evolving policy ecosystem supports these pathways, ranging from the Steel Scrap Recycling Policy (2019) and the National Solar Mission (2010) to the National Green Hydrogen Mission (2023), the Perform, Achieve & Trade Scheme, the Motor Vehicle Scrapping Rules (2021), the Carbon Credit Trading Scheme (2023), and the Production Linked Incentive Scheme for Specialty Steel. The Greening the Steel Sector Task Force has laid out a phased adoption roadmap linking technology, infrastructure, and enabling markets. Strategic objectives in this report include driving demand for low-carbon steel through collaboration with MSMEs, major buyers, and real estate developers; improving awareness and technical capability; scaling renewable energy, energy efficiency, and circular economy adoption; strengthening industry–academia–government partnerships; and implementing coherent policies that de-risk investment in low-carbon solutions. Expected outcomes include a stronger domestic green steel market, accelerated uptake of efficiency measures and renewables, and more integrated collaboration networks supported by aligned regulatory frameworks.

The analytical synthesis identifies three cross-cutting enablers critical to accelerating this transition: mobilising green finance and blended capital to fund large-scale technology deployment; deepening academia–industry partnerships to create cost-effective, locally tailored solutions; and harmonising state-level and central policies to provide predictable, investment-friendly conditions. The sector's long-term competitiveness and resilience will depend on aligning financial planning, technology deployment, and policy frameworks so they reinforce each other. With coordinated action from industry, government, and civil society, India can not only meet its climate commitments but also position its steel sector as a global leader in sustainable production—advancing economic growth, protecting export competitiveness, and delivering a replicable model for "industrialisation without carbonisation".

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1. Introduction

India's steel sector stands at the intersection of industrial expansion and climate responsibility. As the world's second-largest steel producer with 144 million tonnes of crude steel output in 2024, the country's ambition to reach 300 million tonnes by 2030 has to contend with the reality of a substantial carbon footprint. The sector contributes 12% of national CO_2 emissions, consumes over 80 million tonnes of oil equivalent annually, and remains dominated by coal-intensive blast furnace–basic oxygen furnace (BF–BOF) routes with high energy intensity. At the same time, India's net-zero by 2070 commitment demands a decisive shift toward low-carbon technologies, renewable energy integration, and circular economy practices.

The urgency for transformation is not only climate-driven but also market-led. The European Union's Carbon Border Adjustment Mechanism (CBAM), effective in 2026, will impose €173.8 per tonne on higher-carbon steel imports — a potential US$2 billion annual export risk for India if emissions intensity is not reduced. Yet, this challenge opens avenues for structural reform, technological innovation, and competitive differentiation in global green steel markets.

This report sets out a strategic approach designed to accelerate the sector's decarbonisation in a manner that is economically viable, socially inclusive, and technologically future-ready.
Our approach seeks to:

1. Drive demand for low-carbon steel through collaboration with MSMEs, major end-users, and real estate developers to establish early and scalable markets.
2. Enhance awareness among manufacturers on available green steel pathways and associated market opportunities.
3. Promote adoption of renewable energy, energy efficiency, and circular economy practices to achieve measurable emissions reduction.
4. Strengthen industry–academia–government partnerships for research, innovation, and technology transfer.
5. Support enabling policies and financial incentives that reduce investment risks and foster large-scale adoption of low-carbon solutions.

Expected outcomes include a broader public and industry demand for low-carbon steel, greater adoption of renewable and energy-efficient measures, and stronger collaboration networks underpinned by coherent policy frameworks. By aligning decarbonisation imperatives with market opportunities, the report aims to outline a pathway that positions India not just as a fast-growing steel producer, but as a global leader in sustainable steelmaking.

2. Present Landscape

India's steel sector is both the backbone of industrial growth and a critical front for climate action. As the world's second-largest producer, with 144 million tonnes of crude steel output in 2024, the country's goal of reaching 300 million tonnes by 2030 must be met while addressing its significant environmental footprint. The industry accounts for 12% of national CO_2 emissions and consumes 80 million tonnes of oil equivalent annually, primarily driven by the dominance of coal-based blast furnace–basic oxygen furnace (BF–BOF) routes and their high energy intensity. , making it the largest industrial energy user. India's net-zero by 2070 commitment now places the sector under increasing pressure to adopt renewable energy and low-carbon technologies.

Table: Annual Crude steel production and emission intensity

Year	Value (million tonnes)
2019-20	109.14 million tonnes
2020-21	103.54 million tonnes
2021-22	120.29 million tonnes
2022-23	127.20 million tonnes
2023-24	144.30 million tonnes
Average Emission Intensity (2023-24)	2.54 tonnes CO_2 per tonne crude steel (Ministry of Steel statement in Rajya Sabha (2024))

Source: Ministry of Steel, Joint Plant Committee

That urgency is sharpened by global trade realities. From 2026, the EU's Carbon Border Adjustment Mechanism (CBAM) will add €173.8 per tonne (₹15,394) to Indian steel exports, around 16% of unit export value. With the EU purchasing 38% of India's $3.7 billion annual steel exports, CBAM could erode up to US$2 billion in revenue if carbon intensity is not reduced. This external pressure is now driving domestic producers to accelerate decarbonisation.

Market shifts add another layer of opportunity. Although green steel demand is negligible today, projections show it reaching 4.49 Mt by 2030 and 179 Mt by 2050, with construction (56%), infrastructure (33%), and automotive (11%) leading adoption. This growth, driven by rapid urbanisation and infrastructure spending, positions early adopters to capture both domestic and export market share.

Yet the pathway is uneven. Large producers have the capital and expertise to invest in advanced decarbonisation technologies, while MSMEs—accounting for 55% of secondary steel output—face limitations in finance, modern equipment, and technical know-how. In Jharkhand, many small units still depend on coal-fired rotary kilns and induction furnaces, underscoring the need for targeted support to ensure no segment is left behind in the transition.

Policy action is already accelerating this shift. The ₹19,744 crore National Green Hydrogen Mission targets 5 Mt annual production by 2030, including ₹455 crore for steel sector pilots. The Green Steel Taxonomy (2024) defines an emissions benchmark of <0.5 t CO_2 per tonne of crude steel. Demonstrations—such as Tata Steel's 40% hydrogen injection trial (cutting emissions by 7–10%) and SAIL's bamboo biochar trials (targeting 15–20% reduction)—show technical readiness, while SRTMI fosters industry–academia partnerships to scale such innovations.

Crucially, this transition must be just and inclusive. The **Jharkhand Task Force on Sustainable Just Transition** highlights the need to safeguard livelihoods while advancing decarbonisation. If managed well, Eastern India's transformation can protect exports, attract global investments, and offer a model of "industrialisation without carbonisation" for other emerging economies.

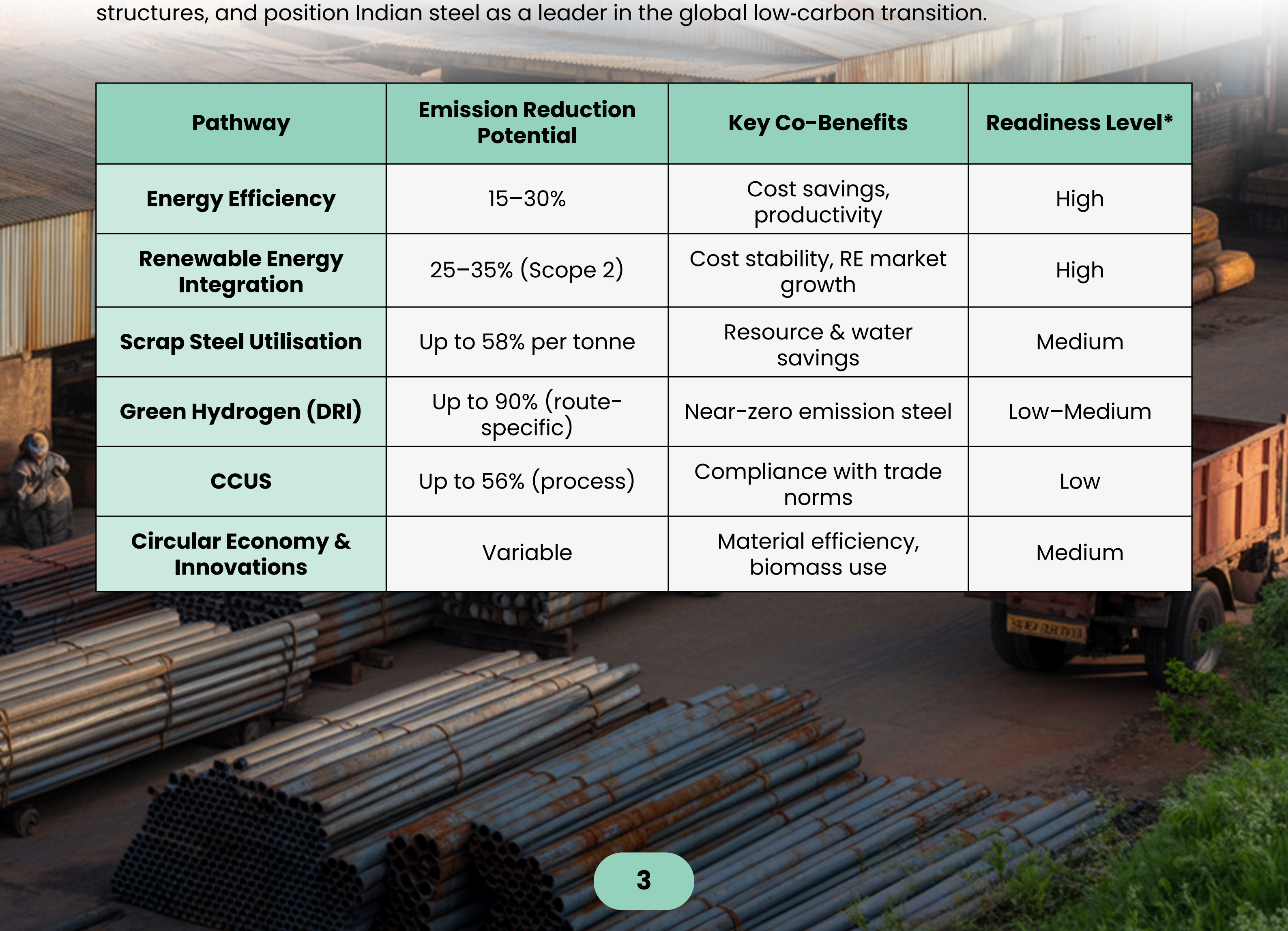
3. Decarbonisation Pathways and Interventions

Decarbonising India's steel sector is both a technological challenge and an economic opportunity, essential for meeting national climate commitments and maintaining global competitiveness. The sector's heavy reliance on coal-based processes, combined with a diverse producer base ranging from large integrated plants to numerous MSMEs, demands a multi-pronged strategy that can address varied operational realities.

This section outlines the key demand- and supply-side pathways that can cut emissions while supporting growth: improving energy efficiency, integrating renewable energy, expanding scrap steel utilisation, deploying green hydrogen, applying carbon capture, utilisation, and storage (CCUS), and preparing for emerging trade-linked carbon regulations such as the EU's Carbon Border Adjustment Mechanism (CBAM). Each of these approaches offers distinct opportunities and faces specific barriers, making policy support, financing, and capacity building critical for success.

These interventions are interconnected. Renewable energy integration can enable cost-effective green hydrogen production, energy efficiency lowers total power demand to make other solutions more viable, while scrap utilisation reduces the need for carbon-intensive primary ironmaking. By leveraging these synergies, the sector can achieve system-wide emissions reductions, improve cost structures, and position Indian steel as a leader in the global low-carbon transition.

Pathway	Emission Reduction Potential	Key Co-Benefits	Readiness Level*
Energy Efficiency	15–30%	Cost savings, productivity	High
Renewable Energy Integration	25–35% (Scope 2)	Cost stability, RE market growth	High
Scrap Steel Utilisation	Up to 58% per tonne	Resource & water savings	Medium
Green Hydrogen (DRI)	Up to 90% (route-specific)	Near-zero emission steel	Low–Medium
CCUS	Up to 56% (process)	Compliance with trade norms	Low
Circular Economy & Innovations	Variable	Material efficiency, biomass use	Medium



3.1 Renewable Energy Integration

Renewable energy integration plays a pivotal role in decarbonizing India's steel sector by reducing Scope 2 emissions by an estimated 25–35%, stabilizing operational costs, and enabling the electrification of key processes such as electric arc furnace (EAF) steelmaking and green hydrogen production. In 2022, India's steel industry consumed around 39 TWh of electricity, with demand projected to increase to 56 TWh by 2030. Harnessing the sector's substantial renewable potential — particularly the 9.4 GW open access solar capacity — could abate approximately 29 million tonnes of CO_2 annually, alongside delivering operational cost savings of 2 to 10 percent. This dual advantage makes renewable energy both an environmental necessity and an economic opportunity.

Current Pathways for Renewable Integration

- **Solar Rooftop (SRT):** Solar rooftop systems offer immediate deployment potential with minimal land use, ideal for secondary steel producers and auxiliary operations. Under existing net metering and gross metering policies, industrial facilities can reduce operational costs by 2–5%, with annual savings ranging from ₹50 million to ₹200 million. However, challenges such as structural load limits, capacity restrictions, and varying settlement periods across states constrain rapid scale-up.

- **Green Energy Open Access:** This mechanism allows industrial consumers to procure renewable energy from off-site solar and wind projects via power purchase agreements (PPAs) — including captive, third-party, or group-captive models. Open access solar can reduce tariffs by an average of 44%, yielding cost savings of ₹1–4 per kWh, with states like West Bengal offering the highest benefits. Nevertheless, surcharges such as cross-subsidy, wheeling, and banking fees, combined with complex and inconsistent approval processes, introduce cost and administrative barriers.

- **Solar Captive Power Plants:** Large captive solar installations, like ArcelorMittal's 1 GW hybrid project (Solar and wind power together) with 2,400 acres dedicated to solar panels and 700 acres to wind turbines, provide reliable 24/7 renewable power with annual generation of 2.5 billion kWh, sufficient to power nearly 10 million Indian households when integrated with storage solutions, achieving significant grid independence. Captive consumers in most cases, are exempt from certain surcharges, making such investments financially attractive for large producers . Group captive models also enable smaller producers to jointly invest and benefit. Despite these advantages, high upfront costs (₹4–5 crore per MW) and complex regulations — including connectivity approvals and compliance requirements — limit wider adoption. Regulatory inconsistencies among states exacerbate these challenges.

Challenges :

- **Regulatory Fragmentation:** With 29 different State Electricity Regulatory Commissions overseeing net metering (28 SERC) and open access policies (22 SERC), a lack of harmonization causes significant uncertainty around capacity limits, compensation methods, metering technology requirements, and settlement periods.

- **Financial Barriers:** Utility-scale solar projects require capital investment of ₹4–5 crore per MW; rooftop systems cost ₹50–70 lakh per MW excluding installation; battery energy storage systems add approximately ₹2–3 crore per MWh. MSMEs face difficulties securing funding under conventional financial frameworks due to thin margins and limited access to institutional finance.

- **Technical Expertise Gaps:** Many MSMEs lack in-house capabilities for renewable integration, including grid synchronization, voltage regulation, power quality management, and energy storage integration. Continuous specialized technical support is needed, which is often scarce within traditional steel production teams.

- **Carbon Credit Monetisation Opportunity:** Large-scale renewable energy projects can be registered under domestic and international carbon market mechanisms to generate tradable carbon credits, creating additional revenue streams that improve financial returns and accelerate adoption.

Way Forward :

- **ESCO Models:** Energy Service Companies providing shared savings and guaranteed performance contracts can reduce financial and technical risks for MSMEs, enabling adoption with minimal upfront investment.

- **Project Preparation Facilities (PPF):** Establishing dedicated support centers to link MSME clusters with certified ESCOs can facilitate project development, regulatory compliance, and access to financing.

- **Green Financing Mechanisms:** Increased availability of concessional finance from climate funds, development banks, and sustainability-linked loans can lower capital costs and improve financing terms.

- **Policy Harmonization:** Standardizing net metering, open access regulations, and tariff policies across states under central oversight will create consistent market conditions, reduce transaction costs, and enable scale.

- **Capacity Building:** Platforms such as the Steel Research & Technology Mission of India (SRTMI), combined with industry-academia partnerships, are essential to upgrade technical expertise within steel operations to ensure effective renewable deployment and innovation.

By addressing these challenges and advancing these pathways, India's steel sector can leverage renewable energy to achieve both significant emission reductions and enhanced economic competitiveness, aligning with national climate goals and global sustainability trends.

Table: Renewable energy genration:

Parameter	Value in Giga Watt(March 2024)	Percentage
Total Installed Power Capacity (all sources)	~486 GW	100
Total Renewable Energy Installed Capacity (incl. large hydro)	~190.57 GW	43.12
Renewable Energy Installed Capacity (Solar, Wind, BioPower, Small Hydro)	~143.64 GW	32.5
Solar Power Installed Capacity	~92.12 GW	20.8
Wind Power Installed Capacity	~47.72 GW	10.8
Large Hydro Installed Capacity	~46.93 GW	10.6
Small Hydro Installed Capacity	~5.07 GW	1.2
Biopower Installed Capacity	~11.32 GW	2.6

Data Source: Ministry of New and Renewable Energy (MNRE), 2024

Table: solar energy installed capacity over the years

Year	Installed Solar Capacity (GW)	Percentage of Total Installed Capacity	Year	Installed Solar Capacity (GW)	Percentage of Total Installed Capacity
2014	2.82	1.15%	2020	45	11.39%
2015	3.99	1.48%	2021	60	13.79%
2016	5.5	1.90%	2022	75	16.67%
2017	10	3.17%	2023	81.81	17.78%
2018	20	5.71%	2024	92.12	19.61%
2019	30	8.00%	2025	105.65	22.20%

Source: Central Electricity Authority (CEA) and Ministry of Power reports

Solar Energy Type	Installed Capacity (GW)	Percentage of Total Solar Capacity (%)
Ground-Mounted Utility-Scale	81.01	88
Rooftop Solar	17.02	18.5
Solar Component of Hybrid Projects	2.87	3.1
Off-Grid Solar	4.74	5.1
Total Solar Capacity (July 2025)	119.02	100

Data Source: Ministry of New and Renewable Energy (MNRE)

3.2 Scrap Steel Utilisation

Scrap steel utilisation is a critical lever for decarbonising India's steel sector, offering substantial environmental and resource conservation benefits. Recycling one tonne of steel scrap can reduce greenhouse gas (GHG) emissions by up to 58%, save approximately 40% of water, and conserve 1.1 tonnes of iron ore, 0.63 tonnes of coking coal, and 55 kg of limestone. Given India's ambition to expand steel production to 300 million tonnes by 2030, accelerating scrap use is essential for meeting climate targets while supporting circular economy principles.

Present Usage and Data

India currently generates around 25 million tonnes of scrap annually, but supply falls short, necessitating imports of 10–12 million tonnes per year. Scrap already plays a vital role, contributing 30–40% of the feedstock for secondary steel production. With steel demand expected to grow sharply, bridging the scrap deficit will require a rapid expansion of organised collection networks, processing capacity, and quality enhancement systems. The Steel Scrap Recycling Policy (2019) and the Motor Vehicle Scrapping Rules (2021) aim to formalise this market and boost domestic availability, but their impact will depend on effective implementation.

Pathways for Scrap Integration

- **Formal and Informal Collection Networks:** Develop organised collection zones and hubs to improve both the quantity and consistency of available scrap.

- **Digital Registries and Marketplaces:** Use digital platforms for transparent scrap trading, traceability, and price discovery.

- **Advanced Sorting and Processing:** Deploy AI-driven sorting and sensor-based separation to produce higher-grade scrap suitable for premium steel applications.

- **End-of-Life Vehicle (ELV) Recycling:** Integrate certified dismantling and shredding facilities with steel producers to secure a steady supply of homogeneous, high-quality ferrous scrap.

Challenges :

- **Supply Deficit and Seasonal Fluctuations:** Domestic scrap generation remains insufficient and varies by season, affecting production planning.
- **Inconsistent Quality:** Predominantly unorganised sourcing leads to variability in scrap quality, impacting furnace efficiency and end-product performance.
- **Price Volatility:** Fluctuating scrap prices create procurement uncertainty, disproportionately affecting MSMEs with limited financial buffers.

Way Forward :

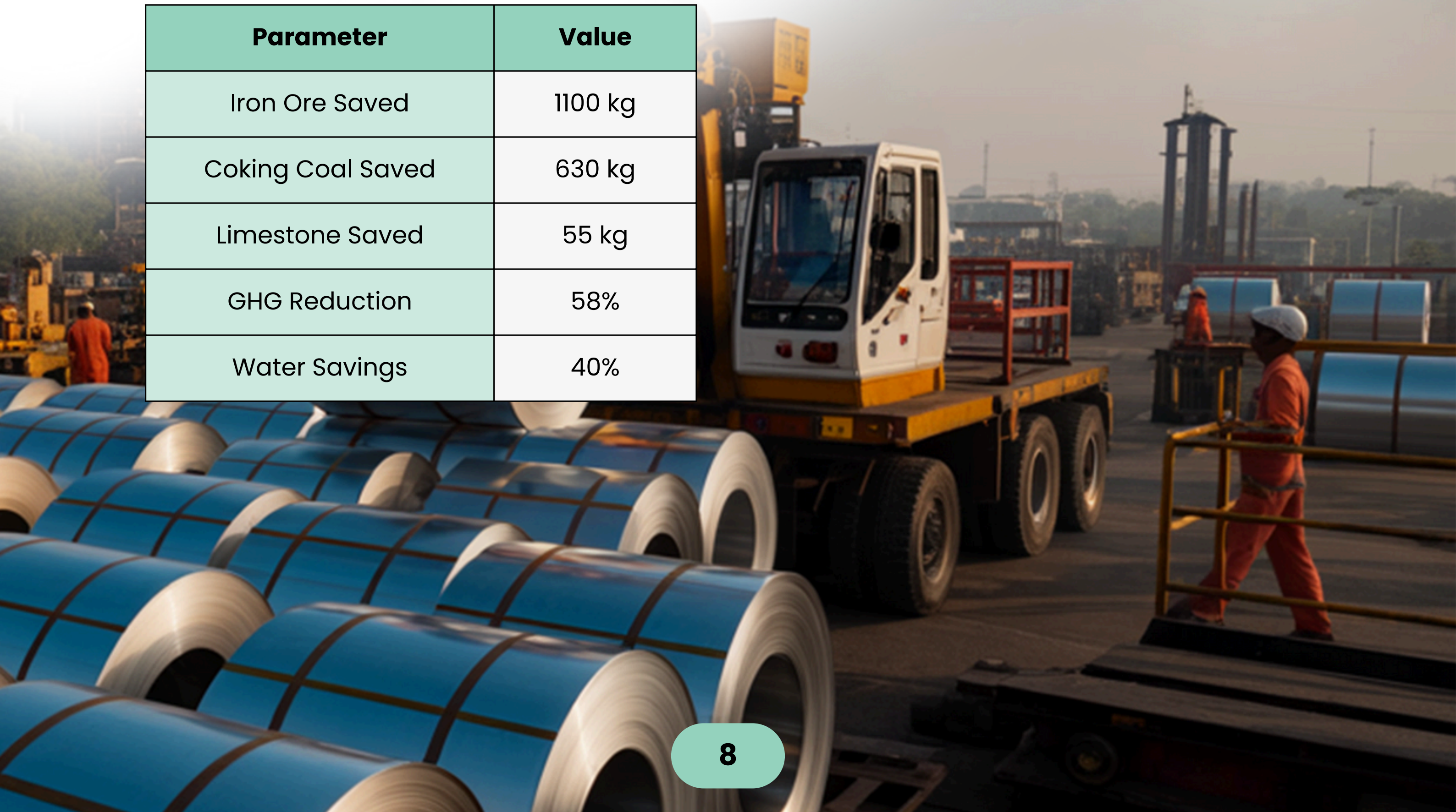
To address these barriers and scale scrap utilisation, the following measures are recommended:

- **Formalised Scrap Markets:** Establish hub-and-spoke models linking collection, dismantling, and processing centres under standardised quality protocols.
- **Digital and AI Integration:** Adopt blockchain-based registries and AI-enabled sorting systems to improve quality control, data accuracy, and operational efficiency.
- **Policy and Regulatory Support:** Strengthen Extended Producer Responsibility (EPR) frameworks to channel post-consumer steel, including ELVs, into formal supply chains.
- **Import:** Identify additional cost effective international sources of scrap and establish sourcing linkages.

By expanding scrap steel utilisation through these pathways and addressing supply chain challenges, India's steel sector can achieve substantial emission reductions, resource conservation, and economic resilience, supporting the country's climate and industrial objectives.

Table: One Tonne of Scrap Steel Saving different materials:

Parameter	Value
Iron Ore Saved	1100 kg
Coking Coal Saved	630 kg
Limestone Saved	55 kg
GHG Reduction	58%
Water Savings	40%



Summary Table: India Scrap Steel Generation and Consumption Trends

Year	Domestic Scrap Generation (Million Tonnes)	Scrap Used in Steelmaking (Million Tonnes)	Scrap Imports (Million Tonnes)	Source
2019	32	32	-	Metals Hub, Trade.gov
2023	35	29	11.76	BigMint, S&P Global
2024	-	-	9.49	Recycling Today
2025	32	-	8.4	Metal Expert
2030 (Projected)	42	65 (Demand)	~20-30 (Gap)	Metals Hub, BigMint

3.3 Energy Efficiency:

Energy efficiency is one of the most immediate and cost-effective levers for reducing CO_2 emissions in India's steel sector. By optimising existing processes and adopting advanced equipment, steel producers can achieve substantial energy savings with relatively short payback periods. This not only contributes to national decarbonisation targets but also improves operational competitiveness in a tightening global market.

Role in Decarbonization

India's steel production currently consumes approximately 6–6.5 Gcal per tonne of crude steel, which is significantly higher than the global best practice of 4.5–5 Gcal per tonne (Ministry of Steel; World Steel Association). Improving energy efficiency directly reduces fuel and electricity use, thereby cutting GHG emissions across the value chain and enabling easier future integration of renewable energy and other low-carbon technologies.

Present Usage and Data

Successful energy efficiency interventions have already been demonstrated in India. The Ministry of Steel, in collaboration with UNDP and AusAID, retrofitted energy systems in 321 mini-steel mills, achieving 20–30% savings in energy consumption and avoiding approximately 0.4 million tonnes of CO_2 annually (UNDP/Ministry of Steel Project Report, 2018). These results are replicable, especially for MSME steel producers that represent a large share of secondary production but often operate with outdated, inefficient technologies.

Key Energy Efficiency Pathways

- **Reheating Furnaces with Recuperators:** Recovering waste heat from furnace exhaust gases to preheat combustion air can yield 15–20% fuel savings by improving thermal efficiency.

- **Energy-Efficient Motors and Variable Frequency Drives (VFDs):** Adoption of VFDs and high-efficiency motors in pumps, fans, and compressors can reduce electricity consumption by 10–30%.

- **Covered Electric Arc Furnaces (EAF) and Induction Furnaces:** Using covered furnaces minimizes heat loss and enhances melting efficiency, enabling 10–15% energy savings in key melting operations.

- **LED Lighting and Smart Controls:** Upgrading to LED lighting and implementing smart energy management systems across plants can reduce energy consumption by an additional 5–10%.

Table for Key Energy Efficiency Pathways

Pathway / Technology	Typical Energy Savings*	Co-Benefits
Reheating Furnaces with Recuperators	15–20% fuel savings	Lower fuel costs, better thermal efficiency
Energy-Efficient Motors & Variable Frequency Drives	10–30% electricity savings	Improved equipment life, process control
Covered Electric Arc & Induction Furnaces	10–15% energy savings	Reduced heat loss, improved melt quality
LED Lighting & Smart Controls	5–10% electricity savings	Lower operating costs, improved workplace lighting

Data: Ministry of Steel, Bureau of Energy Efficiency (BEE)

Challenges :

- **Technological Barriers:** MSMEs and older plants often lack access to modern energy-efficient equipment and process control systems.
- **Financial Constraints:** High upfront costs and limited access to concessional or tailored financing deter timely adoption, especially among smaller producers operating on thin margins.
- **Capacity & Awareness Gaps:** Many steel plant operators lack technical knowledge of energy auditing, monitoring, and maintenance practices, limiting effective implementation.

Way Forward:

- **Policy Incentives & Inclusion:** Expand schemes like the Perform, Achieve & Trade (PAT) programme to cover MSMEs, with dedicated financial support and incentives for compliance.
- **ESCO & Project Preparation Facilities:** Facilitate partnerships with Energy Service Companies (ESCOs) to deliver shared-savings models that lower upfront costs and provide technical expertise.
- **Capacity Building & Technical Support:** Strengthen platforms such as the Steel Research & Technology Mission of India (SRTMI) to train operators and share best practices.
- **Leverage Carbon Credit Markets:** Projects can be monetised through domestic and voluntary carbon credit markets, enhancing return on investment and attracting blended finance opportunities.
- **Integrated Energy Management:** Combine energy efficiency upgrades with renewable integration, waste-heat recovery, and digital process control for maximum long-term impact.

Energy efficiency is a no-regret strategy for the steel sector, providing immediate carbon and cost savings while laying the foundation for future low-carbon transformations. Well-designed policies, targeted financing mechanisms, and industry-wide capacity building can scale these interventions quickly, ensuring India's steel industry remains competitive while contributing meaningfully to national climate goals.

3.4 Green Hydrogen

Green hydrogen is emerging as one of the most impactful decarbonisation pathways for India's steel sector, particularly for Direct Reduced Iron (DRI) production. Produced via electrolysis powered by renewable electricity, green hydrogen can replace fossil-based reducing agents such as natural gas or coal, achieving near-zero process emissions in the DRI–Electric Arc Furnace (EAF) route. Replacing fossil reductants with green hydrogen in DRI processes can reduce route-specific CO_2 emissions by up to 90% compared to the conventional coal-based Blast Furnace–Basic Oxygen Furnace (BF–BOF) route, provided renewable electricity is used for hydrogen production and EAF operation (Ministry of Steel, 2024; CEEW, 2025; TERI, 2021). This potential reduction directly supports India's net-zero by 2070 pathway and compliance with tightening trade measures such as the EU's Carbon Border Adjustment Mechanism (CBAM).

Current Status and Demonstrations in India

The ₹19,744 crore National Green Hydrogen Mission (NGHM, 2023) targets 5 million tonnes (Mt) of annual green hydrogen production capacity by 2030, with dedicated funding of ₹455 crore for steel-sector pilots.

- Tata Steel Jamshedpur conducted a 40% hydrogen injection in the blast furnace, achieving a 7–10% reduction in CO_2 emissions during the trial (Ministry of Steel/PIB, 2024).
- JSW Steel and ArcelorMittal Nippon Steel (AM/NS) India have announced feasibility studies for hydrogen-ready DRI plants integrated with renewable power procurement.
- The Steel Research & Technology Mission of India (SRTMI) is coordinating R&D on cost-effective electrolyser integration and hydrogen storage for industrial-scale steelmaking.

Key Challenges :

- **Cost Competitiveness –** The current levelised cost of green hydrogen in India is ₹250–300/kg, significantly higher than fossil-based hydrogen (₹120/kg) or coal reductants (MoP/MoS, 2024).
- **Infrastructure –** Need for large-scale electrolyser capacity, renewable power integration, storage, and transport pipelines.
- **Technology Readiness –** Hydrogen-based shaft furnaces are still in early deployment stages, requiring adaptation to Indian raw material profiles (e.g., high gangue iron ore).

Opportunities and Enablers :

- Expansion of India's renewable power base (105.65 GW solar, 47.7 GW wind as of 2025 – MNRE, 2025) lowers green hydrogen costs via competitive open access RE procurement.
- Government incentives under Production Linked Incentive (PLI) for speciality steel and concessional financing for green hydrogen projects through blended capital models.
- Collaboration between central PSUs (SAIL, NMDC) and private majors to develop shared hydrogen infrastructure, ensuring economies of scale.

Integrating green hydrogen into India's steelmaking not only delivers deep decarbonisation benefits but also yields significant strategic co-benefits. By reducing dependence on imported coking coal, it enhances raw material security and mitigates exposure to volatile global commodity markets. At the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same time, the production of low-emission steel positions Indian producers to compete more effectively in export markets increasingly shaped by the EU's Carbon Border Adjustment Mechanism (CBAM) and similar carbon border measures. Moreover, green hydrogen adoption reinforces India's alignment with the Sustainable Development Goals (SDGs), advancing clean energy deployment, fostering industrial innovation, and contributing directly to global climate action targets.

3.5 Carbon Capture, Utilisation, and Storage (CCUS)

Carbon Capture, Utilisation, and Storage (CCUS) is a pivotal technology for reducing process emissions in India's steel sector, especially in blast furnace (BF) steelmaking, which still depends heavily on coal. CCUS can potentially abate up to 56% of process emissions from BF-based steel production by capturing CO_2 before its release into the atmosphere and either utilising it for commercial applications or safely storing it underground. This technology is indispensable for achieving deep decarbonization goals while accommodating the steel industry's ongoing growth and transition.

Present Usage and Pilots in India

India has initiated pilot projects to validate CCUS technology and prepare for its broader deployment:

- Tata Steel Jamshedpur runs an experimental facility capturing approximately 5 tonnes of CO_2 daily, focusing on validating the technology and integrating it with existing steel operations.

- JSW Steel Dolvi operates a larger plant capturing around 100 tonnes of CO_2 per day, aiming to develop scalable models tailored for India's steel industry.

These pilot projects are critical testbeds, helping to build operational expertise, optimize costs, and establish technical and safety standards necessary for wider adoption.

Role in Decarbonization

CCUS directly targets the unavoidable carbon emissions from chemical processes in blast furnace operations, which are difficult to eliminate by other means. By capturing carbon at the source, it significantly reduces the carbon intensity of steel production without necessitating immediate overhaul of existing infrastructure. CCUS complements other pathways such as improving energy efficiency, integrating renewable energy, and deploying low-carbon steelmaking technologies like green hydrogen.

Challenges :

- **High Capital and Operational Costs**: CCUS involves expensive capture units, CO_2 transport infrastructure, and storage facilities. Without enabling policies or carbon pricing, its economic viability remains limited.

- **Safety and Regulatory Concerns:** Ensuring long-term secure CO_2 storage requires stringent monitoring, robust regulatory frameworks, and gaining public acceptance to address leak risks.

- **Lack of Standardization:** India currently lacks comprehensive technical and safety standards for CCUS deployments in heavy industry, hindering investor confidence and slowing deployment.

- **Infrastructure Needs:** The development of coordinated CO_2 transport pipelines and regional storage hubs, especially across industrial clusters, is still nascent.

Way Forward :

- **Domestic Manufacturing and Innovation:** Investing in India-based manufacturing capabilities for CCUS equipment will reduce costs and support technology localization.

- **Development of CCUS Hubs:** Establishing regional infrastructure where multiple steel plants share CO_2 transport and storage facilities can achieve economies of scale and reduce individual plant investment burdens.

- **Integration with Green Hydrogen and Utilisation Technologies:** Combining CCUS with green hydrogen production enables creation of value-added products such as methanol and synthetic fuels, fostering new revenue streams and advancing circular carbon strategies.

- **Policy Support and Market Incentives:** Clear carbon pricing mechanisms, subsidies, or mandates are essential to incentivize CCUS adoption, alongside the development of safety and operational standards.

- **Capacity Building and Partnerships:** Strengthening collaborative research among industry players, academia, and government agencies is vital to advance CCUS knowledge, tailor technology deployment to Indian conditions, and build operational capacity.

CCUS holds a transformative promise for decarbonizing traditional steelmaking processes in India. When integrated with other green technologies, it can position the steel sector on a credible, sustainable trajectory to meet both national and global climate commitments.

3.6 Carbon Credit Mechanisms

Carbon credit mechanisms are a vital market-based instrument to accelerate decarbonisation in India's steel sector by assigning economic value to verified reductions in greenhouse gas (GHG) emissions. Each credit represents one tonne of CO_2 equivalent avoided, reduced, or removed, and can be traded in domestic or international markets. By quantifying, certifying, and monetising these reductions, such mechanisms create new revenue streams that help offset the high capital and operational costs of clean technologies, including, energy efficiency upgrades, green hydrogen-based steelmaking, scrap steel utilisation, and carbon capture, utilisation, and storage (CCUS).

For a carbon-intensive industry like steel, carbon markets provide powerful financial incentives to scale low-carbon solutions. Participation not only supports alignment with India's Net Zero by 2070 commitment but also enhances the sector's integration into the emerging global low-carbon economy, improving competitiveness in both domestic and export markets.

Present Usage and Data

India's existing Perform, Achieve & Trade (PAT) scheme, implemented by the Bureau of Energy Efficiency (BEE), allows the steel sector to convert energy savings into tradable Energy Saving Certificates (ESCerts). Complementing this, the newly introduced Carbon Credit Trading Scheme (CCTS), 2023 aims to establish a unified domestic carbon market with both voluntary and compliance segments. This scheme broadens opportunities for industries—including steel—to monetize verified GHG reductions.

Leading steel producers such as Tata Steel, JSW Steel, and SAIL have embedded Measurement, Reporting, and Verification (MRV) processes into their environmental, social, and governance (ESG) strategies, positioning themselves to benefit from emerging carbon credit revenue streams. Globally, carbon credit prices range widely—from under USD 5 per tonne in voluntary markets up to over USD 80 in the European Union Emissions Trading System (EU ETS)—underscoring the significant financial upside achievable by exporters who meet premium certification standards.

Pathways for Integration

- Energy Efficiency Upgrades: Certify and monetize documented energy savings under PAT and voluntary carbon programs.
- Green Hydrogen in Direct Reduced Iron (DRI): Generate high-value credits through the deep decarbonisation of steelmaking processes.
- CCUS Deployment: Obtain credits via verified capture and storage of CO_2 emissions in industrial processes.
- Circular Economy Measures: Secure credits for emissions avoided through scrap steel utilisation and biomass substitution for coal.

Challenges :

- **Regulatory Uncertainty:** With CCTS still under development, alignment with international standards like VERRA and Gold Standard is evolving.
- **Price Volatility:** Carbon credit prices fluctuate significantly between voluntary and compliance markets, adding financial unpredictability.
- **High MRV Costs:** Robust monitoring, reporting, and verification implementation can be expensive, particularly for MSMEs with limited resources.
- **Limited MSME Access:** Smaller producers often lack the technical expertise and upfront capital necessary to register and manage credit-generating projects effectively.

Way Forward :

- **Strengthen MRV Systems:** Develop standardized, CCUS-specific measurement, reporting, and verification protocols to ensure transparency, reduce verification costs, and support credit issuance.
- **Link Domestic and International Markets:** Align the Carbon Credit Trading Scheme (CCTS) with global standards (e.g., EU ETS, CORSIA) to enable sale of CCUS-generated credits in higher-value markets.
- **Dedicated MSME Support:** Facilitate participation of smaller producers in CCUS projects by mobilizing public climate finance or channeling a portion of carbon credit revenues through aggregator or cluster-based programmes.
- **Pre-Certification and Fast-Track Approvals:** Introduce validated methodologies and default emissions factors for proven CCUS applications, expediting registration and deployment.
- **Revenue Recycling for Sectoral Transformation:** Direct a share of CCUS-generated carbon credit revenues toward funding further decarbonisation projects, infrastructure, and workforce transition programmes.
- **Leverage Carbon Credit Potential:** Captured CO_2 can generate high-value credits under domestic and international mechanisms, significantly improving the financial viability and investment attractiveness of CCUS projects.

When effectively integrated, carbon credit mechanisms can transform decarbonisation from primarily a cost center into a revenue-generating strategy for India's steel sector. Combined synergistically with technical pathways such as CCUS, green hydrogen adoption, renewable energy integration, and energy efficiency improvements, they can accelerate emissions reductions while bolstering competitive advantages in both domestic and export markets. While the carbon credit markets create positive financial incentives for emissions reduction, trade-linked regulations such as the EU's CBAM introduce compliance costs that require equally strategic preparation — the focus of the following section.

3.7 Navigating CBAM

The European Union's Carbon Border Adjustment Mechanism (CBAM), set to be implemented from 2026, introduces a carbon cost parity between EU producers and foreign exporters by imposing charges based on the carbon embedded in imported goods. This mechanism aims to prevent carbon leakage and encourage low-carbon production globally. For India's steel sector, CBAM represents both a significant challenge and a catalyst to accelerate decarbonization efforts.

Role in Decarbonization and Trade Impact

India's steel exports to the EU, valued at approximately USD 3.7 billion annually, face substantial risk under CBAM. The current carbon intensity of Indian steel exports is estimated at around USD 4.36 per tonne of CO_2 released, translating to an additional CBAM cost of €173.8 per tonne (₹15,394). This additional cost accounts for about 16.06% of the unit export value, posing a potential revenue loss of up to USD 2 billion if carbon reduction measures are not swiftly adopted. This external regulatory pressure aligns with domestic climate objectives, creating an imperative for the Indian steel industry to reduce its carbon footprint to maintain market access and competitiveness in the EU market.

Present Industry Responses

Leading Indian steel producers are proactively addressing the challenges posed by CBAM through diversified and forward-looking strategies:

- Tata Steel is advocating for trade safeguard mechanisms while piloting green steel production technologies. The company has undertaken extensive hydrogen injection trials in blast furnaces and is scaling renewable energy integration to comply with strict carbon standards.

- JSW Steel has publicly committed to green steel production by 2030, investing in renewable energy projects and green hydrogen technologies aimed at substantially reducing carbon intensity.

- Kalyani Steels is launching premium green steel brands that emphasize transparency and adherence to stringent low-emission standards, targeting premium markets as a competitive advantage.

These initiatives collectively demonstrate the steel sector's readiness to align with CBAM requirements and position Indian steel as a trusted low-carbon supplier in global markets.

Challenges :

- **High Carbon Intensity:** The dominant use of coal-based blast furnace technology poses intrinsic challenges for rapid emissions reduction.
- **Cost Burden:** The imposition of CBAM-related charges adds to export pricing, potentially eroding competitiveness against lower-carbon rivals.
- **Regulatory Complexity:** Navigating evolving international carbon standards and ensuring coherence with domestic policy frameworks create compliance challenges, especially for exporters and MSMEs.

Way Forward :

- **Accelerate Decarbonization:** Rapidly scale up renewable energy adoption, energy efficiency improvements, steel scrap usage, green hydrogen usage, and carbon capture technologies to reduce carbon intensity below CBAM thresholds.
- **Policy Advocacy:** Engage actively with government and international trade bodies to negotiate safeguard provisions and align domestic policies with global carbon standards.
- **Market Differentiation:** Develop and promote certified green steel brands to tap growing low-carbon market segments within and beyond the EU.
- **Capacity Building:** Provide targeted support to MSMEs and secondary producers to upgrade technologies and compliance capabilities, ensuring the entire sector is prepared for CBAM.
- **Collaboration Platforms:** Leverage initiatives such as the Steel Research & Technology Mission of India (SRTMI) to foster innovation, disseminate knowledge, and build compliance readiness around CBAM.

By effectively navigating the CBAM landscape through technological advancement, policy engagement, and strategic market positioning, India's steel sector can protect export revenues, enhance its global competitiveness, and reinforce its commitment to sustainable industrial growth in line with national and international climate goals.

4. Emission Reduction Potential Across Pathways

India's steel sector presents multiple decarbonization pathways, each with varying potential to reduce CO_2 emissions critical for achieving national climate targets while maintaining global competitiveness. The Ministry of Steel's 2024 roadmap highlights targeted interventions aligned with India's steel production profile, especially addressing the reliance on coal-based blast furnace (BF) technology predominant in the country.

Key Emission Reduction Pathways and Impacts

- **Energy Efficiency Improvements:** Utilizing technologies such as reheating furnace recuperators, energy-efficient motors, variable frequency drives, covered electric arc furnaces (EAF), and LED lighting can significantly reduce energy consumption. These measures enable immediate CO_2 reductions in the range of 15–30%, serving as the foundation for lowering the carbon intensity of existing steelmaking processes.

- **Renewable Energy Integration:** Switching grid electricity supply to renewable sources like solar and wind for processes such as EAF and green hydrogen steelmaking can cut Scope 2 emissions by 25–35%. This not only reduces emissions but also promotes cost stabilization amid a carbon-constrained global market landscape.

- **Scrap Steel Utilization:** Increasing the use of scrap steel dramatically lowers emissions by up to 58% per tonne of steel and yields additional benefits including 40% water savings and conservation of essential raw materials such as iron ore, coking coal, and limestone. Such recycling facilitates near-term emission reductions and material circularity within the steel industry.

- **Green Hydrogen Adoption:** Replacing fossil fuels with green hydrogen in direct reduced iron (DRI) production pathways offers deep decarbonization potential—up to 90% reduction in emissions from DRI routes. This pathway is vital for transitioning away from carbon-intensive BF methods and achieving near-zero emission steelmaking.

- **Carbon Capture, Utilisation, and Storage (CCUS):** CCUS technology can abate up to 56% of process emissions from blast furnace operations. While still capital-intensive and under pilot phases (e.g., Tata Steel and JSW Steel projects), CCUS represents a scalable mitigation solution for unavoidable process emissions.

- **Circular Economy and Material Innovation:** Innovations like biomass-derived biochar and enhanced material efficiency further supplement emission reductions, advancing systemic sustainability within steel production.

Quantitative Reduction Potential (Indicative)

Intervention	CO_2 Emission Reduction Potential
Energy Efficiency	Up to 15–30% reduction
Renewable Energy Integration	25–35% reduction in Scope 2 emissions
Scrap Steel Utilization	Up to 58% GHG reduction per tonne
Green Hydrogen in DRI	Up to 90% reduction in DRI routes
CCUS	Up to 56% process emission reduction

These interventions are synergistic rather than isolated; for example, renewable energy enables viable green hydrogen production, while energy efficiency lowers overall energy demand, improving the cost-effectiveness of all decarbonization efforts. Similarly, increased scrap utilization reduces demand for primary ironmaking, cutting reliance on carbon-intensive coke and coal inputs.

By integrating these pathways, India's steel sector can comprehensively reduce its carbon footprint while aligning with national climate commitments and strengthening its position in the global green steel market.

5. Government Policy Landscape

India's steel sector decarbonization is guided by a comprehensive policy ecosystem that blends regulatory mandates, financial incentives, and strategic missions. Together, these initiatives aim to accelerate emissions reduction, scale green technologies, and safeguard the sector's competitiveness in an evolving global market. The framework addresses the full range of decarbonization pathways—energy efficiency, renewable integration, scrap utilization, hydrogen adoption, and CCUS—while strengthening circular economy linkages.

Key Policy Measures

- **Greening the Steel Sector Task Force (2019–20):** Constituted with 14 task forces comprising industry, academia, and government ministries, this initiative delivered the "Greening the Steel Sector in India – Roadmap & Action Plan". It outlined phased decarbonization strategies, prioritizing interventions such as renewable integration, efficiency upgrades, scrap recycling, hydrogen adoption, and CCUS deployment.

- **Steel Scrap Recycling Policy (2019):** Establishes standards for scrap-processing facilities and End-of-Life Vehicle (ELV) dismantling centers. Aims to formalize the scrap value chain, boost domestic scrap availability, reduce import dependency, and enhance circularity in steelmaking.

- **National Solar Mission (2010):** Under the National Action Plan on Climate Change (NAPCC), this mission promotes solar PV deployment, including rooftop and captive systems for industries. Dedicated incentives, targets, and policy mechanisms encourage the steel sector to integrate solar energy and reduce Scope 2 emissions.

- **Perform, Achieve & Trade (PAT) Scheme:** Part of the National Mission on Enhanced Energy Efficiency (NMEEE), PAT sets industry-specific energy efficiency targets with tradable Energy Saving Certificates (ESCerts). In Cycles I–III, 167 steel plants saved 5.58 million tonnes of oil equivalent (MTOE) and avoided 20.52 Mt CO_2 emissions by 2020.

- **Motor Vehicle Scrapping Rules (2021):** Mandates scientific dismantling and scrapping of ELVs to improve road safety, reduce environmental hazards, and generate ferrous scrap for secondary steelmaking, thereby supporting resource security and emission cuts.

- **National Green Hydrogen Mission (2023):** Allocates ₹19,744 crore to produce 5 million tonnes of green hydrogen annually by 2030, with ₹455 crore specifically for steel sector pilot projects. Promotes hydrogen-based reduction processes to replace coal in DRI and BF operations.

- **Carbon Credit Trading Scheme (CCTS, 2023):** Establishes a national market for carbon credits, enabling steel producers to earn and trade credits from verified emission reductions. Complements mechanisms like the EU's CBAM by internalizing carbon costs domestically.

- **Production Linked Incentive (PLI) Scheme for Specialty Steel:** Targets ₹27,106 crore investments to boost domestic manufacturing of high-grade and specialty steels, including low-carbon grades, to meet rising global sustainability standards.

Decarbonization Roadmap

- **Short-Term (to 2030):** Emphasizes energy efficiency improvements, renewable energy integration in steel operations, and increased scrap steel utilization. These interventions offer immediate emission reductions and cost optimization.

- **Medium-Term (2030–2047):** Focuses on scaling green hydrogen adoption and deploying Carbon Capture, Utilization, and Storage (CCUS) technologies to enable deeper decarbonization of primary steel production routes.
- **Long-Term (2047–2070):** Looks toward disruptive, near-zero emission technologies such as electro-steel processes and fully electric steelmaking routes, promising revolutionary industrial transformation.

This progressive policy landscape underpins India's commitment to a holistic steel sector decarbonization. It balances technological maturity with economic viability and social inclusiveness. By fostering innovation, market creation, and leadership in sustainability, these policies position the steel industry to meet national climate targets while retaining global competitive advantage.

6. Analytical Synthesis

Decarbonising India's steel sector is a multi-dimensional challenge, shaped by financial, technological, infrastructural, and regulatory constraints. Heavy reliance on coal-based blast furnace (BF) routes creates high baseline emissions, while the sector faces mounting pressure from both domestic climate commitments and international trade measures, notably the EU's Carbon Border Adjustment Mechanism (CBAM). Addressing these pressures requires a two-track strategy — deep structural transformation in the long term, and targeted transitional measures in the short to medium term to safeguard competitiveness.

While the risks are clear — high capital requirements for clean technologies, limited MSME readiness, fragmented state-level regulations, and inconsistent renewable energy access — the opportunities are equally compelling. India's strong industrial base, rapidly growing renewable capacity, and expanding domestic market offer a platform to leapfrog incremental changes and adopt next-generation low-carbon solutions at scale.

Analysis of current policy, industry trends, and market dynamics points to three critical enablers for accelerating this transition:

- **Green Financing and Blended Capital:** Expand access to concessional finance, climate funds, and blended capital models that combine public incentives with private investment to de-risk large-scale green technology adoption. Instruments such as green bonds, sustainability-linked loans, and revenues from domestic and international carbon credit markets.

- **Stronger Academia–Industry Partnerships:** Deepen collaborative R&D between steel producers, universities, and research bodies to accelerate innovation. Platforms like the Steel Research & Technology Mission of India (SRTMI) should be strengthened to deliver solutions tailored to Indian conditions — from cost-effective hydrogen-based DRI units to AI-enabled scrap sorting technologies.

- **Policy Harmonisation Across States and the Centre:** Align renewable energy frameworks, open access rules, and fiscal incentives to reduce transaction costs and create predictable investment conditions. Consistency in policy implementation will enable faster scaling for both large integrated players and MSMEs.

The sector's long-term competitiveness will depend on integrated thinking — linking finance with technology innovation, harmonising policies across governance levels, and ensuring that decarbonisation strategies generate both economic returns and environmental gains. This holistic approach can position Indian steel as a global leader in sustainable production while supporting national net-zero targets.

7. Conclusion

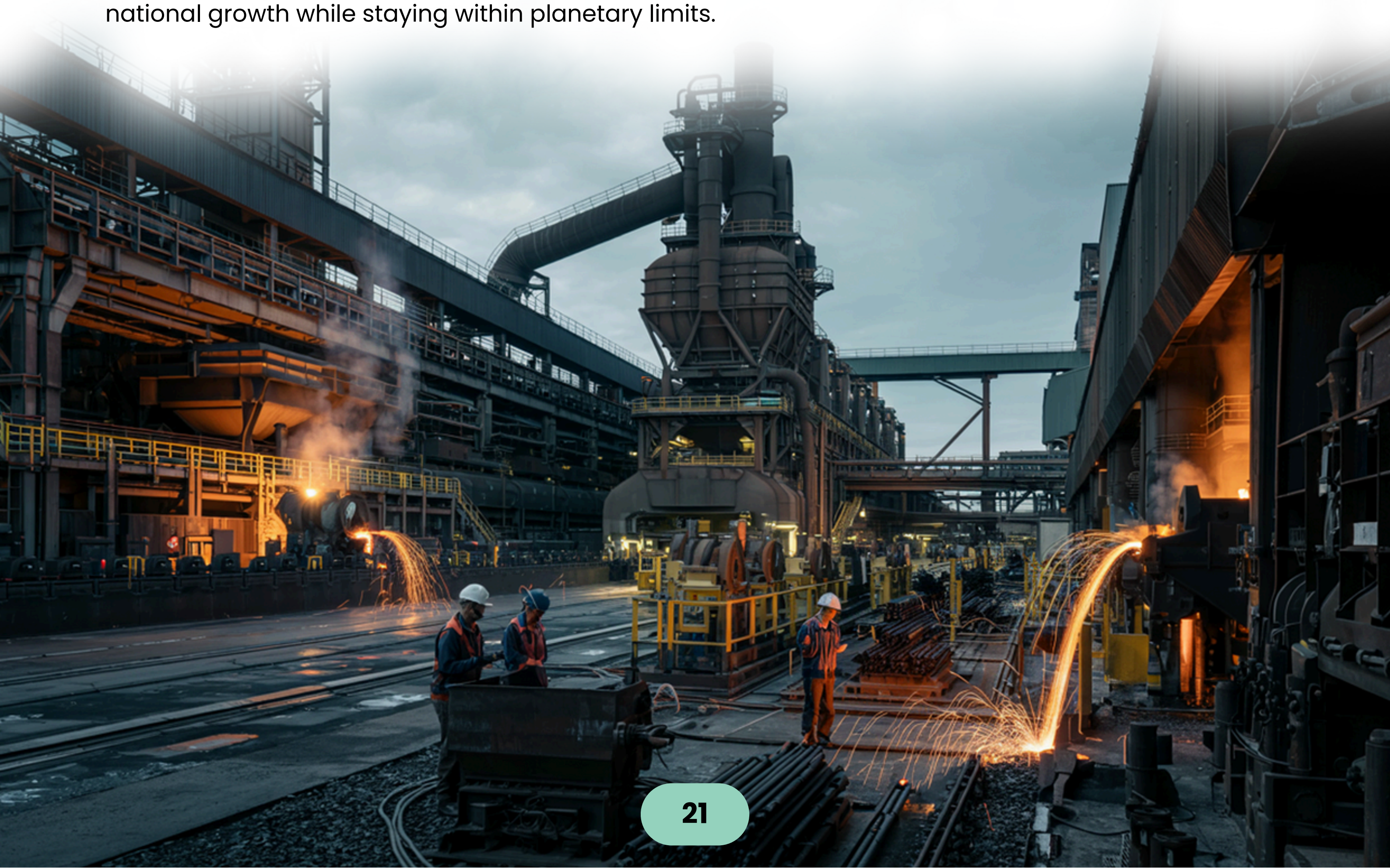
The transition of India's steel sector from a carbon-intensive industry to a low-carbon, competitive, and innovation-driven ecosystem is both a climate imperative and a strategic economic opportunity. Facing overlapping pressures from domestic net-zero commitments, rising energy costs, and trade-linked carbon regulations such as the EU's CBAM, the sector must adopt a multidimensional response — combining near-term efficiency measures with long-term shifts to breakthrough technologies.

This report demonstrates that the main decarbonisation levers — renewable energy integration, expanded scrap steel utilisation, targeted energy efficiency upgrades, green hydrogen adoption, CCUS deployment, and CBAM preparedness — are mutually reinforcing. When applied in synergy, they can significantly reduce emissions intensity, lower production costs over time, and enhance India's position in both domestic and global steel markets.

Realising this vision will depend on:

- Decisive industry action to invest in clean technologies, scale innovation, and differentiate products in low-carbon markets.
- Policy stability and harmonisation across states and the Centre to provide predictable conditions for long-term investment.
- Collaborative platforms that connect government, industry, academia, and civil society, ensuring that breakthrough technologies benefit all, including MSMEs.
- Just transition measures to safeguard the livelihoods of workers and communities dependent on traditional steelmaking.

If executed with foresight, this transformation can protect export competitiveness, unlock billions in green investment, and deliver tangible environmental and economic gains. Most importantly, it can establish India as a global reference for "industrialisation without carbonisation" — advancing national growth while staying within planetary limits.



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