Greening the Steel Sector in India

Roadmap and Action Plan

सत्यमेव जयते

इस्पात मंत्रालय
MINISTRY OF
STEEL

इस्पात मंत्रालय
MINISTRY OF
STEEL

सत्यमेव जयते

Greening the Steel Sector in India

Roadmap and Action Plan

CEEW
THE COUNCIL

THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

SHAKTI
SUSTAINABLE ENERGY
FOUNDATION

September 2024

Greening the Steel Sector in India Roadmap and Action Plan

Authors:

Ms. Neha Verma, Director, Ministry of Steel, (GOI), Deepak Yadav (CEEW), Karthik Shetty (CEEW), Rudhi Pradhan (CEEW), Karan Kothadiya (CEEW), Rishabh Patidar (CEEW), Hemant Mallya (CEEW), Sobhanbabu PRK (TERI), Dr. N K Ram (TERI), Dr. Souvik Bhattacharjya (TERI), Dr Manish Kumar Shrivastava (TERI), Arupendra Nath Mullick (TERI), Mayank Aggarwal (TERI), Mandavi Singh (TERI)

Citation:

Ministry of Steel, Government of India. (2024) *Greening the steel sector in India: Roadmap and action plan*. Neha Verma, Deepak Yadav, Karthik Shetty, Rudhi Pradhan, Karan Kothadiya, Rishabh Patidar, Hemant Mallya, Sobhanbabu PRK, Dr. N K Ram, Souvik Bhattacharjya, Manish Kumar Shrivastava, Arupendra Nath Mullick, Mayank Aggarwal, Mandavi Singh (Authors).

एच. डी. कुमारस्वामी
H. D. Kumaraswamy

सत्यमेव जयते

मंत्री
भारी उद्योग एवं इस्पात मंत्रालय
भारत सरकार, नई दिल्ली
Minister of
Heavy Industries and Steel
Government of India, New Delhi

Message

India's steel sector stands as a cornerstone of our nation's economic growth and industrial development. As the world's second-largest producer of crude steel, this industry not only contributes significantly to our GDP but also provides livelihoods for millions across the country. However, as we stride forward, we must address the pressing need to align this vital sector with our global climate commitments.

This report, "Greening the Steel Sector in India: Roadmap and Action Plan," presents a comprehensive strategy for transforming the steel industry into a more sustainable and low-carbon sector. It offers actionable insights to help us achieve our climate objectives while ensuring that the steel industry continues to be a pillar of our nation's progress.

The path ahead requires collaboration, innovation, and a sustained commitment across the sector. The Ministry is dedicated to facilitating the adoption of advanced technologies, promoting the use of clean energy, and ensuring that the steel industry continues to thrive while meeting future demands in an environmentally responsible manner, as is outlined in the report.

I deeply appreciate the work of all the officers, experts and knowledge partners who have played a pivotal role in the creation of this report. Your hard work and dedication have laid the groundwork for a sustainable future for India's steel industry. The insights and recommendations offered in this report will be invaluable for policymakers, industry leaders, and all stakeholders involved in this crucial transition.

(H. D. Kumaraswamy)

Ministry of Steel : Room No. 192, 'G' Wing, 1st Floor, Udyog Bhawan, New Delhi-110011, Tel. : +91-11-23062345, Fax : +91-11-23061395
Ministry of Heavy Industries : Room No. 176, 'E' Wing, 1st Floor, Udyog Bhawan, New Delhi-110 011, Phone : 91-11-23061782, Fax : 91-11-23062552

भूपतिराजु श्रीनिवास वर्मा
భూపతిరాజు శ్రీనివాస వర్మ
BHUPATHIRAJU SRINIVASA VARMA

सत्यमेव जयते

इस्पात एवं
भारी उद्योग राज्य मंत्री
भारत सरकार
उद्योग भवन, नई दिल्ली–110011
MINISTER OF STATE FOR STEEL
AND HEAVY INDUSTRIES
GOVERNMENT OF INDIA
UDYOG BHAWAN, NEW DELHI-110011

MESSAGE

India's steel industry is a backbone of our nation's industrial strength, playing a pivotal role in our economic development and global trade. As the third-largest consumer of steel globally, India's demand continues to rise, driven by sectors such as construction, infrastructure, and manufacturing. However, as we forge ahead on the path of growth, we must ensure that this progress is sustainable and aligned with global environmental imperative to achieve 2070 net zero goal.

The Indian steel industry has taken several critical steps to decarbonise its production processes. These efforts are vital as we strive to future-proof our steel industry against the challenges posed by climate change. From adopting energy-efficient technologies and using renewable energy to enhancing raw material beneficiation, using green hydrogen and developing carbon capture and utilisation methods, the industry is making significant strides towards a greener future while at the same time striving to be competitive with peers across the globe.

The report, "Greening the Steel Sector in India: Roadmap and Action Plan," provides a detailed blueprint for this transition and highlights our collective journey towards a more sustainable and resilient steel industry. This document is a testament to our unwavering commitment to ensuring that India's steel sector remains robust, and adaptable in the face of global challenges.

The road ahead is challenging, but it is also filled with opportunities. By embracing innovation and fostering collaboration across the industry, we can turn the steel sector's decarbonization into a driving force for economic growth and global competitiveness.

I would like to acknowledge the dedication and expertise of all those who contributed to this report. Your efforts are instrumental in guiding India's steel industry towards a future that balances economic aspirations with environmental responsibility.

(Bhupathiraju Srinivasa Varma)

Ministry of Steel : 146, Udyog Bhawan, New Delhi-110011 • Tel. : +91-11-23063810, Fax : +91-11-23062703, Email : mos-steel@gov.in
Ministry of Heavy Industries : 36, Udyog Bhawan, New Delhi-110011 • Tel. : +91-11-23062676/78, +91-11-23061593, Fax : +91-11-23060584

संदीप पौण्डरीक, भा.प्र.से.
सचिव
Sandeep Poundrik, IAS
Secretary

सत्यमेव जयते

भारत सरकार
इस्पात मंत्रालय
GOVERNMENT OF INDIA
MINISTRY OF STEEL

02nd September, 2024

MESSAGE

Steel plays a pivotal role in shaping our modern economy, serving as the backbone of industrial development and infrastructure. However, this vital industry is also a significant contributor to global emissions. Recognizing this duality, we have embarked on a crucial journey towards sustainability.

With great pride, I present this report, **"Greening the Steel Sector in India: Roadmap and Action Plan"**, a milestone in our collective endeavour to guide the steel industry towards a more sustainable future. This comprehensive report offers an in-depth analysis of the current state of the steel industry and outlines a pathway for its decarbonization in alignment with 2070 net zero goals. It delves into critical areas such as technology, policy, and finance, providing a detailed examination of the opportunities and challenges ahead. Its significance lies in its potential to serve as a guide for industry leaders, policymakers, and investors as they navigate the complexities of transitioning to a low-carbon economy.

This report builds upon the work of 14 task forces on decarbonization which covered crucial areas such as energy efficiency, renewable energy, green hydrogen, biochar and carbon capture on technology side while delving with policy levers of green steel taxonomy, CO2 monitoring, and green steel demand generation.

I would express my deepest thanks for the Chairpersons, members and knowledge partners of the Task Forces, and nodal officers from the Ministry of Steel, who engaged in brainstorming sessions to come up with their recommendations. The hard work of all has ensured that this report is both comprehensive and actionable. The next steps involve translating the recommendations into tangible actions, which the Ministry of Steel is committed to.

This document embodies Ministry of Steel's steadfast commitment in harmonizing industrial growth with environmental responsibility and economic resilience. We eagerly anticipate collaborating with all stakeholders to ensure that the steel industry not only meets but exceeds its sustainability goals, paving the way for a greener and more prosperous future.

(Sandeep Poundrik)

Room No. 291, Gate No. 5, Udyog Bhawan, New Delhi-110011
Tel. : +91-11-23063912, 23063489 (Fax); E-mail : secy-steel@nic.in

विनोद कु. त्रिपाठी
संयुक्त सचिव
VINOD K. TRIPATHI
Joint Secretary

सत्यमेव जयते

इस्पात मंत्रालय
भारत सरकार
MINISTRY OF STEEL
GOVERNMENT OF INDIA

PREFACE

Steel is classified as a "hard-to-abate" sector due to its significant energy requirements and high carbon emissions. The production of steel involves intensive processes, such as blast furnaces and electric arc furnaces, which contribute substantially to greenhouse gas emissions. This makes the sector particularly challenging to decarbonize, as it requires major technological and process innovations.

Despite these challenges, steel remains an anchor of India's economic growth and development. It underpins the nation's progress and supports various industries essential for economic prosperity. The sector's role in building and sustaining infrastructure is indispensable for advancing India's development goals and enhancing its global competitiveness.

Balancing the need for continued growth in the steel sector with our climate commitments is both a challenge and an imperative. As we strive to meet our national and global climate goals, it is essential to address the sector's environmental impact while ensuring that our economic objectives are not compromised. This report, "Greening the Steel Sector in India: Roadmap and Action Plan," was developed to provide a strategic framework for achieving this balance.

Initiated in March 2023, this document is a culmination of long and arduous journey of discussions, deliberations and brainstorming sessions of the 14 Task Forces. Each taskforce was led by a distinguished chairperson with expertise in the relevant field and engaged a diverse range of stakeholders from government entities, industry, academia, research institutes, and civil society. Over this period, about 130 consultations were held, involving more than 200 stakeholders.

The report explores three key policy demand-side levers viz developing taxonomy of green steel, monitoring CO2 emissions and generating market-based incentives. It also examines seven supply side levers such as energy efficiency, renewable energy, material efficiency, process transition, green hydrogen, biochar and CCUS. Additionally, the report addresses four crucial enablers for transition- finance, international focus, skill development and R&D. Through these focus areas, this report offers a comprehensive analysis of the steel industry's current state and outlines actionable strategies for its transformation.

This report is particularly relevant in the context of the current challenges faced by the steel sector, including rising energy costs, stringent environmental regulations, and the need for technological innovation. By addressing these challenges head-on, the report offers actionable insights that can help ensure the steel industry remains competitive both domestically and globally.

2/9/24

(Vinod K. Tripathi)

कमरा नं. 198, उद्योग भवन, नई दिल्ली-110 001, दूरभाष : Tel. : 23063138, 23063297, ई-मेल : vinod.tripathi@gov.in
Room No. 198, Udyog Bhawan, New Delhi-110 001, Tel. : 23063138, 23063297, E-mail : vinod.tripathi@gov.in

ACKNOWLEDGMENT

The Ministry of Steel (MoS) extends its deepest appreciation to Shri H. D. Kumaraswamy, Minister of Steel; Shri Bhupathiraju Srinivasa Varma, Minister of State for Steel; Shri Sandeep Poundrik, Secretary, MoS; Shri Vinod K. Tripathi, Joint Secretary, Smt. Swapna Bhattacharya, DDG and Shri Ashwini Kumar, Economic Advisor, MoS, for their exceptional leadership in the development of this report. The Ministry also acknowledges the invaluable contributions of the nodal officers, including Smt. Neha Verma, Director, MoS; Shri Paramjeet Singh, Additional Industrial Adviser; Shri Devidatta Satapathy, Director; and Shri Subhash Kumar, Deputy Secretary, whose dedicated efforts were instrumental in bringing this report to fruition. Further appreciation is extended to Abhimanyu Kaushik, ASO, Young Professionals, Shri Harsh Jape and Shri Chandrabhal Chakraborty, and Consultant, Ms. Rashi, for their significant contributions.

The Ministry of Steel expresses its profound gratitude to former Ministers and officers of the Ministry, including Shri Jyotiraditya Scindia, former Minister of Steel; Shri Faggan Singh Kulaste, former Minister of State for Steel; Shri Nagendra Nath Sinha, former Secretary, MoS; and Ms. Ruchika Chaudhry Govil, former Additional Secretary, for their visionary leadership, which laid the foundation for this report.

The Ministry is particularly grateful to the Chairpersons of all the 14 task forces for their invaluable insights, unparalleled expertise and contributions that have profoundly shaped this report. These include Shri Saraswati Prasad (Former Special Secretary, MoS); Shri R. P. Gupta (Former Secretary, MoEFCC); Smt. Aruna Sharma (Former Secretary, MoS); Shri Ashok K. Tripathi (Independent Director, SAIL); Shri Aniruddha Kumar (Former Additional Secretary, MNRE); Dr. Anup K. Pujari (Former Secretary, Ministry of Mines); Shri Indu Shekhar Chaturvedi (Former Secretary, MNRE); Dr. V. K. Saraswat (Member, NITI Aayog); Dr. Indranil Chattoraj (Former Director, NML, CSIR-NML); Dr. Parvinder Maini (Scientific Secretary to the Principal Scientific Advisor to the PM); Shri Sunil Mehta (Chief Executive, IBA); Shri Ajay Bisaria (Former Indian High Commissioner to Pakistan); Smt. Sunita Sanghi (Former Principal Advisor, MSDE); and Shri Sanak Mishra (Former President of the Indian National Academy of Engineering). Further, sincere thanks are due to all the members of these task forces for their time, effort and expertise.

The Ministry acknowledges the contribution of Council on Energy, Environment and Water (CEEW) as a key knowledge partner for development of the overall report and providing crucial support to the formation of task forces. Apart from the authors, contributions from Sanyogita Satpute, Kartheek Nitturu, Pratheek Sripathy and Kumaresh Ramesh are also highly appreciated. CEEW specifically developed the chapters on Introduction, Taxonomy, Demand Generation, Renewable Energy, Green Hydrogen, CCUS, Process Transition for DRI, RD&D, Governance Framework, Action Plan, and Roadmap. Additionally, the Ministry recognizes The Energy and Resources Institute (TERI) for its valuable contributions as a knowledge partner to the task forces and for the development of the seven chapters on Monitoring Carbon Emissions, Energy Efficiency, Material Efficiency, Biochar, Finance, International Focus, and Skill Development. Additionally, the Ministry appreciates the continuous support from the Shakti Sustainable Energy Foundation (SSEF) in advancing green transitions within the steel sector. We also thank FICCI and CII for facilitating the work of the Task Forces.

Finally, the Ministry extends its sincere thanks to all others who contributed to the development of this report.

Table of CONTENTS

EXECUTIVE SUMMARY

India is currently one of the fastest-growing economies in the world. However, several challenges confront India's development agenda, including climate change. It is seen that India's historical contribution to the accumulation of GHGs is about 4%, even though it is home to 17% of the global population. Nevertheless, India is committed to combating climate change by making development choices that can ensure economic growth along the low-carbon pathways. Further, India has revised its nationally determined contributions (NDCs) and has achieved considerable progress in deploying renewable energy (RE) capacity and greening the grid. However, achieving the aggressive climate goals such as 2070 net zero targets will also require India to decarbonise its industrial sector, including steel.

India is the second largest crude steel producer in the world, with a capacity to produce 179.5 million tonnes of crude steel and the largest production capacity of sponge iron in the world at 55 million tonnes in FY 2023 -24. However, the per capita steel consumption in India is only 97.7 kg in FY 2024 compared with the global average per capita consumption of 221.8 kg in 2022. The National Steel Policy 2017 aims to increase the per capita consumption to 160 kg by 2030. Therefore, given India's lower per capita steel consumption, it is expected that India's steel sector will continue to grow rapidly even beyond 2030.

The structure of the steel sector in India is significantly different from other countries. Developed countries have a higher share of scrap in total steel production, pellet uptake is high, the grid is less carbon-intensive, and low-carbon fuels like natural gas are available at affordable prices. Conversely, India has a limited scrap availability and natural gas is significantly expensive. Additionally, India has low-grade coal and iron ore, whose usage increases overall energy consumption and emissions. In addition, integrated steel plants (ISPs) rely on captive coal-based thermal power plants that have significantly higher emissions intensity of power than cleaner grids in developed countries. In summary, the Indian steel industry is constrained to use coal-based blast furnaces and rotary kilns for steelmaking due to a lack of affordable alternatives. Consequently, the emission intensity of steel produced in India, at 2.54 T CO_2/T Crude Steel (tCO_2/TCS), is significantly higher than the global average of 1.91.

The steel industry accounts for 10-12% of India's total emissions. Therefore, the sector's decarbonisation is imperative for India to meet its climate goals. In response to India's climate commitments and in a bid to create a globally competitive and sustainable steel industry, the Ministry of Steel constituted 14 task forces that cover the pertinent aspects of decarbonisation of the steel industry. The initiative, summarised in Figure ES1, focuses on three key pillars: the incentivisation and ecosystem development for green steel, levers to enable decarbonisation, and avenues to support the transition. This report is an outcome of the key findings from the 14 task forces and contains a harmonised action plan for steel decarbonisation in the country.

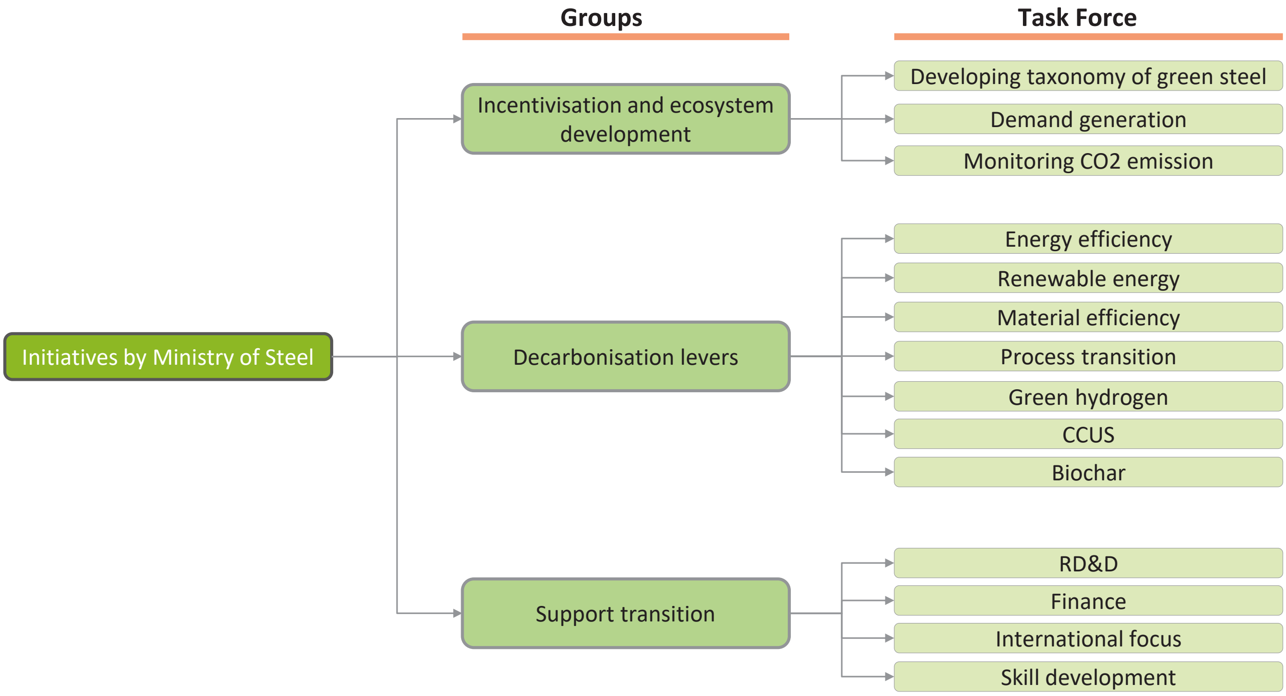


Figure ES1: *List of task forces constituted by the Ministry of Steel*

Incentivisation and ecosystem development

Defining green steel

The definition of green steel (or any other related terminology) is a prerequisite for developing a coherent policy for decarbonising the sector and creating demand for products with green attributes. Globally, there is no commonly accepted definition of green steel yet, though multiple organisations and various countries are working on it. There are multiple challenges to defining green steel in the Indian context. The cost of producing 'fossil-free' and 'near-zero emissions' steel is prohibitively high today. Further, the disparity in the availability of resources like natural gas, scrap, etc. and different milestone years across countries for achieving net zero emissions will be key challenges for developing a globally accepted definition of green steel. Within India, developing a just and fair definition that will incentivise incremental decarbonisation across various production pathways and creating an ecosystem equipped with monitoring, reporting and verification (MRV), green steel certification and registry would be critical to ensure cost-effective decarbonisation of the sector.

Given this background, there are a few design considerations that can be used to define green steel in the Indian context. These considerations, listed in Figure ES2, are an outcome of definitions proposed globally and focus on various aspects related to defining green steel. Based on globally proposed definitions, a key deliberation would be to have scrap-agnostic or scrap-centric targets on the emission intensity of steel that can be further used to estimate the amount of green steel. Further, given the heterogeneity of India's steel industry, the emissions intensity targets could either be production route agnostic or production route specific. The targets on the emission intensity of steel could also be one single value or multiple bands of emissions intensity can be considered for categorising steel based on emissions intensity. The future targets on emissions intensity of steel could either be dynamic, implying that it can be changed in the future based on the progress achieved, or it can be a static value where, irrespective of the progress made by the sector, the targets for future years will not be changed.

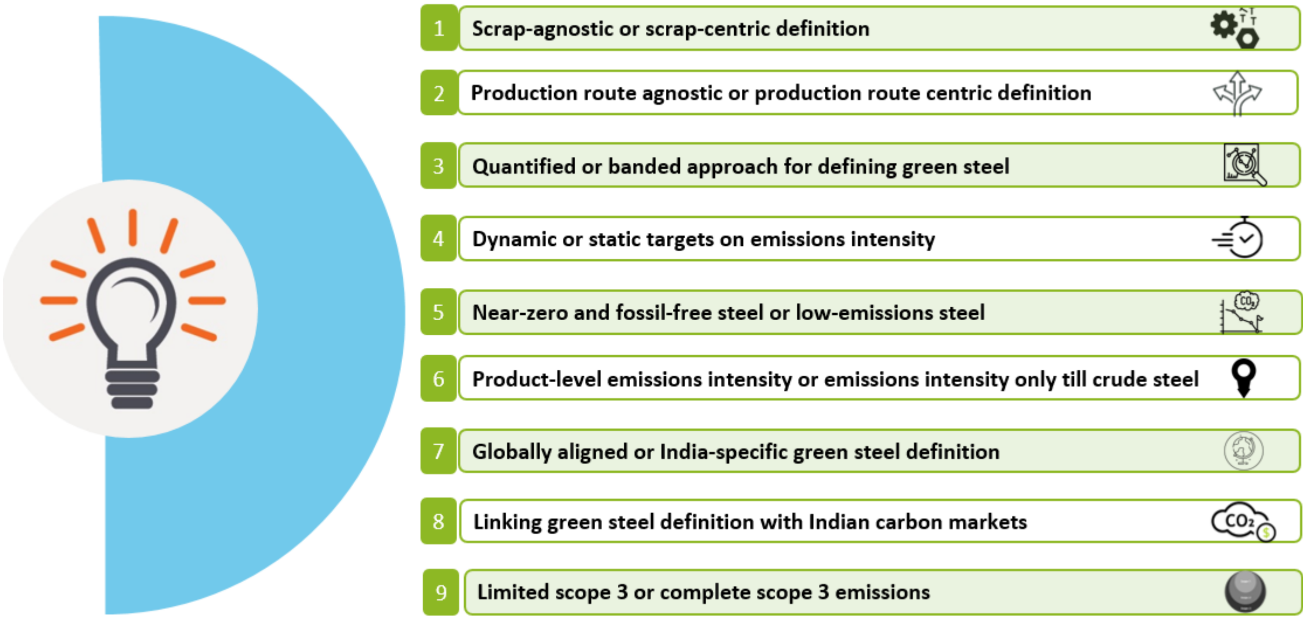


Figure ES2: *Design considerations for defining green steel in India*

There are also deliberations on whether green steel should be 'near-zero emissions' and 'fossil-free' steel based on absolute emissions intensity values or should India incentivise incremental decarbonisation of existing production pathways based on the targeted emissions intensity. Further, the scope of emissions accounting for both downstream and upstream processes is also a critical aspect. For downstream processes, the key design consideration would be on whether there should be product-level emissions intensity accounting or emissions intensity should be measured only till crude steel. On upstream emissions, the key deliberation could be on whether complete or limited scope 3 emissions be considered. India has an upcoming carbon market. Therefore, the green steel definition can also be linked with the Indian carbon market based on the average emissions intensity targets identified for the steel sector. Finally, a key design consideration would be whether India should have a globally aligned or India-specific green steel definition that aligns with its larger climate goals.

The task force constituted by the Ministry of Steel is already working on developing a green steel definition for India, considering these design considerations. The Ministry of Steel may take a final call on the definition of green steel based on the findings of the task force and in consultation with all relevant stakeholders. From an operational perspective, it is envisaged that the Bureau of Energy Efficiency (BEE) shall create a registry of green steel in India.

Monitoring CO_2 emissions

While there are multiple methodologies proposed for CO_2 emissions monitoring globally, the integrated steel plants (ISPs) in India follow the World Steel Association (WSA) methodology for voluntary emissions disclosure as a part of their sustainability practice. Although steel plants report and monitor their scope 1 and scope 2 emissions, scope 3 emissions, which include upstream (procurement of raw materials, shipping) and downstream (transport, warehouse management, scrap processing) emissions, are complex due to lack of data and clarity and thus, scope 3 emissions are not fully adopted internationally. There are a number of challenges for monitoring CO_2 emissions in the Indian iron and steel industry, such as a complex network of supply chain partners without visibility into operations; lack of reliable, accurate, and specific data required for GHG calculations; primary data sources, often maintained on multiple platforms (interoperability) within the organisation, not integrated or accessible to all stakeholders; lack of adequate infrastructure for measuring and monitoring the data; lack of skilled experts who can perform carbon measurement, life cycle analysis, data management and established data quality processes.

The upcoming India Carbon Market (ICM) will necessitate mandatory emissions monitoring of all obligated entities, including the iron and steel sector. BEE is the nodal agency for implementing ICM in India and will publish the Compliance Procedure for the obligated entities along with the monitoring, reporting and verification requirements. The monitoring and reporting aspects will cover details about emission sources to be covered, development and implementation of the monitoring plan, collection of activity data, application of emission factors, fuel quality testing to determine the emissions factors, calculation of absolute emissions and intensity emissions, verification procedure and requirements. Further, BEE will empanel and accredit third-party carbon verifiers. An accreditation advisory committee (AAC) has been constituted by BEE for the purpose of accreditation of carbon verification agencies (ACV).

The Ministry of Steel may support developing an ecosystem for monitoring, reporting, and verification (MRV) in the Indian steel industry. In this regard, the Ministry of Steel may coordinate with BEE to develop a protocol for measuring emissions from all the sector steel plants, including those that are not covered as Obligated Entities under CCTS. Further, the Ministry of Steel may coordinate with BEE to develop a dataset for default emission values for all those input materials where the data is not available, with the help of the industry stakeholders.

Demand generation

There is a need to create a demand-side pull for green steel in India to accelerate the decarbonisation of the sector. This can be achieved by developing a consumer base in the public and private sectors that can pay a premium for green steel. While globally, there are many initiatives for green public procurement (GPP) that include the steel sector as a subset; there are no steel-specific public procurement programmes yet. A few initiatives have been able to create demand for green steel (or any other related terminology) amongst consumers in the private sector, including a few from India. However, it has not led to any green steel offtake, given that most signatories have committed to consuming green steel by 2030-31 and beyond.

There are multiple challenges to the public and private consumption of green steel in India. For the public sector, any premium on green steel is likely to impact the pace of infrastructure deployment in the country. Further, the decentralised nature of public procurement in India will be a challenge in the implementation of GPPP. The macroeconomic implications of GPPP are not fully understood for a developing economy like India. India is also a price-sensitive market. Any increase in the cost of a white good or an automobile due to the procurement of green steel might affect the competitiveness of the manufacturer, and it risks losing market share. While luxury brands of automobiles, white goods, and construction projects can be the first movers in buying green steel, the market penetration of these luxury brands might not be significant enough to create a big market for green steel in India. There are also ecosystem challenges related to the MRV mechanism, green steel certification, and registry, which will take some time to develop.

The total steel consumption by the public sector in India is expected to increase from 25 MT in 2022-23 to 67 -73 MT by 2030-31. As shown in Table ES1, steel consumption constitutes only ~18% of the total cost of infrastructure projects in the country. While the premium on green steel will depend on the definition adopted, as shown in Figure ES3, even a 30% premium on green steel and 20% replacement of conventionally produced steel with green steel will increase the cost of infrastructure projects by only 1.1%. Similarly, based on global studies, the impact on private sector goods like automobiles and white goods is also expected to be minimal at 0.5-1%.

Table ES1: *Budgetary Impact of public procurement of green steel*

	Unit	Base case (FY 2023)	With green steel premium @10%	With green steel premium @20%	With green steel premium @30%
Steel Cost	INR/tonne	55000	60500	66000	71500
Government steel consumption for infrastructure in 2023	MT	25	25	25	25
Total cost of steel procurement	INR lakh crore	1.38	1.51	1.65	1.79
Infrastructure expense	INR lakh crore	7.5	7.5	7.5	7.5
Steel cost as share of total infrastructure cost	%	18%	20%	22%	24%
Budget Impact	%	-	1.83%	3.67%	5.50%

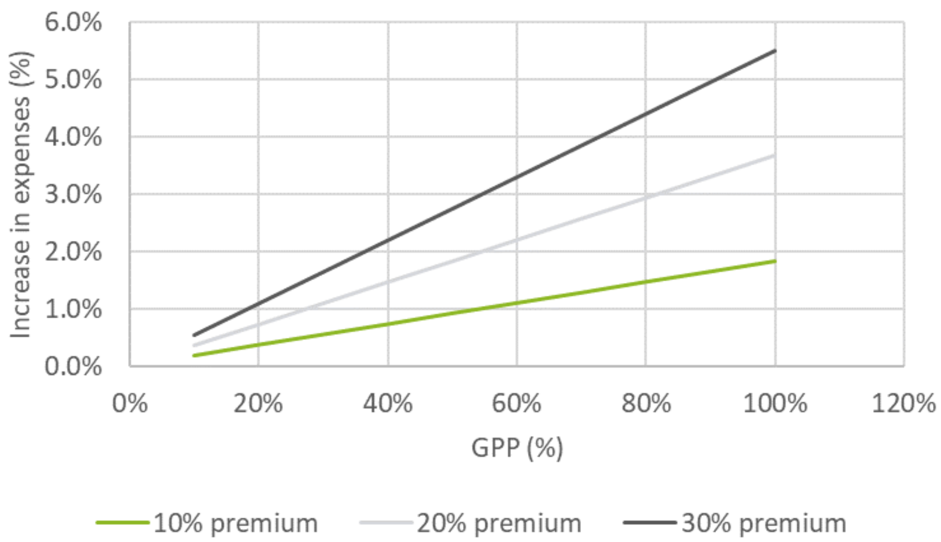


Figure ES3: *Impact of green steel procurement on infrastructure sector*

The Ministry of Steel is keen to create a demand for green steel in India by developing the framework for the Green Public Procurement (GPP) policy for the steel sector, which could then be taken up by the Ministry of Finance for development and action. The Ministry of Steel may set up an agency along the lines of EESL for bulk procurement of green steel to facilitate consumption in both public and private procurement. The Ministry of Steel may also prioritise developing an ecosystem for green steel production and consumption by creating a robust MRV system for emissions accounting, a registry of green steel production and consumption, and tracking of green steel certification. Green steel consumption by the private sector may be encouraged through voluntary disclosure of scope 3 emissions by end-users of steel, reviewing of green building codes, enhanced Environmental, Social and Corporate Governance (ESG) rating points for green steel consumers and other measures on these lines.

Decarbonisation levers

Energy efficiency (EE), material efficiency, renewable energy, process transition, green hydrogen, carbon capture utilisation and storage (CCUS) and biomass are key levers to decarbonise India's steel industry.

Energy efficiency

Energy efficiency not only reduces the emissions intensity of steel but also, in most cases, reduces the cost of production. The perform, achieve and trade (PAT) scheme, implemented by BEE, has been instrumental in driving energy efficiency efforts in the Indian iron and steel industry as the sector achieved total energy savings of 6.137 million tonnes of oil equivalent (Mtoe) up to Cycle V (2019-22) exceeding the targeted energy savings of 4.575 Mtoe and contributed to 24% of total energy savings achieved in the country under the PAT scheme.

There is significant potential for further reduction in the energy intensity of steel production in India. As shown in Figure ES4, the average specific energy consumption for the blast furnace–basic oxygen furnace (BF-BOF) route in India is 6.0-6.5 Gcal/tcs, whereas the global average SEC is 4.5-5.0 Gcal/tcs. The theoretical SEC for the BF-BOF plant is 4.0 Gcal/tcs. Similarly, as shown in Figure ES5, the average SEC of Indian coal direct reduced iron (DRI) – electric arc furnace (EAF)/induction furnace (IF) plants are 7.0 Gcal/tcs vis-à-vis the theoretical SEC of 5.3 Gcal/tcs for the average DRI-EAF plant

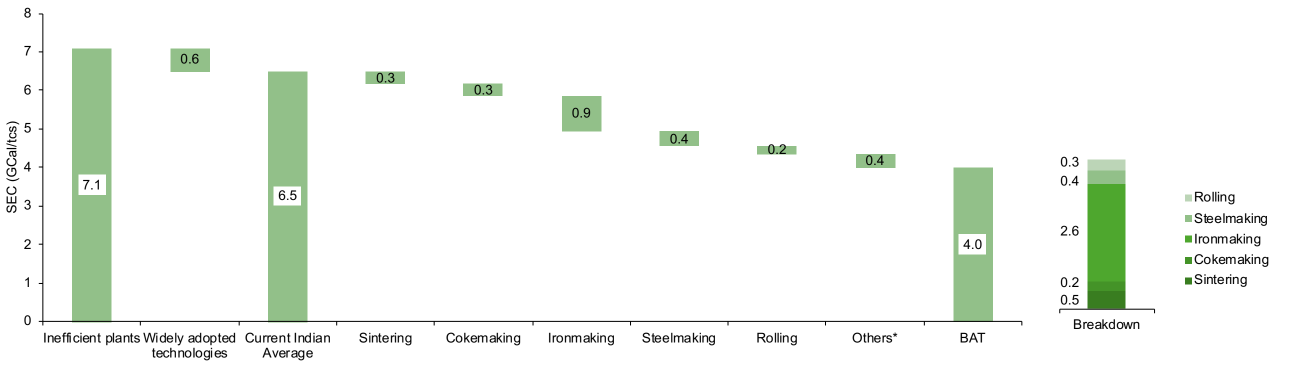


Figure ES4: Energy efficiency improvement potential for BF-BOF route

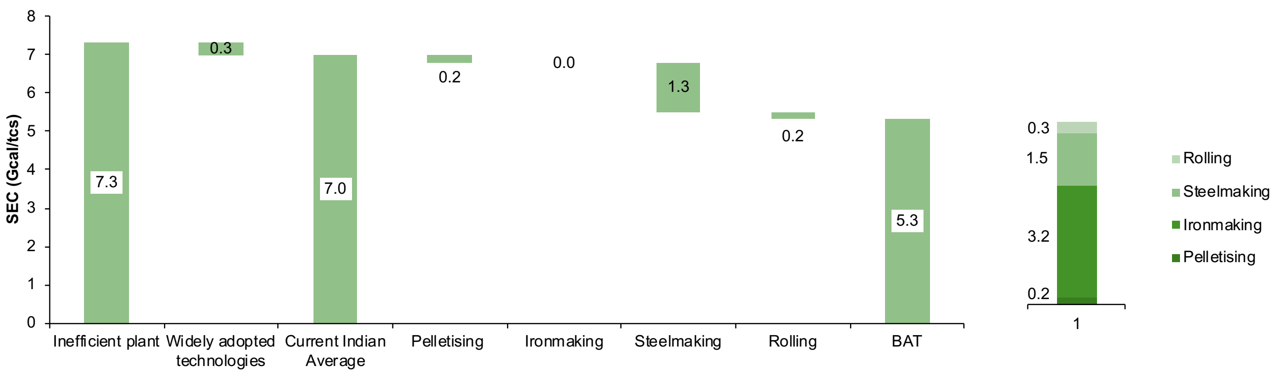


Figure ES5: Energy efficiency measures for the coal-based DR-EAF/IF route

Energy consumption in the steel sector can be reduced by adopting the best available technologies (BATs). There are many proven BATs for the BF-BOF and the DRI- EAF/IF route that can help achieve the global best energy consumption norms. However, the average penetration rate of the BATs in ISPs is only ~50-60%, and it is much lower than 50% for the secondary steelmaking processes. Figures ES4 and ES5 depict the potential of the Indian Steel sector to improve energy efficiency through the implementation of various BATs across different sub-processes in both production routes.

There are multiple challenges for uptaking BATs in the steel sector. Most ISPs face challenges in retrofitting EE technologies within existing units due to layout/space constraints. In a few cases, steel plants prioritise short-term gains over-investment in energy efficiency measures. The secondary steel sector, especially, faces challenges due to the high capital cost of EE technologies, lack of awareness of potential gains from energy efficiency, not having access to affordable finance and a skilled workforce to handle EE technologies.

The Ministry of Steel is keen on promoting the deployment of EE technologies in the steel sector. In this regard, the Ministry of Steel may work towards developing mandates for the implementation of BATs in the greenfield and brownfield projects in the steel sector. Further, the Ministry of Steel may work with BEE to set benchmarks and energy-saving targets for different steelmaking routes. The Ministry of Steel may also work with BEE to increase the number of obligated entities (OE) of the iron and steel industry under the CCTS scheme from the present level. Furthermore, the Ministry may also develop a policy to promote the adoption of Industry 4.0 by integrating digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), Machine Learning (ML) and advanced analytics for medium/ big steel plants. Additionally, The Ministry of Steel may strengthen national institutes and industry associations to provide technical support for the handholding of small-scale industries (SSI) to improve energy efficiency.

Renewable energy

Renewable energy offers an opportunity to reduce emissions from steelmaking without any modifications to the existing production process. Electricity consumption in the steel sector is expected to increase from 94 TWh in 2021-22 to 184 TWh by 2030-31. ISPs are expected to account for 53% of the total power consumption, while SSIs will account for the remaining 47%. As of FY 22, renewable energy (RE) penetration is estimated to be 7.2% of the total electricity requirement in the steel sector. The share of RE power in the ISP's electricity requirement is around 3% owing to higher reliance on thermal captive power and around 11% in SSIs due to higher reliance on grid power with higher RPO (Renewable Purchase Obligation) compliance.

The Ministry of Power (MoP) has notified the RPO target of 43.33% by 2030. With the current level of RE penetration in the captive sources (0.39%) and RPO target of 43.33% in the grid power (BAU scenario), the RE penetration in the steel sector will rise to 16.3% (from the current level of 7.2%), and at 30% penetration of RE in the captive sources the steel sector will achieve 35% of RE penetration. The steel sector would require a capex of INR 73,861 crores to achieve the overall RE penetration of 43.33 per cent by 2030-31. This will lead to a reduction in CO_2 emissions with an overall decrease in the electricity emission intensity (tCO_2/MWh) from 0.85 in 2021-22 to 0.78 in 2030-31 in the BAU scenario and to 0.60 with 30 per cent RE penetration in captive sources. As shown in Table ES2, the RE penetration will lead to a reduction in the emission intensity of the steel sector (tCO_2/tcs) from 2.54 in 2023 -24 to 2.46 in 2030-31 in the BAU Scenario, to 2.41 in Scenario 1, to 2.38 in Scenario 2 and to 2.35 in case of Scenario 3. With 43% RE penetration in the steel sector by 2030-31 will lead to an emission reduction of 8% from 2.54 to 2.35 tCO_2/tcs

Table ES2: *CO_2 Emissions due to electricity consumption in the steel sector: 2030-31*

Sr. No.	Parameters for 2030	Scenario BAU	Scenario 1 (20% RE in Captive)	Scenario 2 (30% RE in Captive)	Scenario 3 (43.33% RE in Captive)
1	Grid power	53,878 MU			
2	Grid RE penetration	43.33%			
3	Grid CO_2 factor	0.46 tCO_2/MWh			
4	CO_2 from grid	24.9 mn tCO_2			
5	CPP power	91,741 MU			
6	CPP RE penetration	0.39%	20%	30%	43.33%
7	CPP CO_2 factor	0.96 tCO_2/MWh	0.77 tCO_2/MWh	0.68 tCO_2/MWh	0.55 tCO_2/MWh
8	CO_2 from CPPs	88.5 mn tCO_2	71.0 mn tCO_2	62.2 mn tCO_2	50.3 mn tCO_2
9	Total CO_2	113.3 mn tCO_2	95.9 mn tCO_2	87.0 mn tCO_2	75.2 mn tCO_2
10	Overall CO_2 factor	0.78 tCO_2/MWh	0.66 tCO_2/MWh	0.60 tCO_2/MWh	0.52 tCO_2/MWh
11	Emission intensity of steel (tCO2/tcs)	2.46	2.41	2.38	2.35

Among the various modes of RE power procurement, the cost of RE power is lowest in the intrastate captive RE plant procurement mode due to low transmission losses and waiver on open access charges. Declining trends in the cost of renewable energy have reduced the price of power from the new RE plant as compared to the new thermal captive plant. Despite these potential benefits, the steel industries are reluctant to opt for RE power due to various challenges like - lack of access to low-cost finance, land unavailability issues, lack of consistency and long-term visibility of policies and lack of awareness among the SSIs.

MoS has taken an ambitious target of RE penetration of 45 per cent by 2030-31. To overcome the challenges w.r.t RE adoption, the Ministry of Steel may set up a coordination cell to provide support to the SSIs across aspects such as - coordination between developers and financial institutions, awareness creation through workshops and webinars, RE demand aggregation from the SSIs to have the low-cost and benefit from economies of scale. Further, the Ministry of Steel may focus on providing financial support to steel players opting for captive/third party RE open access through - line of credits from MDBs, GST Reimbursement for Captive RE Projects, credit from coal cess and setting up of the Payment Security Reserve Fund. Supporting land acquisition for RE projects and promoting the green power market through the introduction of floor price or VPPA model are some of the other interventions that the Ministry of Steel may carry out to enhance RE penetration among the steel industries.

Material efficiency

Beneficiation, pelletization, and scrap utilisation are the key material efficiency measures for the steel sector. Out of the total iron ore (hematite) availability of 24,058 MT in India, only 12% is high-grade ore while medium-grade and lower-grade constitute 38% and 31% respectively. Iron ore beneficiation is essential to prevent resource loss and environmental damage from the growing slimes and fines, which have increased by 9% from 2016 to 2021. It is seen that a 1% increase in Fe content through beneficiation or pelletisation improves the BF productivity by 2% and reduces the coke consumption by 1%.

India has an iron ore beneficiation capacity of approximately 136 MT, which is expected to increase to 170 MT by 2030. However, the beneficiation facilities in the country are inadequately utilised due to constraints like high impurities in iron ore, limited water availability for wet beneficiation units, high capital and operating costs, mismatch between locations of iron ore mines, beneficiation plant and agglomeration units and lack of space for disposing tailings. The Ministry of Steel may support the beneficiation units by incentivising the use of low-grade iron ore through tax incentives and/or facilitating land allotment to establish beneficiation units and dispose of tailings through effective management techniques. The Ministry of Steel may also endeavour to develop a production-linked incentive (PLI) scheme and facilitate public-private partnerships for joint technology development in a cost-effective manner.

India's pelletisation sector also faces challenges similar to those of the beneficiation sector. Of the total production capacity of 136.7 MTPA, India's pellet production stood at 84 MT i.e., 61% of the total capacity. There are challenges with respect to high power cost, infrastructure and logistic challenges for managing the supply chain, pellet availability at competitive prices compared to iron ore and beneficiation technology amenable to various ore types. The Ministry of Steel may support the consumption of pellets in the steel industry by incentivising the integration of pellet-making units within ISPs and large DRI plants, ensuring water availability while incentivising the uptake of low-water intense technologies and supporting provisions for land banks near steel plants and ports.

Each ton of scrap saves 1.1 tonnes of iron ore, 630 kg of coking coal, and 55 kg of limestone while cutting water consumption and GHG emissions by 40% and 58%, respectively, compared to the reduction of iron ore. However, there are manifold challenges related to scrap utilisation in India. The scrap recycling process in India relies on manual dismantling and segregation of scrap components, which increases the cost of scrap processing. Furthermore, the scrap recycling ecosystem operates informally, resulting in fragmentation, non-compliance with regulations, and low-quality scrap production. India is also import dependent on scrap availability for its secondary steelmaking units. However, the evolving geopolitical situation regarding restrictions on scrap exports from developed countries will exacerbate the challenges for incorporating material efficiency practices in India's steel sector. The Ministry of Steel may support the industry in overcoming these challenges by establishing circular economy parks and recycling zones, incorporating Extended Producer Responsibility (EPR) and integrating the informal sector by granting industry status to the recycling sector and developing an e-marketplace for the unorganised sector. Further, the Ministry of Steel may work with various Ministries to provide financial support and incentives for vehicle scrappage policies to incentivise the adoption of BATs in the recycling sector.

Green hydrogen

Green hydrogen can be used in blast furnaces and gas-based shaft furnaces as a substitute for fossil fuels, thus reducing carbon emissions. It can also be used to produce 100% hydrogen-based DRI or in-horizon technologies like hydrogen plasma reduction. Globally, there have been a few pilots on hydrogen injection either on an experimental or a large capacity blast furnace. Similarly, there have been pilots on replacing natural gas with green hydrogen up to 90%. Further, there exists one pilot on a 100% hydrogen-based DRI plant, and many are being planned or implemented. In India, Tata Steel has demonstrated hydrogen injection in blast furnaces while JSW is planning for hydrogen injection in shaft furnaces. There are also research efforts on a laboratory scale for hydrogen plasma smelting reduction.

The Indian steel industry can theoretically consume 1.8 MTPA of green hydrogen in 2023-24, which can potentially increase to 3.5 MTPA by 2030-31. As indicated in Figure ES6, hydrogen injection in BFs is limited to ~15 kg/tcs and can reduce coke consumption by 45-60 kg and decrease the emissions by ~190 kg CO_2/tcs (~7-8% of total emissions from ISPs). However, the breakeven cost of green hydrogen is significantly lower at 0.48-0.88 USD/kg for a coking coal price of USD 180-260/tonne. Similarly, as indicated in Figure ES7, for shaft furnaces, green hydrogen can replace 60-70% of the total gas consumption and reduce the emissions intensity of steel by ~340 kg CO_2/tcs. The breakeven price of hydrogen ranges from USD 0.75-2.02/kg for a natural gas price of 8 - 18 USD per MMBtu. The significantly lower breakeven cost of green hydrogen for its utilisation in the blast and shaft furnaces can be attributed to the high capex required for modifying the furnaces.

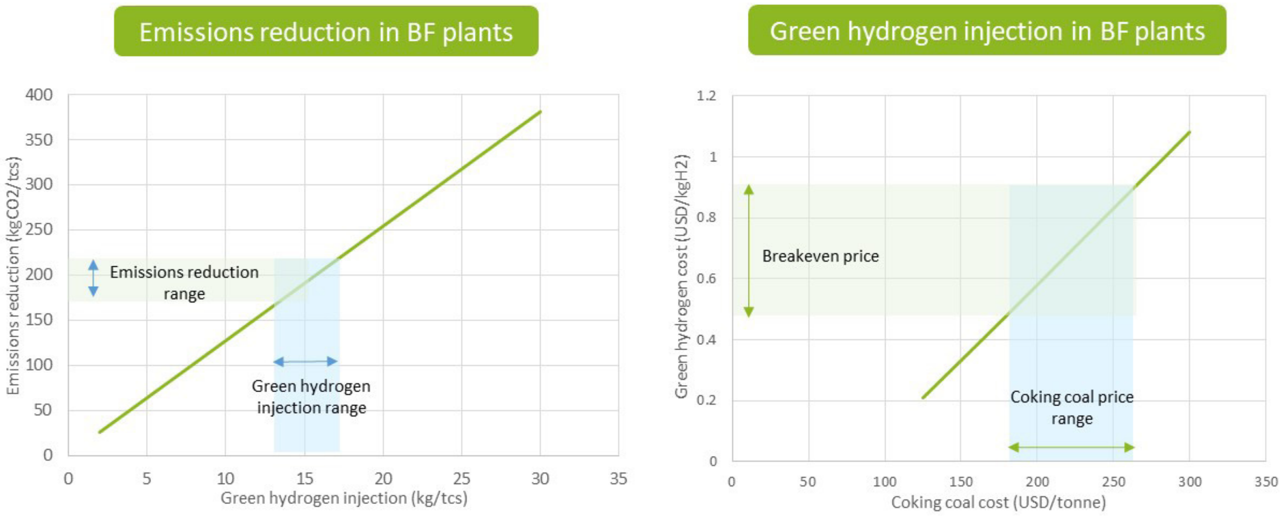


Figure ES6: *Emission reduction potential and breakeven cost for green hydrogen injection in blast furnaces*

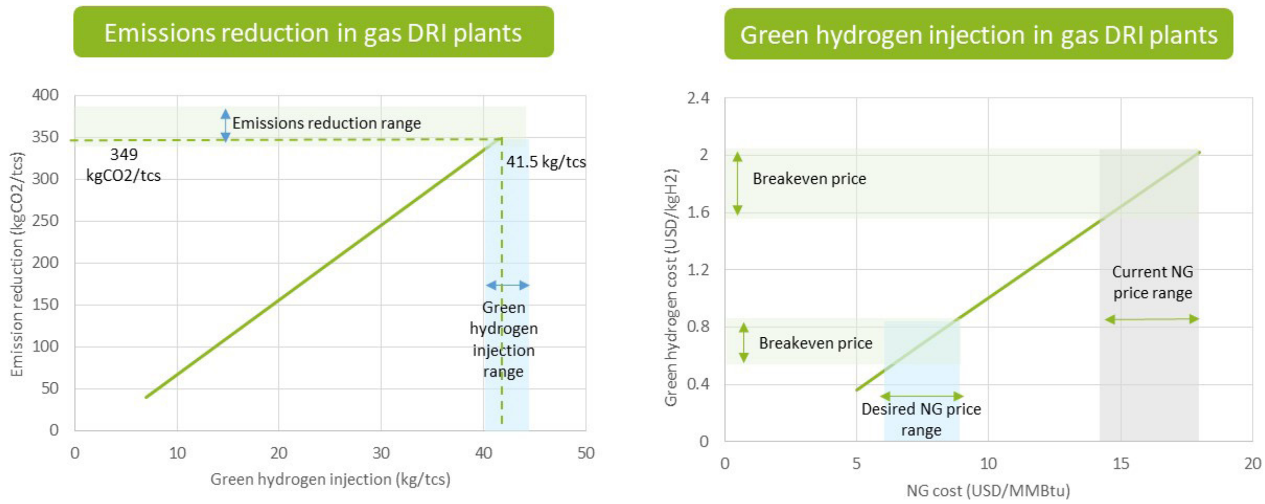


Figure ES7: *Emission reduction potential and breakeven cost for green hydrogen injection in shaft furnaces*

It is expected that under certain aggressive assumptions where green hydrogen reaches a price of 1 USD/kg and incumbent natural gas at 9.5 USD/MMBtu is commercially viable, the steel industry can potentially consume up to 1.1 MTPA of green hydrogen by 2030-31. Green hydrogen consumption in the steel sector faces challenges from the lack of a fully developed ecosystem, geographic hurdles in the availability of green hydrogen in India's steel belt and high production costs. Further, green hydrogen has a limited role in decarbonising the existing processes for steel production and the greenfield/brownfield capacity expansions till 2030-31. This is because ISPs are planning for capacity expansion through the blast furnace route, where green hydrogen has a limited uptake potential. There are also challenges related to technological maturity, lack of experience in handling hydrogen by the steel industry and high upfront capital requirements for setting up green hydrogen plants.

The Ministry of Steel may support pilot projects across all three end-use applications of green hydrogen - hydrogen uptake in the blast furnace, hydrogen blending in an existing shaft furnace and a 100% hydrogen-based DRI plant. Further, the Ministry of Steel may coordinate with other ministries to extend benefits provided to green hydrogen projects in the refinery and fertiliser sector to the steel industry as well. The Ministry of Steel may also develop experimental blast furnaces and shaft furnaces in India for trials with hydrogen injection. Further, the efforts at international and multilateral collaborations may be accelerated to derive maximum benefits for accelerating the adoption of green hydrogen in the Indian steel industry.

Carbon capture, utilisation and storage (CCUS)

CCUS is essential for the deep decarbonisation of the steel sector. It is estimated that 56% of the emissions from existing steel production technologies can only be mitigated through the CCUS pathways. CCUS involves three aspects – CO_2 capture, utilisation and storage. In India, sufficient experience in the industrial sector on carbon capture exists, and there are a few pilots in the Indian steel industry. The key challenge with CO_2 capture is reducing the cost of capture from 45 – 60 USD/tonne CO_2 to less than 20 USD/tonne CO_2. This challenge is significant for the steel industry as the CO_2 concentration in the flue gas is only 15-20% compared to some other industrial processes that have higher concentrations. Further, the steel industry today lacks clarity on steps after carbon capture due to the premium on products obtained with CO_2 utilisation and the lack of ecosystem development on storage.

It is observed that most CCU applications need CO_2 purity exceeding 99%, implying that CO_2 capture is inevitable. Another key challenge with CCU is that, as indicated in Table ES3, the cost of mitigation for green hydrogen-based fuels and chemicals can be prohibitively high, around 300-500 USD/tonne CO_2, which can increase the cost of steel by up to 100%. Therefore, it is expected that CCU will be the least preferred decarbonisation option today, and the steel industry will prioritise other levers like energy efficiency and renewable energy to mitigate their emissions. Consequently, it is important that non-green hydrogen-based CCU applications like carbonates and new applications like carbon recycling for producing iron from iron ore are also explored on priority.

Table ES3: *Impact of CCUS on steel production cost*

	CCS		CCU*				
	Base-case	Best-case	Methanol	SAF	Olefins	SNG	Carbonates
Cost of steel (USD/tcs)	688	688	688	688	688	688	688
Emissions intensity (tCO_2/tcs)	2.46	2.46	2.46	2.46	2.46	2.46	2.46
Cost of abatement (USD/tCO_2)	64	26	503	508	506	553	42
Share of emission abatement through CCUS in BF (%)	59%	59%	59%	59%	59%	59%	59%
Increase in cost of steel (USD/tcs)	92.89	37.74	730.05	737.31	734.41	802.62	60.96
Increase in cost of steel (%)	14%	5%	106%	107%	107%	117%	9%

India has a theoretical CO_2 storage potential of 395-614 GT across saline aquifers (291 GT), basalt (97-316 GT), enhanced oil recovery (EOR) (3.4 GT) and enhanced coal bed methane recovery (ECBMR) (3.7 GT). Considering the above-ground challenges, the realisable storage potential is around 101-359 GT. However, there is no estimate on the true CO_2 sequestration potential in India based on actual site characterisation, which creates significant uncertainty for investments in CCS projects in the country. Further, given that, except for EOR and ECBMR, sequestered CO_2 has limited economic value, CCS will always have a positive cost of CO_2 mitigation, implying that the cost of steel will most likely increase due to CCS. Also, currently, there is no policy for CCS, and there are no clear governance structures across the value chain. There is also limited experience in the transportation and storage of CO_2 as there are no pilot projects in India.

To overcome the challenges associated with the CCUS ecosystem in India, the Ministry of Steel may coordinate with NITI Ayog and other Ministries/Departments and extend support in developing a dedicated, objective-based and dynamic policy for CCU and CCS technology deployment. Further, technology providers for various CCU applications may be invited for detailed techno-commercial due diligence against specific proposals. The Ministry of Steel may also develop an RD&D roadmap for scaling up CCUS technologies in the steel sector, focusing on indigenising critical value chain components and establishing India as a leader in manufacturing these technologies. The Ministry of Steel may coordinate with other government organisations to support CO_2 storage capacities and risk assessment studies for secure storage of CO_2 that rely on available geological and geophysical data. The Ministry of Steel may also coordinate with other Ministries to develop policy guidelines for preferential procurement of CCU products manufactured in steel plants to scale up the technology development and deployment in India.

Process transition

India's DRI industry is predominantly coal-based, where rotary kilns constitute approximately 80% of the total sponge iron production capacity of 60.5 MTPA. The rotary kilns in India face significant challenges for transition due to no reliable estimate on the injection of alternative fuel in kilns and lack of adoption of energy efficiency measures like waste heat recovery owing to high upfront cost. Further, rotary kilns are constrained to use domestically high-ash coal and low-grade iron ore, which in turn increases the overall emissions from the sector.

Figure ES8: *Natural gas cost curve for the steel sector in India*

Natural gas is a potential bridge fuel to green hydrogen. On a life cycle basis, natural gas-based steel production has ~30% lower emissions than coal gasification and rotary kiln-based production processes. However, access to affordable natural gas is an impediment to the decarbonisation of the steel industry. Only 21% of the existing BF capacity and 5% of the coal-based DRI capacity have access to gas pipelines (i.e., assuming they are within 25 km of a gas transmission pipeline). Further, the steel industry needs gas at 6-8 USD/MMBtu to be competitive with coal-based production processes. However, the average landed price of liquefied natural gas (LNG) in India is between 6-16 USD/MMBtu; the delivered price will be significantly higher depending on the location of the end consumer. A natural gas cost curve, shown in Figure ES8, developed based on inputs by major ISPs suggests that the industry has an appetite to consume 10 BCM of natural gas for a price of 4 USD/MMBtu, reducing to 0.53 BCM for a gas price of 9 USD/MMBtu.

India has the world's only coal gasification-based DRI production plant. However, imported coal gasification technologies, available for large-capacity DRI plants, have primarily been developed for the use of low-ash coal. Consequently, these technologies face challenges in utilising domestic high-ash coal to produce syngas. Although several pilot projects have been aimed at showcasing coal gasification using high-ash coal within India, these endeavours have encountered difficulties in scaling up to commercial levels. Further, coal gasification-based DRI production is highly capital intensive, and the small-to-medium scale rotary kiln industry might not have the financial means to invest in such technologies. Moreover, it is seen that on a life cycle basis, coal gasification processes have emissions intensity similar to rotary kilns. Therefore, emissions from the coal gasification route can either be mitigated through CCUS or by providing accelerated depreciation to coal gasification units so that green hydrogen may be incrementally blended in shaft furnaces. The Ministry of Steel may support the DRI industry in overcoming challenges for process transition the action items indicated in Figure ES9.

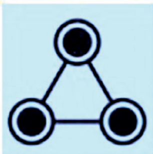
Challenges		Action items by Ministry of Steel
• High cost of NG		• Develop NG cost curve annually, aggregate demand and negotiate long-term offtake contracts with LNG suppliers.
• Access to NG		• Coordinate with MoPNG to provide access to NG in India's iron and steel belt
• Lack of availability of small and medium capacity shaft furnace		• Confer with OEMs and convince them to provide smaller units
• Lack of experience in smaller DRI players for operating gas-based shaft furnace		• Assess feasibility of using a common gas-based shaft furnace in DRI clusters
• Lack of technology to handle high-ash domestic coal		• Co-developing and scaling up technologies for gasifying high-ash domestic coal

Figure ES9: *Challenges and action plan for ensuring process transition in the DRI sector*

Biochar for Iron and Steel sector in India

Heavy reliance on coal and coke in iron and steel-making processes (i.e. for process heat and as a reducing agent) is the predominant source of carbon emissions. Biochar, which is an alternate renewable resource produced from biomass and other farm residues, has the potential to lower the carbon footprint in the iron and steel industry. Additionally, biochar, as an alternate fuel to coal and coke, has comparable metallurgical properties and significant potential for substituting coal/coke, either partially or fully.

Globally, the use of biomass in the production of iron and steel has been steadily rising, though it is still far less than that of conventional fossil fuels. Several countries across the globe have been utilising biochar in small-scale furnaces and some field trials to partially replace coal and coke in large-scale steel production facilities. The iron and steel manufacturers in India such as Tata Steel, JSW and power generator NTPC (cofiring) are utilising biochar on an experimental basis.

Biomass, which is a renewable resource used to produce biochar, can be broadly grouped into the following categories: crop residues, bamboo, forest residues, and bagasse. As per MNRE's recent study, the total surplus biomass from crop residue generated annually in the country is 228.52 MT. The surplus biomass generated could be one of the sources for biochar production, which in turn needs some preprocessing before it is converted into biochar. The biomass, when subjected to different thermochemical conditions through processes (such as torrefaction, gasification and pyrolysis), produces biochar with different properties in line with the requirements of the iron and steel industry. This biochar can be utilised in various processes in the Iron and steel industry replacing coal and coal as an alternate fuel. The potential applications of biochar include iron ore sintering, raw material mix in pellet making, coal blend in coke making, PCI replacement in blast furnaces, coke replacement in blast furnaces, replacing non-coking coal in DRI production in horizontal rotary kilns, and for utilisation in electric arc furnaces.

Biochar has an emission reduction potential of up to 1.19 tCO_2/tcs. To realise the decarbonisation goals of the iron steel steel industry one of the leavers is the utilisation of biochar. However, there are challenges associated with the collection of large quantities of biomass to meet the biochar demand of the iron and steel industry they are inadequate players in the ecosystem i.e (biomass supply chain), the absence of scientific data on the availability of biomass resources, lack of mechanisation in crop harvesting and biomass collection. The absence of storage infrastructure & market mechanisms, the data associated with the benefits of biomass in the existing steel-making process and the type of modifications or retrofitting required for efficient utilisation of biochar in the existing furnace are some of the challenges in using biochar in the iron and steel industry. Limited schemes and incentives in a few states to promote energy crop plantations such as bamboo, hence limited participation from the farmer community, are adding to the development constraint of the supply chain ecosystem of biochar.

To ensure sustainable production, transportation, and utilisation of biochar in the Iron and steel industry, the Ministry may take certain initiatives to enable the smooth transition to biochar in the Iron and steel industry. Some of the suggested measures are to support activities to develop and promote indigenous technologies by providing R&D support for clean technologies, blending mandate, Public-Private-Partnership (PPP) for strengthening industry, research labs, and academia interface for carrying out coordinated & collaborative research, developing market mechanisms like MSP (Minimum Support Price) support, working capital support for biomass aggregator, encouraging cultivators to access priority loans under the non-traditional plantations option to name a few.

Supporting transitions in the steel sector

Research, development and demonstration (RD&D), international focus, finance and skill development are the four pillars for supporting transition in the steel sector.

Research, development, and demonstration (RD&D)

RD&D activities are critical for enabling a sustainable transition in the iron and steel sector and positioning India as a leader in technology development. Hydrogen-based DRI production, aqueous (SIDERWIN) and molten oxide electrolysis are the key breakthrough technologies for iron production that are important for

India. However, the use of hydrogen for DRI production is the most prominent research topic worldwide. The key learning from the analysis of global RD&D efforts in the steel sector is that the industry should anchor a consortium of non-competing entities partially or significantly supported through milestone-based government funding.

There are multiple challenges for RD&D in the steel sector. The RD&D expenses in India are 0.64% of gross domestic product (GDP), which is significantly lower than in other developing (2.4%) and developed (2.9-4.9%) countries. Further, in India, the private sector contributes only 36% of the total RD&D expense, compared to 59-75% in developed countries. It is seen that the RD&D projects in green steel technologies require large investments, often exceeding USD 50 million for demonstration projects that the private sector is reluctant to invest. There is also no umbrella entity within India to coordinate RD&D activities amongst various research groups and industries. In general, there is a reluctance amongst the steel industries to participate in RD&D projects in a consortium mode due to challenges related to the sharing of intellectual property (IP) rights, amongst other issues.

There are a total of 25 RD&D projects identified, covering all levers for decarbonisation like energy efficiency, material efficiency, process transition, CCUS, green hydrogen etc. and are indicated in Table ES4. The RD&D projects have been identified based on research modes like collaboration heavy, mission mode, grand challenge and blue sky for accelerated implementation. Based on these findings, the Ministry of Steel may release a detailed RD&D roadmap for the steel sector in consultation with all stakeholders.

Table ES4: *RD&D projects across various domain*

Sr. No.	Project domain	Number of projects
1	Process transition	3
2	CCUS	6
3	Alternative fuels (H2)	3
4	Miscellaneous	4
5	Energy efficiency	6
6	Material efficiency	1
7	Alternative fuels	2
	Total	**25**

Finance

Global estimates for making the iron and steel sector net-zero range from USD 5.2-6.1 trillion. The existing steel plants in India alone are estimated to need USD 283 billion investment to become green. The adoption of best available technologies in the existing SSPs alone is estimated to be more than USD 13 billion and cost of process transition is an additional USD 150 billion. Irrespective of the accuracy of these estimates, the financial requirements are significant.

From complexity of production processes and value chains, potentially locked in investments in carbon-intensive assets, unviability of current low carbon technologies, inadequate experience, high capital costs and operational expenditure, to high degree of variation in the scale of operations, there are many factors that affect access to finance by the industry. These are further made difficult due to lack of an enabling policy ecosystem, lack of knowledge about technologies and their financial implications, limited availability of finance, maturity of market for green steel, inter alia. Overall, the risk perception about decarbonisation technologies for the sector is high among the industry as well as the finance sector. These factors make industry hesitant leading to a low demand for green finance. At the same time, the financial sector is also cautious, creating a limited availability of finance for decarbonisation of the sector. The action plan for financing decarbonisation of the iron and steel sector in India, therefore, needs to focus on three aspects: mobilisation of finance at scale, addressing demand side barriers, and addressing supply side barriers. Simultaneously, it is important to make the distinction between the domestic and international as well as public and private sources of finance.

Public finance, both domestic as well as international, will play a critical role in mobilising finance at scale. For the domestic sources, the key options include regulatory interventions related to ESG linked financing (particularly extending to the green and sustainability bonds market), expansion of a functional carbon market under the Carbon Credit Trading Scheme (CCTS) and Carbon Contracts for Difference (CCfD) and providing for technical assistance mechanisms as well as setting up dedicated funds to address both demand side as well as supply side barriers. To mobilise international public finance, (or equivalent) the Government of India needs to adopt a comprehensive strategy to build on the potential international public finance availability. It would require strategic partnerships and collaborations with the multilateral banks and other countries to mobilize concessional finance, introduce focused blended finance instruments, partial credit guarantee mechanisms, etc. In addition, careful utilization of the cooperative approaches as well as market-based approaches under the Article 6 of the Paris Agreement can play a potentially transformative role. While the public finance related interventions will also encourage private investors, additional incentives and institutional mechanisms will be required to reduce the barriers of high transaction cost, lack of technical knowledge, high risk perception and cost of capital.

In addition to creating an enabling environment such as introducing green taxonomy for the iron and steel sector, regulatory interventions on ESG linked finance and priority sector lending, expanding the scope of CCTS and CCfD, legal protection against risks, government needs to set up dedicated funds for viability gap funding (VGF), technology upgradation funds (TUFs), pilot financing facility, long-term low-cost financing, risk guarantee mechanisms. Specific attention needs to be given to supporting SSPs.

In institutionalise form, following interventions can be considered:

- National Investment and Infrastructure Fund (NIIF) with equal contributions from government of India and international financial institutions
- A revolving fund with comprehensive financial package for SSPs
- A multi-stakeholder facilitative (technical assistance) platform
- Supply chain linked market-based decarbonisation model

International Focus

The role of international focus assumes significant importance for heavy industries, like steel, as it is often highly traded, serves global markets and its net zero transition involves the massive deployment of emerging technologies and finance. Today India is poised to work through existing global forums and position the heterogeneity of current steel industries through facilitated discussions on the open and free trade of low-emissions steel. India is also leading a few international cooperation efforts specifically aimed at decarbonising the steel sector.

Major countries where steel is produced including - China, Japan, Republic of Korea, Brazil, Turkey, Germany, South Africa, Sweden and USA - have developed national policies and commenced research to identify steel production methods using decarbonisation technologies. Key lessons from global experiences indicate a set of areas of interventions by the Ministry of Steel.

Global experience illustrates that steel sector decarbonisation calls for higher outlays on public infrastructure, public research, stimulus for private R&D, and possible deployment subsidies. Through creating technology demonstration projects, the Ministry of Steel could support domestic steel players to decarbonise their operations. Technologies identified for steel decarbonisation may have an extended timeline for commercialisation, where the Indian domestic steel players need support to implement such technologies. As seen through global experiences, the Ministry of Steel may strive to create an innovation fund for steel decarbonisation. The Ministry of Steel may consult and coordinate with other Ministries and decide spending on green public infrastructure, public support for innovation, and possibly support for deployment of existing low carbon technologies where commercially viability is not proven. Global experiences illustrate that development of indigenous decarbonisation technologies benefits the domestic steel sector in the long run. The Ministry of Steel may consider acting as an anchor to form a consortium, wherein steel players, academic institutions, research agencies can participate to have focused efforts on establishing decarbonisation technologies in India.

The Ministry of Steel may explore multilateral financial transfers that aims to compensate developing countries for the abatement costs under an international agreement on decarbonisation and leverage existing multilateral funds for new energy-efficient technologies. The Ministry of Steel may also consider engaging with companies and financial institutions to leverage public markets to raise lending to promote environmental or social improvement. Sustainability-linked loans and sustainability-linked bonds may be used to raise money, where the debt is tied to a sustainability target for the issuer e.g. a greenhouse gas emission reduction goal, as is evident from the global investments in energy transitions.

The Ministry of Steel may establish a global advisory council for India’s Steel Sector decarbonisation. The proposed Global Advisory Council may enable access to a network of frontrunners for industry transitions, including countries, companies, international organisations, and financial institutions. The Ministry of Steel recognises the need to establish India’s national green steel think tank. Global experiences exhibit that national institutions and organisations have been key to aid implement the national vision of steel sector decarbonisation. The Ministry of Steel may consider establishing India’s National Green Steel Think Tank which may network and collaborate with key national institutions/organisations who are developing new technologies and undertaking Research & Development in other geographies. The existing Steel Research & Technology Mission of India (SRTMI) may be leveraged to establish India’s National Green Steel Think Tank.

Skill development

The iron and steel sector directly and indirectly employs about 2.8 million people. The sector is predominated by small scale units having lower levels of productivity due to low level of skills of workers, usage of old technology, dominant informal employment in the sector and high GHG emission intensity compared to the world average. The manpower intensity in smaller units is generally higher compared to large Integrated Steel Plants (ISPs). At the global level, out of a total 259 million (approx.) jobs in the industry, China accounts for ~36% followed by India (30%). There are wide variations in labour productivity (330-2200 tonne crude steel/man/year) across the world.

The Indian iron and steel sector is currently facing a shortage of skilled manpower. The use of progressive new technologies would necessitate reskilling and upskilling of existing manpower. It is estimated that the reskilling and upskilling requirement over the next ten years would be approximately 0.5 million. Total incremental direct and indirect manpower requiring skilling and certifications in the steel industry (including Rerolling, DRI, Foundry and overseas) is estimated to be 1.1 million in the same period of which 0.84 million is attributed to decarbonisation and digitalisation. There will be a large number of indirect jobs created for example in the Renewable Energy sector. The total cost of reskilling and upskilling the workers engaged in the secondary sector over next 6 years (FY 2024-25 to 2029-30) comes to around Rs 400 Crore.

The skill infrastructure in the steel sector includes IITs, NITs, BPNSI, NISST, IISSSC, polytechnics and training institutes run by ISPs. Several skill development programs like PMKVY, DDU GKY, NULM are also available for skilling the manpower for the steel industry. This existing skill infrastructure needs to develop or modify their courses for the decarbonisation requirement of the steel industry. Lack of availability of robust data base on skills required in the sector especially secondary sector, shortage of specialised skills in renewable energy technologies (solar, wind, hydro), energy efficiency measures, carbon capture and storage (CCS), sustainable transportation, and more rapid technological advancement, interdisciplinary knowledge, limited training infrastructure, absence of industry institute linkage especially with secondary , competition with other sectors and transitioning existing workforce are some of the skill challenges in implementation of the decarbonisation technologies in steel sector.

The Ministry may plan to estimate skill requirements of the secondary sector, strengthen capacity building for training need assessment, promote industry-academia collaboration, develop a mechanism for training need assessments, skill matching and course revision mechanism with line ministries. These initiatives can be funded using various existing government programs and rework the existing policies to bring skill imparting under CSR activities. The resources from both the government and private sector will help to skill the manpower in the sector leading to sustainability in the labour market. These skill development pathways need continuous monitoring and evaluation to support decarbonisation.

Governance framework

A robust governance framework and an institutional mechanism for monitoring and implementing action items are essential to ensure the effective implementation of the strategy and action plan for the decarbonisation of the steel sector. Figure ES10 represents the governance framework for driving the green transition of the Steel Sector in India. The Steering Committee is the apex decision-making body on all aspects of transition. National Green Steel Advisory Group would advise the Steering Committee on the research and technology front. The Executive Committee, reporting to the Steering Committee, oversees the execution of policy recommendations by the Steering Committee by carrying out policy formulations as well as coordination with other Ministries. The Steel Research & Technology Mission of India, an existing Institute under the Ministry of Steel, is envisioned to be transformed into a pioneering institute of the governance framework for decarbonising India's steel sector. It will act as the central hub for innovation, coordination, and implementation of green technologies and practices within the industry.

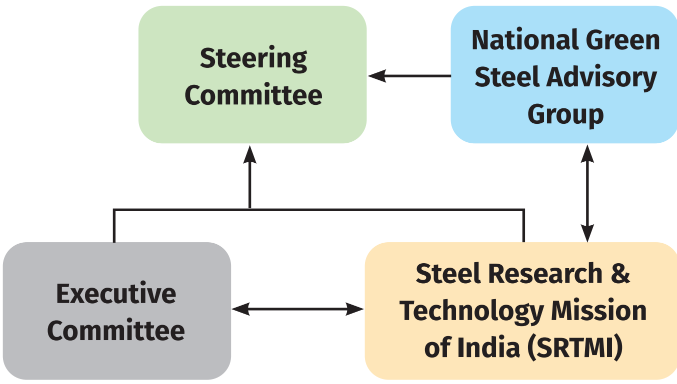


Figure ES10: *Governance framework for implementing action items*

Action plan and Roadmap

India aims to become a global leader in green steel production and consumption through the adoption of clean energy and advanced technologies and by promoting a circular economy to achieve net-zero emissions by 2070. This will be accomplished by setting incremental decarbonisation targets for the steel industry, implementing policy interventions for a smooth transition, creating enabling conditions, and ensuring just transitions. Figure ES11 lists the key targets for ensuring transitions in the steel sector.

- To **define** and standardise green steel
- To ensure **CO2 emission monitoring** in all Steel plants
- To develop a policy for **green public procurement** in steel sector
- To ensure **increased penetration** of BATs in both existing steel plants and new steel plants
- To achieve 45% **RE penetration** in the steel sector by 2030
- To create aggregator model for used **renewable energy** in steel industry
- To promote **circular economy** by increasing the use of **scrap**
- To progressively achieve **resource efficiency** by increasing the use of pellets in ISPs
- To demonstrate pilots for use **of Green hydrogen** in DRI, BF and 100% green hydrogen DRI
- To establish **pilot plants** in CCUS by 2030
- To support development of a policy for **CCUS** in India
- To ensure **increased availability** of Natural gas for steel production
- To ensure **increased utilization of** Biochar
- Release **RD&D roadmap** for steel decarbonisation in India
- Initiate high priority RD&D projects, as identified
- Ensure **enhanced availability** of funds for steel sector
- To increase the **availability of technology and finance** in India through international collaboration
- To ensure **just transition** through skilling, re-skilling and up-skilling

Figure ES11: Major targets for decarbonisation of steel sector

Figure ES12 shows the key strategies and the levers that are part of the decarbonisation strategy. The strategy primarily focuses on five pillars. The first pillar is unlocking opportunities in low-hanging fruits like energy efficiency and renewable energy transition. These technologies are commercially available and can be easily adopted in the sector without any significant modifications to the production process. Transitioning to alternate fuels is another critical part of the strategy for the medium term. Natural gas is a bridge fuel to green hydrogen, biomass is available domestically, while green hydrogen is a fuel for the future. Further, CO_2 recycling for producing iron from iron ore offers an opportunity to reduce dependency on fossil fuels.

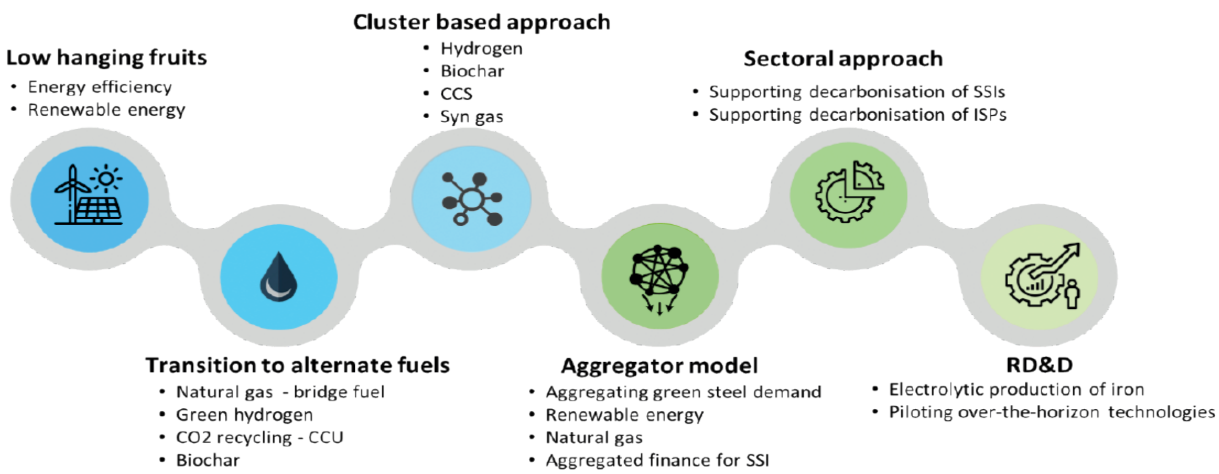


Figure ES12: Strategies for transition in the steel sector

Most steel plants in India are geographically located within a few districts, while the SSIs mostly operate in clusters. Therefore, a cluster-based approach might be suitable for accelerating decarbonisation in the sector by providing access to alternative fuels like green hydrogen, biochar, syngas and deep decarbonisation levers like CCS that can facilitate shared infrastructure, innovation, and resource optimisation. This approach enables the steel industry to collectively tackle common challenges and is useful for SSIs with less financial wherewithal to adopt high-cost interventions. Similarly, the aggregator model supports aggregating green steel demand, the deployment of renewable energy and the uptake of natural gas on a larger scale by pooling investments and resources. Finally, RD&D initiatives are crucial for driving innovation, developing indigenous technologies and making India a manufacturing hub for new-age technologies.

The Bureau of Energy Efficiency (BEE) is developing targets for emissions intensity of steel production in India for the obligated entities under the ambit of Indian Carbon Markets through its Carbon Credit Trading Scheme (CCTS). The proposed industry-wide targets for emissions intensity of steel are indicated in Figure ES13. It is seen that under the CCTS scheme, it is aimed to reduce the average emissions intensity of steel from 2.54 TCO_2/TCS in 2023-24 to 2.2 TCO_2/TCS by 2029-30.

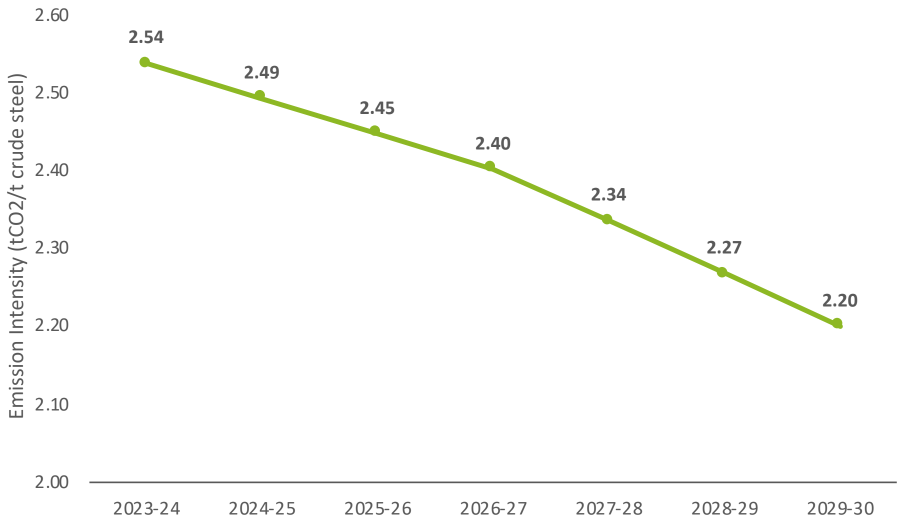


Figure ES13: *Proposed emissions intensity targets for the steel sector*

The Ministry of Steel may support the steel industry for meeting the targets set by BEE and ensure decarbonisation of the steel sector in India. Figure ES14 shows the timeline for major action items under each of the task forces from FY 2025 to 2030. Some actions are immediate and short-term, such as developing a definition for green steel and creating an MRV framework for CO_2 emissions monitoring, set to be completed by FY 2025 and 2026, respectively. Continuous efforts extending until 2030 include promoting energy efficiency, achieving 45% renewable energy penetration, and increasing the use of biochar and circular economy practices. Certain initiatives, like demonstrating pilots for green hydrogen use and establishing pilot plants for CCUS, are scheduled to start later in the timeline but are critical for long-term decarbonisation goals. The implementation of RD&D projects and enhancing finance availability for the steel sector, as well as ensuring just transition, are ongoing efforts that will span across the years, ensuring sustained progress towards reducing emissions. The emission intensity targets are also shown in the figure from FY 2025 to 2030, reducing from 2.54 to 2.2 T/TCS. This may be achieved by the successful implementation of the roadmap.

Sr. No	Action Items	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30
1	**Taxonomy**						
	a. Developing a definition of green steel in consultation with all relevant stakeholders.						
2	**Monitoring CO2**						
	a. To develop an MRV framework for CO2 emission monitoring in steel sector						
3	**Demand Generation**						
	a. To develop a policy for green public procurement in steel sector						
4	**Energy Efficiency**						
	a. To ensure increased penetration of BATs in both existing steel plants and new steel plants						
5	**Renewable Energy**						
	a. To achieve 45% RE penetration in the steel sector by 2030						
	b. To create aggregator model for using renewable energy in steel industry						
6	**Material Efficiency**						
	a. To promote circular economy by increasing the use of scrap by 2030						
	b. To ensure increased uptake of pellets in ISPs						
7	**Green Hydrogen**						
	a. To demonstrate pilots for use of Green hydrogen in blast furnace, gas shaft furnace and 100% green hydrogen DRI						
8	**CCUS**						
	a. To support development of a policy for CCUS in India						
	b. To establish pilot plants in CCUS in India						
9	**Process Transtion for DRI**						
	a. To ensure increased availability of Natural gas for steel production						
	b. To aggregate demand from steel industry and negotiate long term offtake contracts with LNG suppliers						
10	**Biochar**						
	a. To ensure increased utilization of Biochar						
11	**RD&D**						
	a. Release RD&D roadmap for steel decarbonisation in India						
	b. Implement the identified RD&D projects in the report						
12	**Finance**						
	a. Establish dedicated funds for SSIs						
	b. Ensure enhanced availability of funds for steel sector						
13	**International Focus**						
	a. To increase the availability of technology and finance in India through international collaboration						
14	**Skill Development**						
	a. To ensure just transition						
	Target % Reduction in Emission	0.00%	1.97%	3.54%	5.51%	7.87%	13.39%
	Target Carbon Emission Intensity (T/TCS)	2.54	2.49	2.45	2.4	2.34	2.2

Figure ES14: *Roadmap for demand and supply side action items from 2025 to 2030.*

Figure ES15 illustrates the roadmap for decarbonising the steel industry in India, highlighting key milestones from 2023 to 2070. The journey begins in 2023 with the establishment of 14 task forces by the Ministry of Steel. In 2024, the focus is on defining green steel and developing an MRV framework. In 2025, a policy framework for green public procurement (GPP) will be developed, followed by initiatives to increase energy efficiency and renewable energy penetration. The roadmap then emphasises the uptake of pellets and scrap utilisation in steel production. By 2030, significant actions include biochar utilisation and the pilot testing of green hydrogen (GH2) and carbon capture, utilisation, and storage (CCUS) technologies. The period leading up to 2047 involves deep decarbonisation through commercial GH2 steelmaking, advanced CCUS, and breakthrough technologies like direct electrolysis. Finally, the roadmap aims to retire high-emission capacity and achieve net zero emissions by 2070.

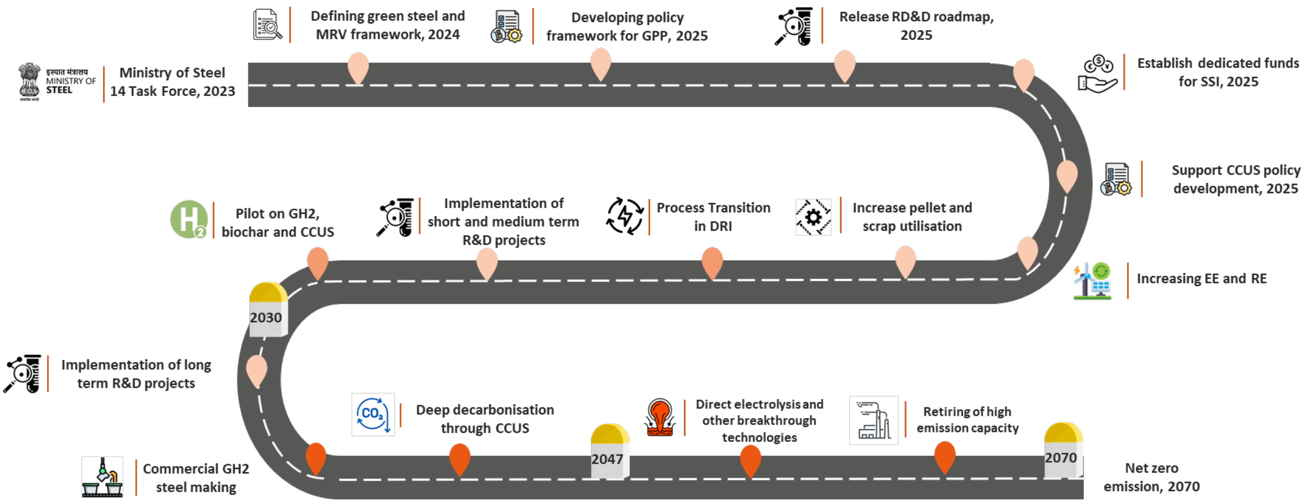


Figure ES15: Roadmap for net zero transition in India

CHAPTER 1

INTRODUCTION

India ranks as the world's second-largest producer of crude steel, with production capacity of 179.5 million tonnes (MT). It also holds the top position globally for sponge iron production, with a capacity of 60.5 MT in the FY 2023-24. Presently, the steel sector contributes approximately 2% to the country's gross domestic product (GDP) and plays a significant role in job creation, employing around 2.8 million people both directly and indirectly. Furthermore, the steel industry has an output multiplier of 1.4 and an employment multiplier of 6.8. This sector is crucial for the country's economic growth and supports its ambitious infrastructural plan.

India is currently one of the fastest growing economies in the world. However, a number of challenges confront India's development agenda, including that of climate change[1,2]. Historically, India's contribution to the accumulation of greenhouse gases (GHGs) is about 4%, despite housing 17% of the global population. India's per capita emissions are well below the global average and have drawn far less than its fair share of the global carbon budget. Nevertheless, India is committed to combating climate change by making development choices that promote the country's economic growth and development along low-carbon pathways.

Figure 1.1 illustrates India's broader climate goals as pledged at international forums. At the 26th Conference of the Parties (COP26), India proposed a fivefold strategy called the Panchamrit goals that target setting up 500 gigawatts (GW) of non-fossil energy by 2030, meeting 50% of energy requirements by 2030 with renewable energy (RE), reducing the projected carbon emissions by 1 MT by 2030, reducing the carbon intensity of its economy by 45% by 2030 and achieving net zero emissions by 2070[3]. This was an enhancement of the earlier nationally determined contribution(NDC) of 2015.

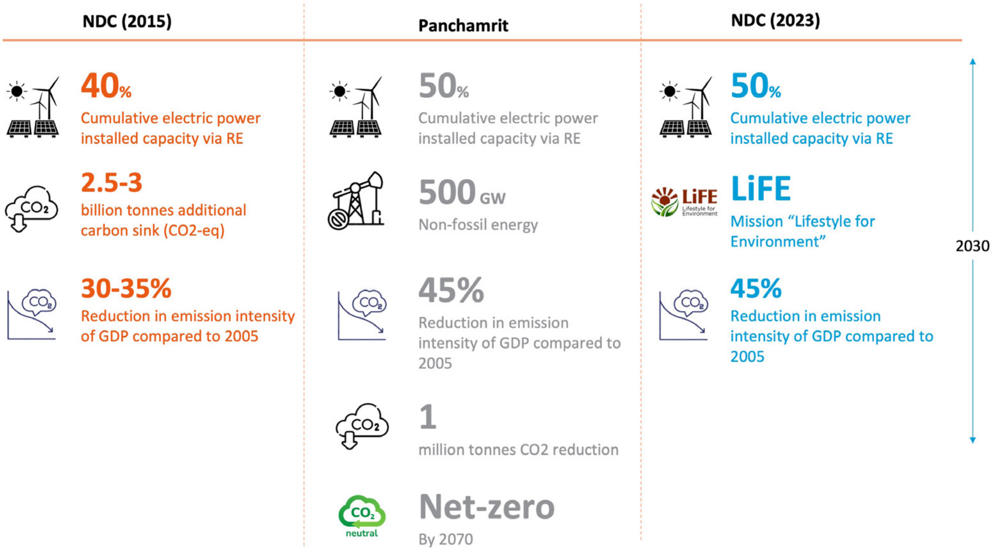


Figure 1.1: *India's 2030 and 2070 targets for decarbonisation*

So far, India's climate commitments have been advanced through significant additions to renewable energy (RE) capacity. Decarbonisation in other sectors, such as mobility, is underway due to multiple policies formulated by the Government of India. However, the latest climate commitments include targets for 2030 and achieving net zero by 2070, which would necessitate deep decarbonisation of the industrial sector. Given that the steel industry accounts for 10-12% of India's total emissions, decarbonisation of the sector is imperative for India to meet its climate goals.

Aligned with these goals, the Ministry of Steel has already embarked on a journey to meet future steel demand in a sustainable manner and streamline efforts and strategies to transition towards low carbon emission steel production, engaging with all the levers of decarbonisation of this sector. However, understanding the current landscape of the Indian steel industry, as provided in the following sections, is imperative to effectively plan and implement these crucial initiatives.

1.1. Indian steel industry at a glance

1.1.1 Overview of the Indian steel industry

Figure 1.2 shows an overview of the Indian steel Industry. India produces about approximately 7.4% of the global steel output[4] and is the second largest producer globally. The Indian steel industry has grown at a compound annual growth rate (CAGR) of 7% since 2004. During FY 2024, the steel production capacity increased by around 11.3% to 179.5 MT, while crude steel production rose by 13.4% to 144.3 MT. India produced approximately 51.56 million tonnes of sponge iron, making it the largest producer globally. Additionally, India is also the second-largest consumer of steel in the world. The finished steel consumption in India grew by 13.7% to 136.29 MT during FY2023-24. India is a net importer of steel. During FY2023-24, India exported 7.49 MT of finished steel while importing 8.32 MT of finished steel. However, despite the significant growth in the steel industry, India's per capita steel consumption is significantly lower than the global average. While the per capita steel consumption in India increased to 97.7 kg in FY 2023-24 from 86.7 kg in FY 2022-23, the global average per capita consumption was 219.3 kg in 2023[5]. Therefore, there is a concerted effort to raise the per capita steel consumption in the country, both in urban and rural areas. The National Steel Policy 2017 aims to increase the production capacity to 300 MT and consequently increase the per capita steel consumption to 160kg per capita by 2030-31.

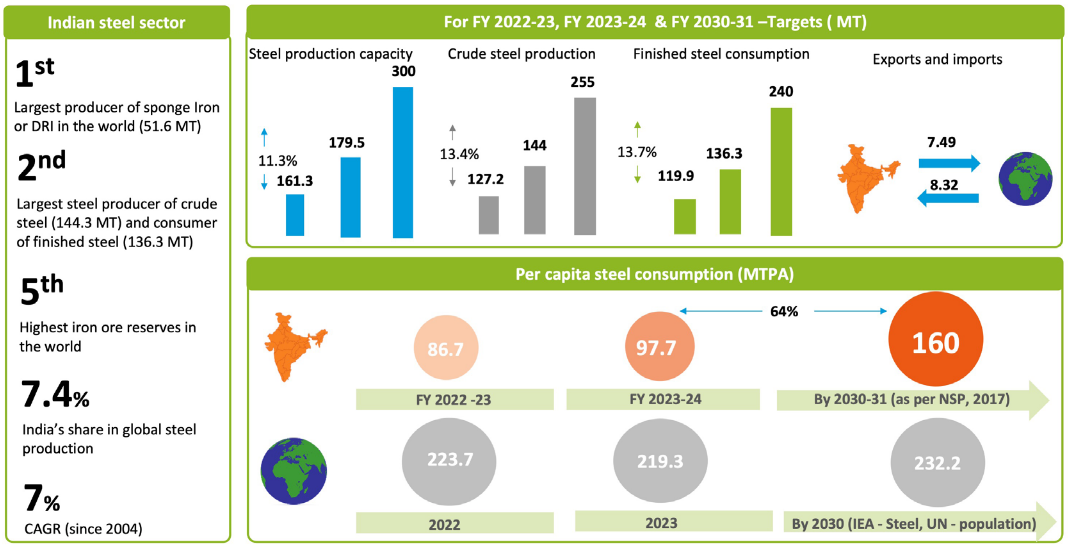


Figure 1.2: Overview of the steel industry[6]

1.1.2. Different Routes of Steelmaking

Primary steel production involves three steps, as shown in Figure 1.3 below. First, raw materials are prepared, followed by the reduction of iron ore to iron, known as ironmaking, and finally, iron is converted to steel, i.e., steelmaking. Iron ore is processed to sinter or pellets from fine ore or used as lump ore, depending on the ironmaking process.

In India, there are primarily three routes to iron production: Blast furnaces (BF) that produce hot metal and two direct reduced iron (DRI) production methods, namely shaft furnaces using natural gas or syngas or other industrial off gases as fuel and rotary kiln furnaces using coal as fuel. Iron produced is then converted to steel through three main processes. Typically, the hot metal is converted into steel through the basic oxygen furnace (BOF) route, while DRI is converted to steel in an electric arc furnace (EAF) and an induction furnace (IF). Further, scrap steel is converted to crude steel using an EAF or IF. The larger integrated steel plants (ISPs) typically use the BF-BOF and DRI-EAF pathways, whereas smaller plants use the coal-based DRI-IF pathway. The crude steel is converted into finished steel in rolling mills.

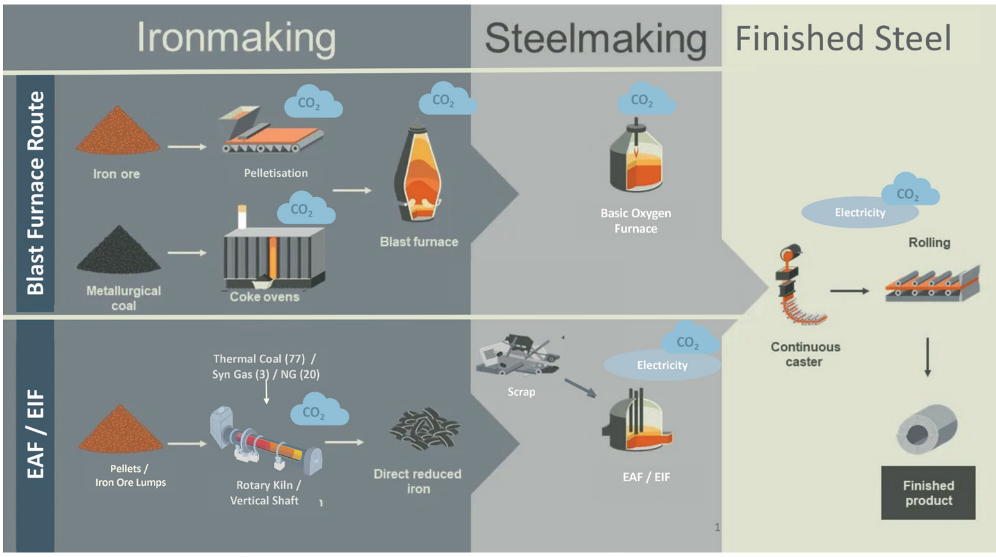


Figure 1.3: *Steel production pathways in India*[7]

1.1.3. Growth of Iron and Steel Industry in India

The ironmaking capacity has substantially increased over the past two decades. Between 2002 and 2023, the total ironmaking capacity has grown at a CAGR of 10%. The production of sponge iron, in particular, has grown at a higher rate of 10.6%, while hot metal production grew at 7% during the same period. However, the blast furnace remains the most dominant method for primary iron production today. India has a small number (55) of large-capacity blast furnaces, while there are a large number (344) of small-capacity sponge iron plants in India.

The growth in steel production is represented in Figure 1.4. Steel production in the country has grown at a rate of 8% during 2002-2023. A higher growth of 8% and 12% was observed in EAF and induction furnace routes of steelmaking compared to 7% for the BOF route.

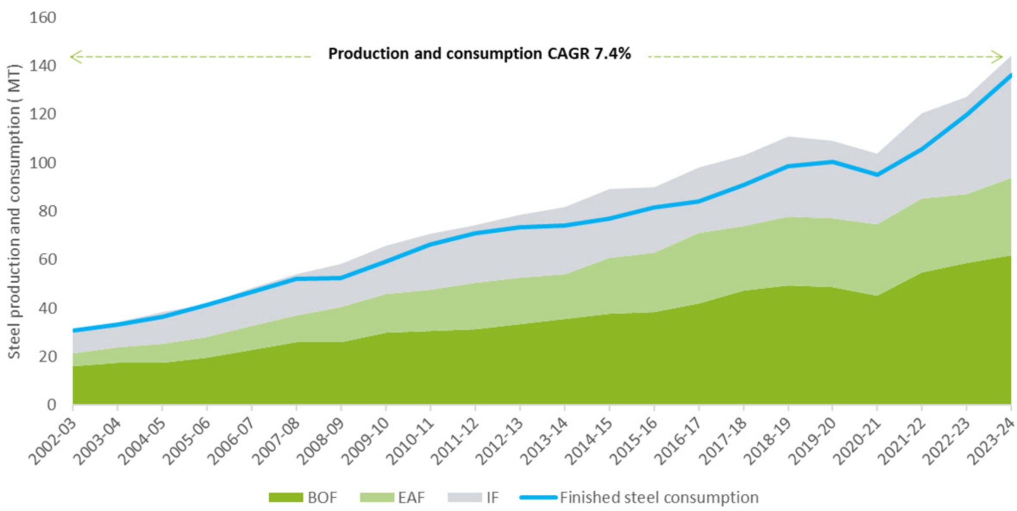


Figure 1.4: *Growth in crude steel production and consumption in India*[8]

India's total finished steel consumption has grown at a CAGR of 7.4% from 30.68MT in 2002-03 to 136.29MT in FY 2023-24, as shown in Figure 1.4. There was a dip in the steel consumption during the pandemic in FY 2020-21. However, following a V-shaped recovery, steel consumption has picked up pace in the economy. The National Steel Policy 2017 has projected a consumption of 230 MT of finished steel by 2030-31.

1.1.4. Sectoral share of steel demand in India

In India, the bulk of the steel demand comes from growth-driving sectors such as construction (43%), infrastructure (25%), automobile (9%), white goods like engineering and packaging (22%), and defence (1%), as shown in Figure 1.5. While the per capita steel consumption in India increased to 97.7 kg in FY 2023-24 from 86.7 kg in FY 2022-23, the global average per capita consumption was 223.7 kg in 2022. Further, the rural per capita consumption in India is only 23 kg, which is far less than the national average. Consequently, as India's economy continues to grow, the demand for steel is also expected to increase significantly. The relative distribution of steel consumption across various sectors is also expected to change in the future. About 90-100 % of the consumption in building and construction, engineering & packaging and automotive sector is by the private sector, and 90-100 % of the consumption in Infrastructure and defence is through government procurement.

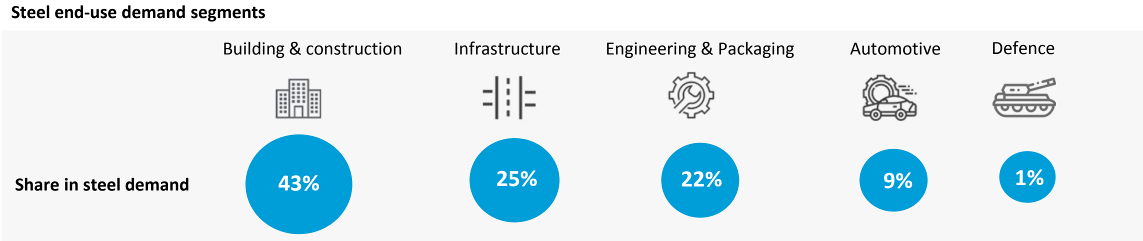


Figure 1.5: *Segment-wise distribution of demand for steel (CRISIL,2021)*

1.1.5. Major feedstocks for iron and steel production

Table 1.1 summarises different feedstocks used in iron and steel production in India. Iron ore and scrap provide the iron source to the iron making industries, while coking coal, thermal coal and natural gas act as the primary energy sources as well as provide the reducing functionality essential for converting iron ore to iron.

Table 1.1: *Raw material consumption by the Indian steel industry*

Sr. No.	Resource consumption (units)	Consumption in FY 24
Iron Sources		
1	Iron ore (MT)	225
2	Scrap (MT)	33.36
Energy Sources		
3	Coking coal (MT)	72
4	Non-coking coal (MT)	72
5	Natural gas (million standard cubic meters) (MMSCM)	1177

Iron ore is the basic raw material for ironmaking. Hematite and magnetite are the most prominent types of iron ores found in India. The total reserves of iron ore (hematite) in the country, as of 2020, are estimated at 24,058 MT[9], while magnetite reserves are estimated at 11,228 MT[10]. Given that each tonne of steel production requires about 1.6 tonnes of processed ore , the overall consumption is a significant amount.

The steel sector also consumes ore in the form of pellets, which are produced from high grade or beneficiated iron ore fines. Utilisation of pellets in DRI and BF increases the productivity and efficiency of the processes, therefore it is highly desirable. Out of the total pellet production capacity of 145.09

million tonnes per annum (MTPA), as seen in Figure 1.6 below, India's pellet production stood at 96.52 MT, i.e., 66.5% of the total capacity for FY 2023-24. India exported 12.24 MT of pellets, and the balance of 84.28 MT was used domestically in DRI making, blast furnaces and other processes.

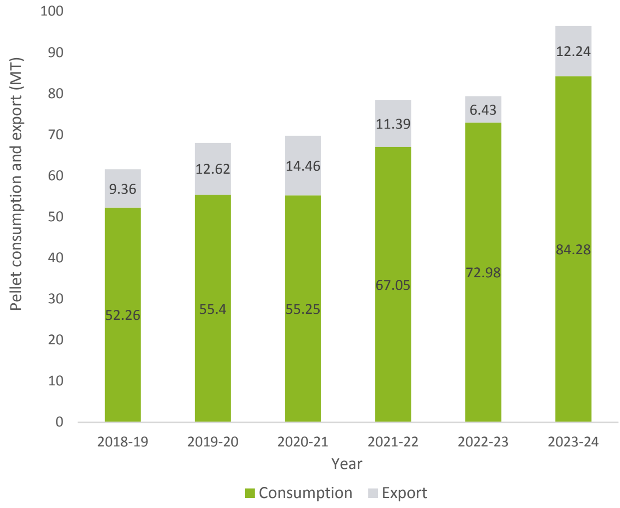


Figure 1.6: *Pellet consumption and export from 2018-19 to 2023-24*[11]

In India, there is a limited availability of scrap. Figure 1.7 shows that the total scrap availability in India has remained around 25-30 MT over the past five years. India imports a small share of scrap. The steel scrap recycling policy, 2019[12] and the vehicle scrappage policy, 2021[13], have marginally increased domestic scrap availability in subsequent years. There has also been a significant increase in scrap imports in FY 2022-23. Nonetheless, this increase is significantly lower than the total amount of scrap needed by the steel industry.

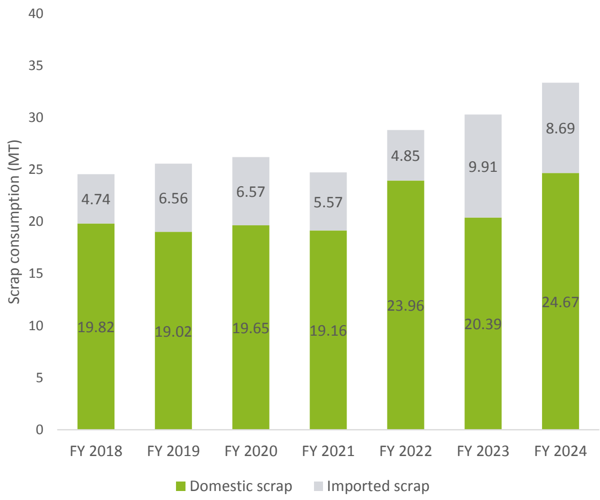


Figure 1.7: *Scrap consumption in India from FY 2018 to FY 2023*[14]

For energy sources, the steel sector in India is dominated by coal-based capacities. As summarised in Table 1.1, the consumption of coking coal in FY 2022-23 was 56 MT, primarily for blast furnaces. In addition, the steel sector also consumes a sizable amount of non-coking coal at 16.11 MT (both for hot metal and sponge iron production). Similarly, the gas-based DRI plants in India use a mix of natural gas and other off-gases like coke oven gas (COG) to produce iron. Syngas obtained from the coal gasification process is also being used for producing DRI. It is estimated that the steel sector in India consumes approximately 1 billion cubic meters (BCM) of natural gas in FY 2023-24.

1.1.6. Route-wise share of iron and steel production

The steelmaking processes in India mainly comprise three distinct routes. They are the BF-BOF pathway, gas-based DRI - EAF pathway, and coal-based DRI - IF pathway. Figure 1.8 illustrates the share of various production pathways in the production of iron and steel in FY 2023-24. The blast furnace is the most dominant route for ironmaking in India, followed by coal and gas-based DRI. The BF-BOF route is most dominant in crude steel production.

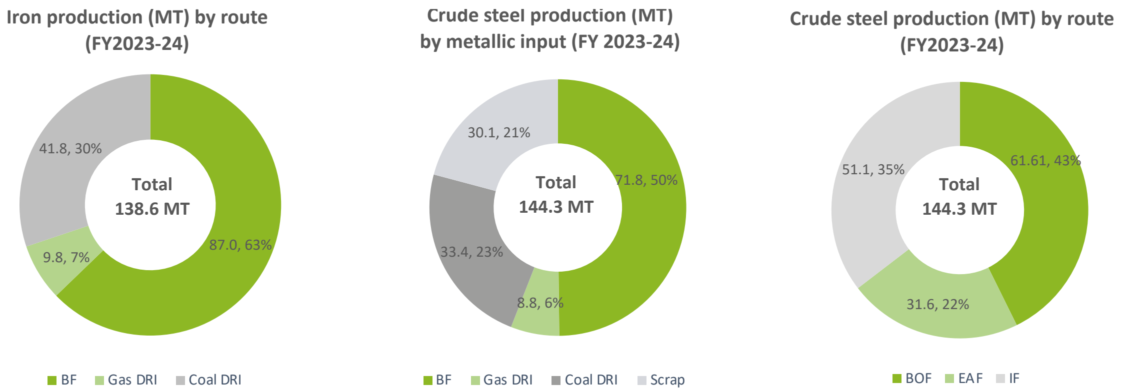


Figure 1.8: *Route wise share of iron production, steel production and metallic input for steel production in India*[15]

The steel industry in India is very heterogeneous, with a mix of different technologies and feedstock distributed across both iron and steel making. This heterogeneity is clearly evident in the Sankey diagram depicted in Figure 1.9, which shows the overlap in the flow of iron and scrap across various steelmaking processes.

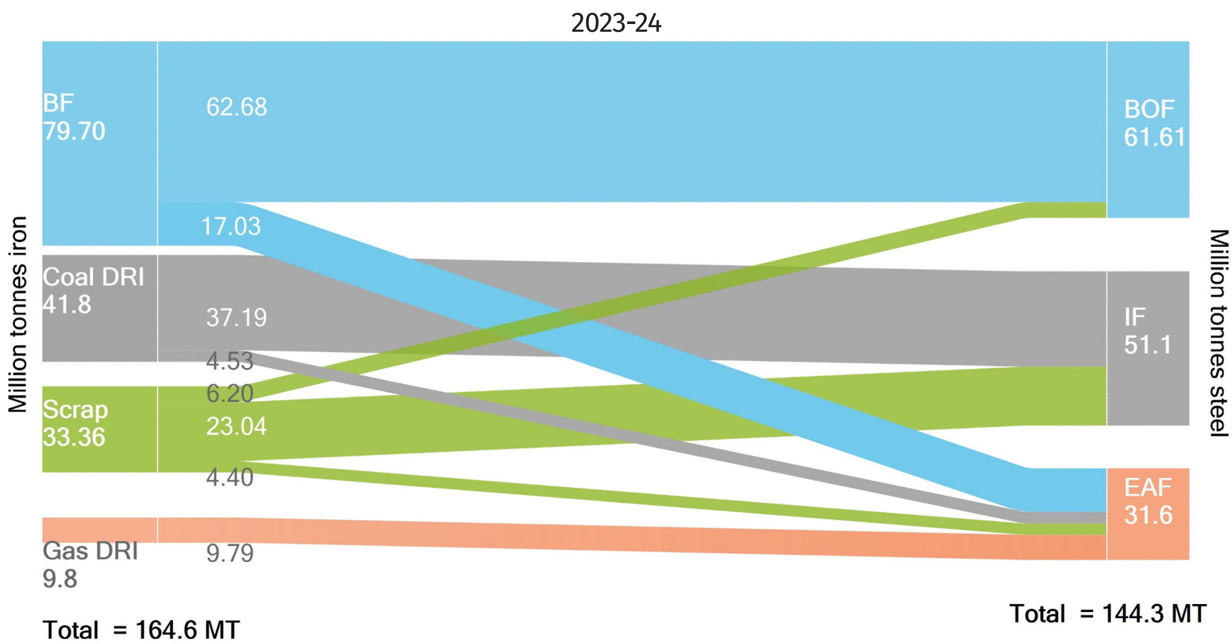


Figure 1.9: *Heterogeneity in iron and steelmaking pathways in India*

As seen from the above diagram and Table 1.2, BOF units use a smaller share of the total scrap consumed in the country. The majority of the scrap is consumed in standalone IF units with an overall charge mix of 41% scrap and 59% DRI. It is estimated that about 90% of the total output from coal-based DRI plants, along with 68% of the total scrap, is used by the IFs. Thus, the coal-DRI sector primarily caters to IFs. EAFs, on the other hand, are mainly catered to by hot metal from BFs and all the available gas DRI, as EAFs in India are predominantly owned by ISPs that have co-located gas-based DRI units and blast furnaces for producing hot metal.

Table 1.2(a): *Distribution of feed iron sources in crude steel production route*

Crude Steel Production	Feed Iron Source			
	BF- Hot metal	Coal DRI	Gas DRI	Scrap
BOF	78%	0%	0%	19%
IF	0%	90%	0%	68%
EAF	22%	10%	100%	13%
Total	**100%**	**100%**	**100%**	**100%**

Table 1.2(b): *Distribution of feed iron source across crude steel production routes*

Crude Steel Production	Feed Iron Source				
	BF- Hot metal	Coal DRI	Gas DRI	Scrap	Total
BOF	91%	0%	0%	9%	**100%**
IF	0%	59%	0%	41%	**100%**
EAF	49%	28%	11%	13%	**100%**

Table 1.3 provides an overview of the iron and steel units in India. The bulk of the iron production of approximately 94 MT, in the country is through the 55 blast furnace units, while 339 DRI units produce about 41.8 MT of sponge iron. There are about 20 BOF units integrated with blast furnaces. However, there are over 1032 IF plants spread across the country that are preferred over EAFs due to their modular size and low capital requirements. Further, a majority of crude steel is converted to long products in a large number of re-rolling mills that produce long products from the crude steel obtained from IF and EAF units. Flat products are obtained from hot strip mills mostly housed within ISPs. Nationwide, there are 1091 steelmaking units with a production capacity of 179.5 MT and producing 144 MT of steel.

Table 1.3: *Overview of the iron and steel units in India*[16]

Sr. No.	End product	Type of Industry	No. of Units	Capacity (MT)	Actual production for FY 2024 (MT)
1	Iron	Blast Furnace- Hot metal	55	95.8	87.04
2		Blast Furnace- Pig Iron			7.36
3		DRI/Sponge Iron Producers - Coal based	339	48.2	41.8
4		DRI/Sponge Iron Producers - Gas based	5	12.3	9.8
Total			**399**	**156.3**	**138.6**

Sr. No.	End product	Type of Industry	No. of Units	Capacity (MT)	Actual production for FY 2024 (MT)
5	Crude Steel	Electric Arc Furnace (Large and Small)	39	39.5	31.61
6		Induction Furnace	1032	68.8	51.08
7		Basic oxygen Furnace	20	71.2	61.61
Total			**1091**	**179.5**	**144.3**
8	Finished steel products	Hot Re-rolling Mills (long products)	1,224	109.4	80.9
9		Hot Strips Mills (Flat products)	24	61.4	57.9
10		Cold Rolling Mills	77	32.6	21.7
11		Wire Drawing Units	65	2.7	1.7
Total			**1390**	**206**	**162**

1.1.7. Integrated Steel Plants and Secondary Steel Industries

The steel plants in India can be categorised as integrated steel plants (ISPs) and secondary steel industries (SSIs). Figure 1.10 shows the ratio of ISPs to SSIs in India's total steel production capacity, with ISPs having approximately 56% share and SSIs 44%. ISPs have all facilities housed within the unit to produce finished products from raw materials and fuels. ISPs are typically larger in size and employ many people across the value chain.

Table 1.4 depicts the distribution of capacities along various ISPs, the largest one being JSW Steel. The public sector's share of steel production capacity stands at 30.93 MT {Steel Authority of India Limited (SAIL), Rashtriya Ispat Nigam Limited (RINL) and National Mineral Development Corporation (NMDC)} (approximately 31%), while the private sector accounts for 68.78 MT, which is 69% of the total capacity.

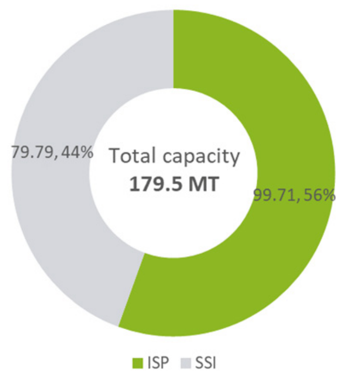


Figure 1.10: Distribution of capacity among ISPs and SSIs 2023-24 (MT)

Table 1.4: Major Integrated steel plants in India and their existing capacities(from JPC)[17]

Sr. No.	Integrated Steel Plants	Capacity FY 23 (MT)	State
1	JSW Steel Ltd	28.08	Karnataka/ Chhattisgarh/ Maharashtra/ Odisha/Tamil Nadu
2	Tata Steel	21.50	Jharkhand/ Odisha
3	SAIL	20.63	Karnataka/ Chhattisgarh/ Jharkhand/ Odisha/ Tamil Nadu/ West Bengal
4	AM/NS	09.60	Gujarat
5	JSPL	09.60	Chhattisgarh/ Odisha

Sr. No.	Integrated Steel Plants	Capacity FY 23 (MT)	State
6	RINL	07.30	Andhra Pradesh
7	NMDC Steel	03.00	Chhattisgarh
	Total	**99.71**	

SSIs comprise smaller units that contribute to the remaining iron and steel production in India. The coal-based DRI process is distinctive to the Indian steel sector, primarily to meet region-specific steel requirements. The preference for DRI in India can be attributed to the low capital required for setting up small-scale plants compared to ISPs, where the capital requirement is significantly higher and the lack of availability of scrap in sufficient quantities at reasonable prices. Further, an abundance of cost-effective domestic thermal coal reserves and the inadequate availability of domestic natural gas and coking coal also contribute to India's significant capacity of coal-based DRI units. The structure of the DRI industry is given in Table 1.5.

India is the largest global producer of coal-based DRI, with approximately 80% of DRI production relying on coal, while the remaining 20% employs a gas-based process. The DRI industry consists of both standalone and composite units. Standalone units produce only DRI, while composite units are integrated with IFs or EAFs and other downstream units to produce finished steel. It is seen that a large number (185) of DRI plants are medium-sized (>0.05 MTPA and ≤0.15 MTPA), whereas the number of small and large players are roughly the same.

Table 1.5: *Structure of the DRI industry in India*[18]

Sr. No.		No. of Units/Location	Capacity (MT/year)
1	Total operational DRI Plants	344	60.5
	Fuel-wise production capacity		
2	Coal-based DRI Plants	339	48.2
3	Gas-based DRI Plants	5	12.3
	a) AMNS (NG)	Hazira	6.8
	b) JSPL (through coal gasification)	Angul	1.8
	c) JSW (NG)	Dolvi	1.6
	d) JSW (NG)	Vijayanagar	1.2
	e) JSW (NG)	Salav	0.9
	Capacity-wise distribution		
4	Small (≤ 0.05 MTPA)	67	2.19
5	Medium (>0.05 MTPA and ≤0.15 MTPA)	205	16.93
6	Large (> 0.15 MTPA)	72	41.40
	Distribution based on the nature of the operation		
7	Standalone	209	33.56
8	Composite	135	26.95

1.1.8. Regional Overview of the Indian Steel Industry

Figure 1.11 shows the locations of iron and steel units in India across various production pathways. The size of the bubble is proportional to the steelmaking capacity. It can be seen that the primary ironmaking units (BF and DRI plants) are located in the eastern states of Odisha, Jharkhand and Chhattisgarh. Consequently, these three states constitute 43% of the total steel produced in India. The state of Karnataka has access to abundant natural resources like iron ore and is the fifth-largest producer of steel in India. Maharashtra and Gujarat also have some capacity of steel plants in the coastal areas. The role of IFs is significant and unique to the Indian steel sector. Typically, smaller steel players deploy IFs for steel production, while larger players rely on EAFs and BOFs. IF units are either co-located with DRI plants or run as standalone operations. While DRI plants are mainly located in the southern and eastern parts of the country due to proximity to iron ore and coal, IF units exist as clusters spread across the country and are located in areas that have good scrap availability. There are a total of 1032 IF units spread across the country, with a capacity to produce 68.8 MT of steel as of FY 2023-24, with an average production of 0.05 MTPA. IFs located in primary ironmaking clusters of Odisha, Jharkhand, Chhattisgarh and Karnataka use DRI as a key ingredient of the charge mix, whereas those located outside primarily rely on steel scrap for producing steel.

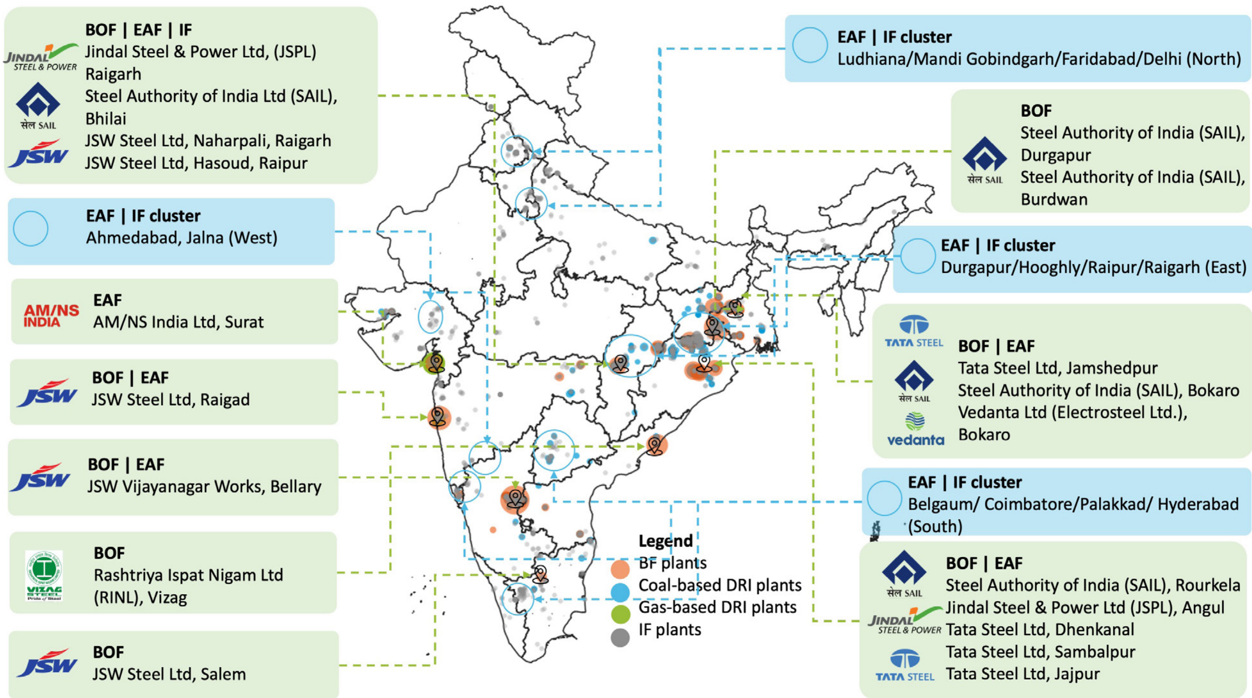


Figure 1.11: Iron and steelmaking units in India.

Figure 1.12 shows the state-wise production capacity of iron. Given the proximity of supply chains to raw materials, iron production is the highest in the state of Odisha, which constitutes 24% of the total production, while Chhattisgarh and Jharkhand constitute 16% and 15%, respectively. Primary ironmaking in India is concentrated in only twelve states.

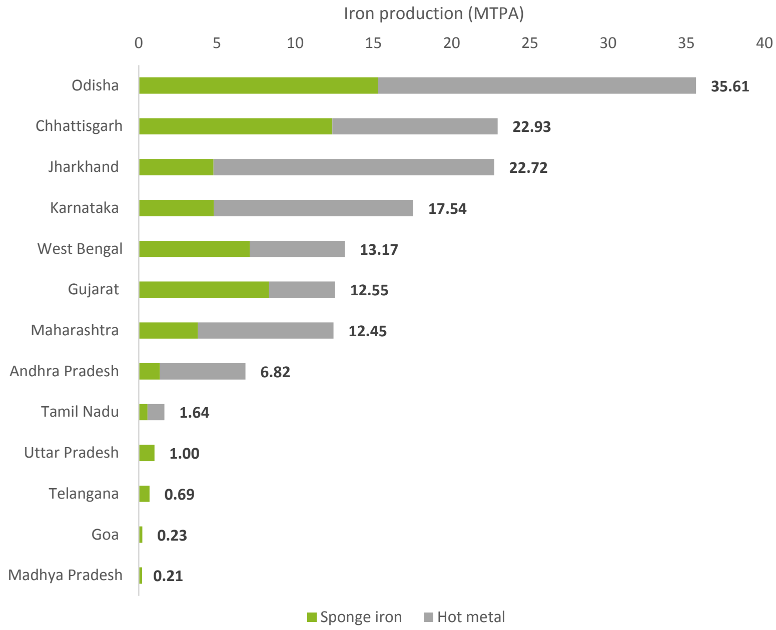


Figure 1.12: *State-wise capacity of Iron production*

Figure 1.13 shows the state-wise production capacity of crude steel. Crude steel is produced in regions different from the primary iron production plants. Therefore, while there are only 12 iron-producing states in India, there are 28 steel-producing states. Odisha, Chhattisgarh and Jharkhand are the largest iron and steel-producing states in India. Although Maharashtra has limited ironmaking capacity, it is the fourth largest steel producing state due to access to scrap. Gujarat has the largest gas-based capacity deployment in the country. Punjab and Tamil Nadu have a significant deployment of IF capacity due to the availability of scrap.

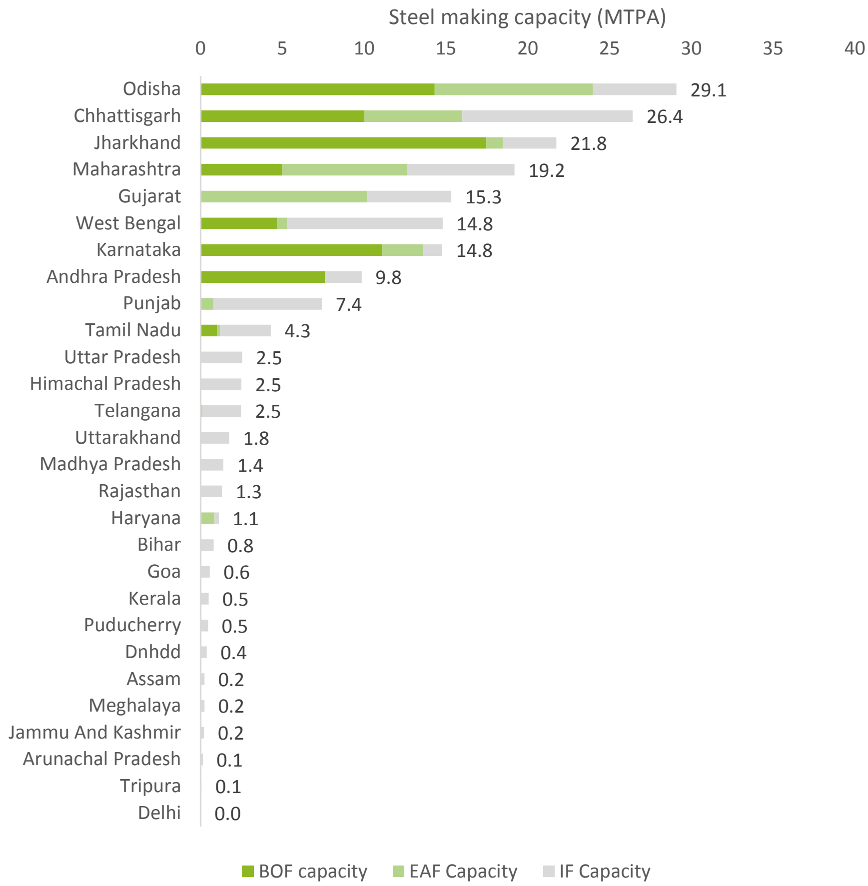


Figure 1.13: *State-wise steel production capacity*

1.2. Overview of the global steel industry

The global crude steel industry is dominated by a handful of countries, with China leading the way at 54% of total production. India follows, contributing 7.4%, as shown in Figure 1.14. The European Union (EU) block of 27 countries collectively accounts for 136.3 MT, which is 7.2 % of the crude steel production[19].

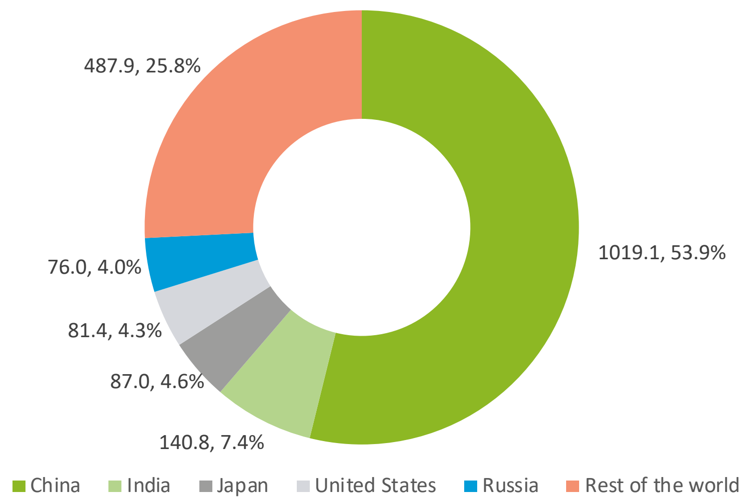


Figure 1.14: *Crude steel production (MT) and share (%) globally, 2023*[20]

A similar trend is observed with regard to hot metal production, with China producing 864 MT, followed by 80 MT in India. Japan, Russia and South Korea cumulatively produced 158 MT, while the rest of the world, produced 200 MT of hot metal. In addition, India and Iran also produced 42.3 MT and 32.9 MT of DRI, respectively. This is depicted in Figure 1.15

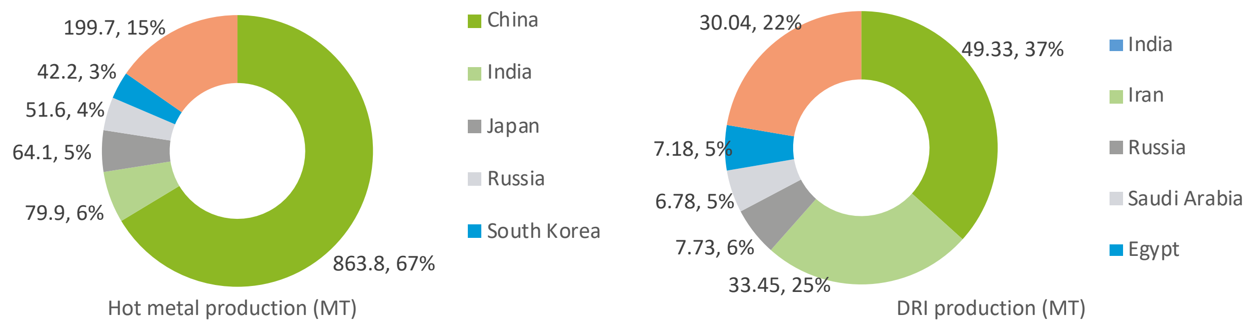


Figure 1.15: *Hot metal and DRI production in the world, 2023*[21]

Table 1.6 shows the share of crude steel across different routes. In nearly all countries under consideration, except India and the United States, the oxygen route dominates, with China topping the list at approximately 91%, Japan at 73%, and Russia at 65%. In contrast, in India, 54.2% of crude steel production is through the electric route, and in the United States, this share is even higher at 69%, with the remaining coming from the oxygen route in both countries. However, for the rest of the world, the major share of crude steel production is through the oxygen route at 72%.

Table 1.6: *Crude steel production by process, 2023*[22]

Sr. No.	Country	Million tonnes	Oxygen %	Electric %	Other %
1	China	1019.10	90.1%	9.9%	-
2	India	140.80	43.6%	56.4%	-
3	Japan	87.00	73.8%	26.2%	-

Sr. No.	Country	Million tonnes	Oxygen %	Electric %	Other %
4	United States	81.40	31.7%	68.3%	-
5	Russia	76.00	65.1%	32.0%	2.90%
6	Rest of the world	487.90	71.5%	28.2%	0.4%

Note: *Data shown for the calendar year 2023*

Figure 1.16 shows a plot of the share of iron, steel and metallic inputs across various production pathways in 2022 across the world. It is evident that the BF route is the most dominant route for ironmaking globally. The split between coal and gas-based DRI is not available. Therefore, DRI is covered under one broad category. Similarly, the BOF route is the most dominant route for steelmaking. The share of scrap in the overall metallic input is significantly higher at 31% than the 21% observed in India.

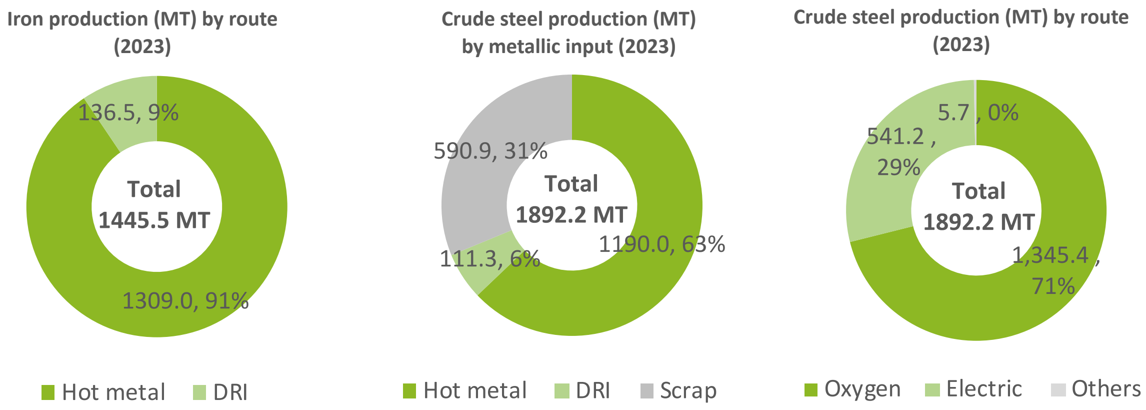


Figure 1.16: *Route-wise share of iron production, steel production and metallic input for steel production in the world*[23]

Figure 1.17 shows the share of scrap in the total steel production across select countries. EU, United States of America (USA), Russia and Turkey have a significant share of scrap-based steel production. However, developing countries like India and China have lower scrap availability, and hence, the share of scrap-based production is significantly lower than that of developed countries. Consequently, the emissions from steelmaking will be higher in developing countries like India, as scrap-based steel production has significantly lower emissions than primary steelmaking processes.

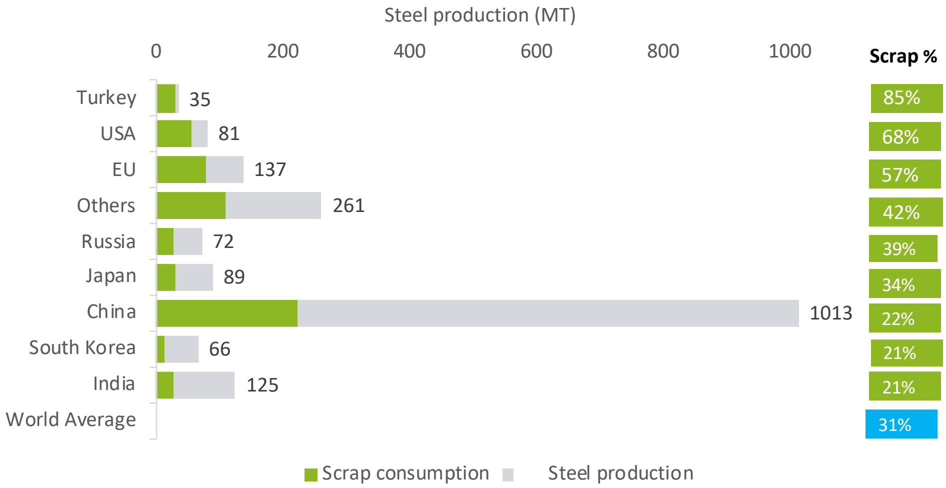


Figure 1.17: *Global overview of scrap consumption for steel production in 2022*[24]

1.3. Review of CO_2 Emissions in the steel sector

Steel production is an energy and emission-intensive process. The iron and steel industry, recognised as a challenging to decarbonise or 'hard-to-abate' sector of the economy, contributes approximately 8%[25] to global CO_2 emissions. On a national level, the steel sector contributes about 10-12% to the total CO_2 emissions.

In the primary steelmaking process, carbon is used in two forms: one as a reducing agent and the other for meeting energy needs. In a blast furnace, coking coal is used as a reducing agent, whereas pulverised coal is used to meet the energy requirements of the process. Similarly, in a rotary kiln used for DRI production, feed coal (thermal) is used as a reducing agent, while fuel coal (thermal) is used to meet the energy requirements of the process. In addition, carbon is also used to drive the sintering process, convert coking coal to coke, produce power in captive power plants, and meet other auxiliary energy needs.

If the carbon, as described above, is sourced from coal, emissions would be high. Replacing it with natural gas significantly reduces emissions by almost half. Further, transitioning from carbon to hydrogen, which can also serve the same function, reduces the emission to near zero, theoretically. Additionally, part of the energy requirement is met through electric power, with a higher percentage in the EAF/IF pathway and lower in the BOF route. Sourcing this energy from renewables rather than coal also leads to emission reduction. Further, switching from primary production of steel through iron ore to scrap based production significantly reduces the use of carbon, and thus emissions.

1.3.1. Indian Emission Scenario

The Indian steel sector consumes approximately 75 MT of oil equivalent (Mtoe) of total energy (as of 2022), with an average emission intensity of 2.54tCO_2/tcs in 2023-24. This accounts for nearly a quarter of the industrial sector's total energy consumption and has emerged as the primary source of industrial CO_2 emissions. Table 1.7 compiles the emission intensities of steel production through various routes. The coal-based DRI-IF route has the highest emission intensity, while scrap-based steel making is the lowest.

Table 1.7: *Emission Intensity of crude steel production by different process route in 2023-24*

Sr. No.	Process Route	CO_2 emission intensity range (tCO_2/tcs)
1	Coal-based DRI- EIF route	2.70-3.10
2	SynGas (Coal Gasification) based DRI - EAF route	2.50-2.90
3	BF – BOF	2.20 - 2.60
4	Natural Gas-based DRI - EAF route	1.40 - 1.60
5	100% Scrap based steel making through the EAF route	0.55 - 0.65
	Average emission intensity of steel production in India	**2.54**

The emissions intensity from steel production can be quantified along the entire value chain, from upstream operations such as mining and processing to downstream processes like finishing and logistics. Figure 1.18 shows the share of emission intensity across the steel value chain for the coal DRI-IF route. Notably, iron production using coal accounts for 72% of total intensity.

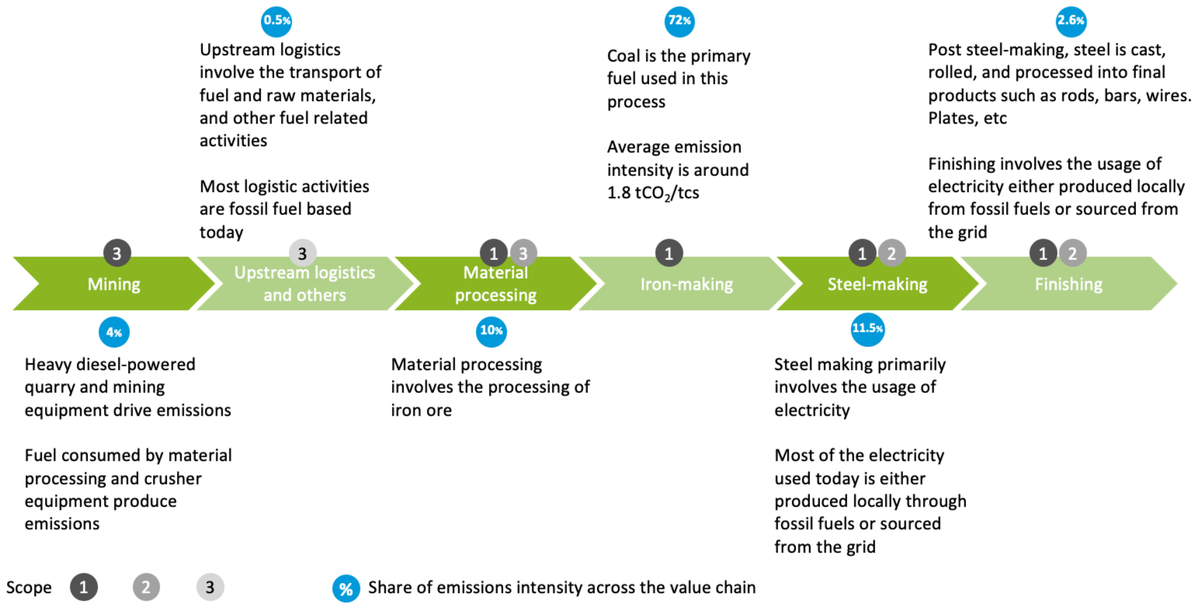


Figure 1.18: *Emission intensity across the entire value chain of steel production through coal DRI-IF route*[26]

1.3.2. Global Scenario

Figure 1.19 indicates the intensity of emissions for steel production across various countries. The emissions intensity varies widely due to several factors, including the proportion of scrap used and the type of fuel utilised. India and China primarily rely on coal to produce steel and have lower scrap availability. Consequently, the emissions intensity of steel from these countries is significantly higher. Russia has access to affordable natural gas, Brazil uses biomass-based fuels, and the USA and Turkey have significant scrap availability. Therefore, the emissions of steel from these countries are significantly lower than that of other developing countries like India and China

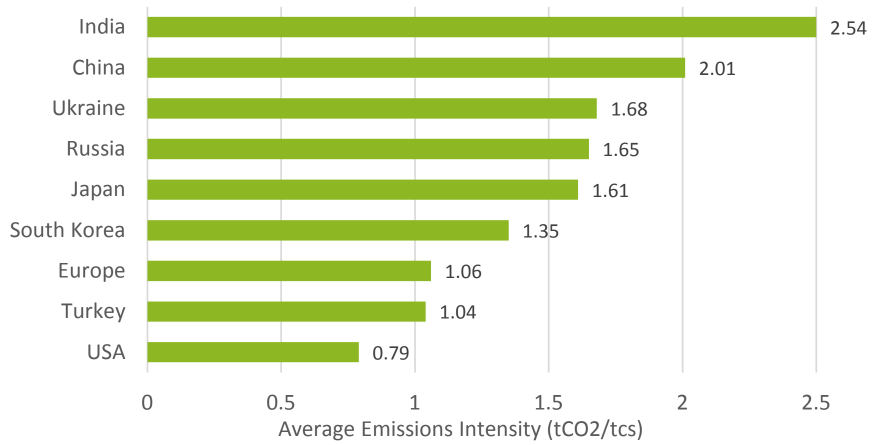


Fig1.19: *Emission intensity of crude steel in major steel producing countries*[27]

In response to the devastating consequences of climate change, major economies globally have pledged to cut carbon emissions. These countries have set a goal for achieving net zero emissions and intermediary milestones for 2030. Table 1.8 lists the decarbonisation goals across a select few large world economies. Most developed countries have targeted achieving net zero emissions by 2050. Developing countries like China and India have set net-zero targets for 2060 and 2070, respectively. Intermediary targets for 2030 have also been detailed in Table 1.8.

***Table 1.8:** Country-wise 2030 emission reduction goals and net zero timeline*[28]

Region	2030 reduction target	Net-zero timeline
US	50-52% Below 2005 Levels by 2030	2050
EU	55% by 2030, compared with 1990 levels	2050
China	Share of non-fossil energy consumption to around 20% by 2030	2060
	Reduce carbon intensity by 60-65% below 2005 levels by 2030, and peak CO_2 emissions by 2030	
Russian Federation	25-30% below 1990 levels by 2030	No commitment
Japan	46% reduction by 2030 from 2013 levels	2050
India	Reduce the emissions intensity of its GDP by 45% by 2030 from the 2005 level	2070
	Non-fossil capacity to be 500 GW by 2030	
	Achieve about 50% of the energy from renewable energy sources	
Canada	30% reduction by 2030 from 2005 levels	2050
Mexico	22% reduction by 2030 from 2000 levels	No Commitment
South Korea	24.4% compared to 2017 levels by 2030	2050
Brazil	37% by 2025 and 43% by 2030 from 2005 levels	2050

The steel units are one of the largest CO_2 emitters from the industrial sector. Consequently, if major economies have to meet their climate goals, then decarbonisation of the steel sector is a must.

1.3.3. Comparison of Indian and Global Scenario

Figure 1.20 compares the Indian steel industry with the global average benchmarks. The global average emissions intensity of steel is 1.91 tCO_2/tcs[29] which is significantly lower than the 2.54 tCO_2/tcs in India. However, the structure of the steel sector in India is significantly different from other countries. Developed countries have reached a plateau in their per capita steel consumption and are likely to witness limited investments in greenfield projects. They have relatively higher share of scrap in total steel production, higher pellet uptake, a less carbon-intensive grid, and access to low-carbon fuels like natural gas at affordable prices. Conversely, India has a lower per capita steel consumption and will have significant investments in greenfield projects. Scrap availability is low, and natural gas is significantly expensive. Additionally, India has low-grade coal and iron ore, whose usage increases overall energy consumption and emissions. Furthermore, ISPs prefer to use captive coal-based thermal power plants, that have significantly higher emissions intensity compared to cleaner grids in developed countries. In summary, the Indian steel industry is constrained to use coal-based blast furnaces and rotary kilns for steelmaking due to a lack of affordable alternatives. Consequently, the emission intensity of steel produced in India is significantly higher than the global average.

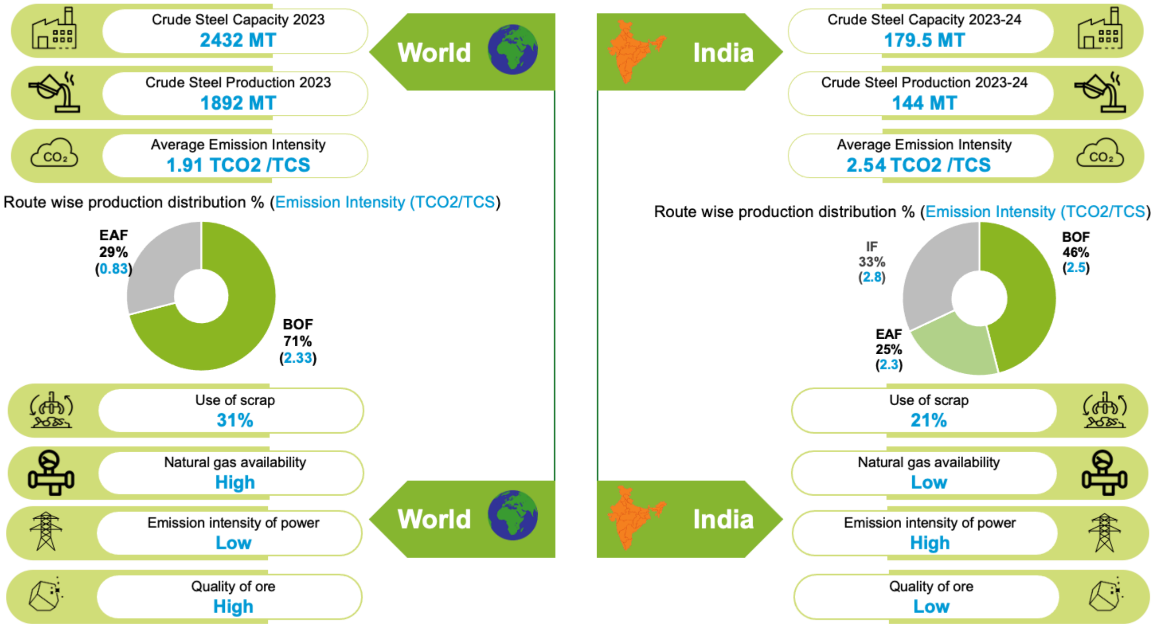


Figure 1.20: Comparison of the global and Indian scenarios across various indicators in steel production[30,31,32]

1.4. Government of India's initiatives to combat climate change in the iron and steel sector

In light of India's commitments[33] to climate goals at various international forums[34], the Government of India has been proactively developing policies to decarbonise the economy. The major government initiatives, which have the potential for decarbonising the steel industry are shown in Figure 1.21.

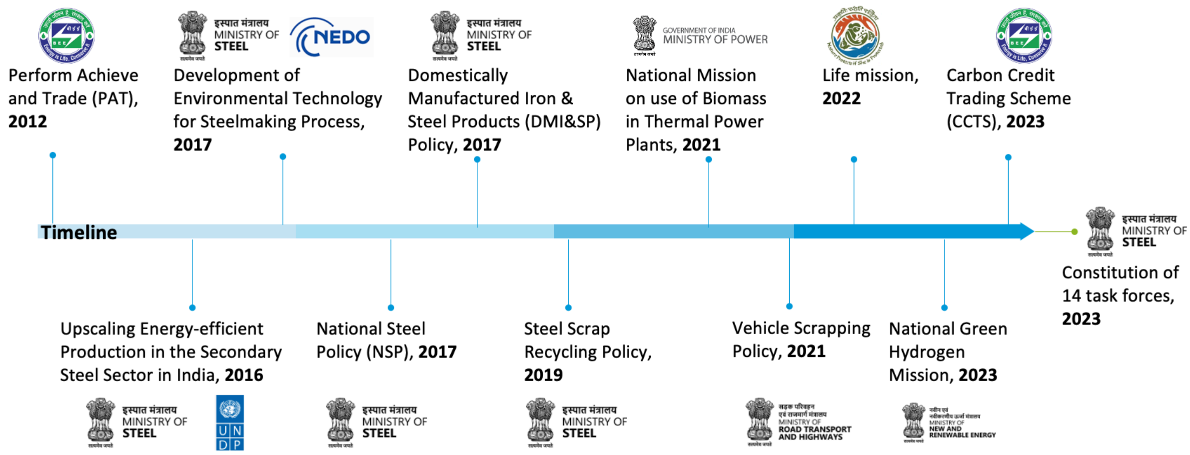


Figure 1.21: Timeline of major government initiatives aiding decarbonisation of the Indian iron and steel industry

1.4.1. Perform Achieve and Trade (PAT) (2012-current)

The Government of India's PAT (Perform, Achieve and Trade) scheme, introduced in 2012, is a key initiative for promoting energy efficiency and reducing carbon emissions in the industrial sector. Developed under the National Mission for Enhanced Energy Efficiency (NMEEE) and administered by the Bureau of Energy Efficiency (BEE), the scheme encourages industries to adopt energy-efficient technologies and practices. Industries complying with Specific Energy Consumption (SEC) targets are awarded tradable Energy Saving Certificates (ECerts), incentivising investment in energy-efficient processes. The PAT scheme, leveraging market-based mechanisms, has significantly improved energy efficiency, thus achieving emission reduction in the Indian iron and steel sector, with many industries surpassing their energy-saving targets. This has led to substantial reductions in energy consumption and greenhouse gas emissions, contributing to India's sustainable development goals.

1.4.2. MoS-UNDP project for upscaling Energy-efficient Production in the Secondary Steel Sector in India (2013-2015)

In India small-scale steel re-rolling mills – which produce nearly two-thirds[35] of long steel products in the country – are responsible for high levels of pollution and inefficient resource utilisation. Overall, they consume about 1%[36] of India's energy. Through an innovative partnership between United Nations Development Programme (UNDP) and the Ministry of Steel, supported by Global Environment Facility (GEF) and AusAid, Energy Efficiency Technologies were implemented in across 355 Mini Steel Mills (Re-rolling Mills & Induction Furnaces). This initiative reduced specific energy consumption by 20% to 30% and reduced CO_2 emissions by about 400,000 tonnes annually. Subsequently, the industry on a continual basis, is self-replicating these technologies with their own funding. Out of around 1200 rolling mill units, these proven Energy Efficient Technologies have been replicated in more than 800 steel mills.

1.4.3. Renewable energy

India has abundant solar and wind energy generation potential. According to the National Institute of Solar Energy (NISE) assessment, India has a solar potential of about 748 GW[37] (assuming 3% of the wasteland area will be covered by solar photovoltaic (PV) modules). Likewise, the National Institute of Wind Energy (NIWE) assessment indicates a gross wind power potential of 695.50 GW at 120 meters and 1163.90 GW at 150 meters above ground level[38]. As of December 2023, India has an installed capacity of 74.31 GW of solar power and 44.97 GW of wind power[39], including captive and grid capacity. Further, India's RE capacity has grown from 76.37 GW in March 2014 to 178.98 GW in October 2023[40]. This represents significant progress in capacity addition. India also ranked fourth globally in total installed RE capacity in 2023.

Starting with policies such as the Electricity Act 2003[41], followed by the National Electricity Policy 2005[42], Tariff Policy 2006[43], and Tariff Policy 2016[44], the government has made substantial efforts to promote RE. These measures include improving grid connectivity, facilitating the sale of electricity, mandating the purchase electricity from renewable sources, and issuing Renewable Energy Certificates (REC) for compliance with Renewable Purchase Obligations (RPO). These initiatives have fostered competition and helped reduce the capital costs of RE projects. REC began trading in March 2011 on the Indian Energy Exchange (IEX) platform and the Power Exchange of India (PXI). To boost round-the-clock RE deployment in India, targets for purchase obligations from storage have also been set with an Energy Storage Obligation (ESO) of 4% in 2030[45]. RE will play a key role in reducing the emission intensity of the steel industry.

1.4.4. MoS - NEDO (Japan) Partnership(2001-Present)

Indian industries have implemented various energy efficiency measures in partnership with the New Energy and Industrial Technology Development Organization (NEDO)[46]. With financial assistance from NEDO, Government of Japan, four model projects have been implemented. The first project involved the installation of a blast furnace hot stove waste gas recovery system at Tata Steel Limited resulting in energy savings of 8,110 toe/year and CO_2 emission reduction of 25,090 tonnes/yr. The second project included the installation of a coke dry quenching (CDQ) at the same facility, leading to energy savings of 50,000 toe/year and a CO_2 emission reduction of 137,000 tonnes/yr. The third project involved the installation of a sinter cooler waste heat recovery system at RashtriyaIspat Nigam Limited, achieving energy savings of 39,000 toe/year and CO_2 emission reduction of 117,000 tonnes/yr. Lastly, an energy monitoring and management system is under implementation at SAIL, which is expected to result in energy savings of 185220 tonnes/year and a CO_2 emissions reduction by 32017 tonnes/year.

1.4.5. National Steel Policy, 2017

National Steel Policy 2017 provides a broad roadmap for encouraging long-term growth for the Indian steel industry, with a focus on the expansion of the Micro, Small, and Medium Enterprise (MSME) sector, improving raw material security, enhancing R&D activities, and reducing import dependency and cost of production. The policy[47] has set a target to increase India's steel capacity to 300 MTPA by 2030. It also aims to increase per capita steel consumption to 160 kg by 2030-31 and to domestically meet the entire demand for high-grade automotive steel, electrical steel, special steels and alloys for strategic applications by 2030-31. In the long term, it sets out a roadmap for the Indian steel industry to have a wider presence globally in value-added, high-grade steel by encouraging the industry to be a world leader in energy-efficient, low-carbon footprint steel production.

1.4.6. Domestically Manufactured Iron and Steel Products (DMI&SP) (2017-present)

The government introduced Domestically Manufactured Iron and Steel Products (DMI&SP) Policy[48] on 8 May 2017 to provide preference to domestically produced iron and steel material in government tenders, thereby effectively creating domestic demand. DMI&SP have been defined as those iron and steel products in which a minimum value addition of 15% has taken place domestically. The policy applies to all such projects and procurements where the aggregated estimated value of the "iron & steel products" is either INR 50 crores or more. The policy covers a list of 49 manufactured iron and steel products and also includes capital goods used for their manufacturing. The policy envisages to promote the growth and development of the domestic steel industry and reduce the inclination to use low-quality and low-cost imported steel in government-funded projects. Figure 1.22 shows that after the implementation of DMI&SP, the export of domestically produced finished steel products has gradually increased while imports have simultaneously reduced.

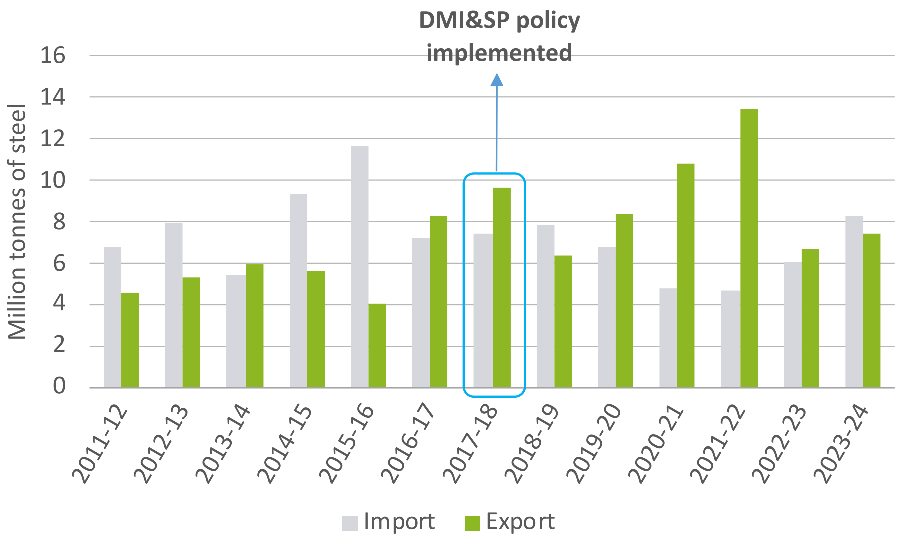


Figure 1.22: *Effects of DMI&SP on Import and Exports of Steel*

1.4.7. Steel Scrap Recycling Policy (2019-present)

Scrap is a crucial decarbonisation lever for the steel industry. Each ton of scrap saves 1.1 tonnes of iron ore, 630 kg of coking coal, and 55 kg of limestone while also reducing water consumption and GHG emissions by 40% and 58%, respectively, compared to producing steel from iron ore[49]. To facilitate the generation of scrap and enable its use, the steel scrap recycling policy aims to:

1. Promote the establishment of metal scrapping centres in India for scientific processing and recycling of ferrous scrap generated from various sources and products.
2. Reduce the dependence on imported coal and iron ore by increasing the availability of domestically generated scrap.
3. Enhance the quality and availability of steel scrap for the secondary steel sector.
4. Minimise the environmental impact of steel production by reducing the energy consumption and GHG emissions.

1.4.8. Vehicle Scrappage Policy (2021-present)

The vehicle scrappage policy, announced in March 2021 by the Ministry of Road Transport and Highways (MoRTH)[50], aims for deregistering and scrapping of vehicles. It also included several benefits for the scrapping of vehicles, such as fixing scrap value of old vehicles, providing incentives such as road tax rebate, discounts, waving of registration fees etc. on purchase of new vehicles on scrapping of older ones. It is expected that the vehicle scrapping policy will increase the availability of scrap from the automobile sector. The availability of domestic scrap can help accelerate the transitions in the Indian steel sector and reduce emissions arising from the primary steelmaking processes.

1.4.9. National Mission on Use of Biomass in Thermal Power Plants (2021-present)

The National Mission on Use of Biomass in Thermal Power Plants[51] was constituted by the Ministry of Power in July 2021 to address air pollution caused by farm stubble burning and reduce carbon footprints associated with thermal power generation. The mission aims to utilise agro residue-based pellets/ torrefied pellets for power generation through biomass co-firing. Around 97000 Tonnes of agro-residue-based biomass have been successfully co-fired in coal-based thermal power plants by March 2023[52].

The mission aims to increase co-firing levels from the current 5% to a higher level, undertake R&D activities in design, address constraints in the supply chain and tackle regulatory issues related to co-firing. Increasing the use of biomass in thermal power plants through the policy will aid in strengthening the necessary ecosystem and improve supply chain linkages for wider biomass adoption in the steel industry. Biomass can be used in blast furnaces and potentially in rotary kilns to reduce the dependency on imported coal. It can also be used in captive thermal power plants in the steel industry to reduce carbon emissions.

1.4.10. Mission LiFE- Lifestyle for Environment

Mission LiFE[53] is an India-led global mass movement introduced in November 2021 to nudge individual and community action to protect and preserve the environment through mindful and deliberate utilisation instead of mindless and destructive consumption. It aims to inspire at least one billion Indians and other global citizens to take personal and collective responsibility for the environment. It also targets making at least 80% of all villages and urban local bodies in India environment-friendly by 2028. The mission plans to create and nurture a global network of individuals, called 'Pro-Planet People' (P3), who will have a shared commitment to adopt and promote environmentally friendly lifestyles[54]. Mission LiFE's holistic approach to protecting and preserving the environment can be supported by making changes to building and construction codes and increasing the efficiency in the utilisation of materials, thus creating a pathway for sustainable material use, including steel.

1.4.11. National Green Hydrogen Mission (NGHM)

Green hydrogen is a key lever to address the need for decarbonisation without deindustrialisation. The National Green Hydrogen Mission[55] adopts a multipronged approach to accelerate its adoption. It focuses on incentivising the entire value chain in relevant sectors and thus enabling the consumption of green hydrogen. The mission targets the production of 5 MTPA of green hydrogen using a renewable energy capacity of 125 GW by 2030. It is estimated that this will decrease India's fossil fuel imports saving INR 1 lakh crore from imports while also creating 6 lakh green jobs. The mission has a total budgetary outlay of INR 19,744 crore.

The NGHM specifically earmarks a budget of INR 455 crore for setting up pilot plants that produce and utilise hydrogen in the iron and steel making process. The funding can be utilised to promote the use of hydrogen in DRI production, redesign the EAF where hydrogen-based DRI is to be used, adapt existing DRI plants, and simulate models on the use of hydrogen in iron production. In addition, it can also be utilised to carry out design, technology and machinery modification for use of hydrogen in the blast furnace. At current prices, green hydrogen is not commercially viable for its use in the steel industry. However, with the advent of the NGHM and its aim of replacing grey hydrogen consumption in the fertiliser and refinery sectors with green hydrogen, its cost is expected to decrease due to economies of scale.

1.4.12. Carbon Credit Trading Scheme (CCTS)

The Carbon Credit Trading Scheme (CCTS), was introduced through the Energy Conservation (Amendment) Bill, 2022 and is being implemented by BEE, proposes the establishment of the Indian Carbon Market (ICM), a mechanism to reduce GHG emissions from industrial sectors in India. The ICM will enable domestic companies to trade carbon credits representing the reduction or removal of one ton of CO_2 equivalent. The ICM will be based on the pre-existing PAT scheme, which sets specific energy-saving targets for designated consumers in various sectors. Industries exceeding their targets can earn Carbon Credits, which can then be traded with other designated consumers who are unable to meet their targets. The ICM will expand the scope of the PAT scheme to include emission intensity targets and allow the participation of voluntary buyers and sellers of carbon credits as well.

The transition from the PAT scheme to CCTS entails a strategic evolution aimed at integrating carbon emissions reduction targets into existing energy efficiency policies. Key steps include policy integration, measurement and verification systems, allocation of carbon credits, market development, incentive structures, capacity building, and stakeholder engagement.

The ICM will have significant implications for the steel industry, which is one of the largest and most carbon-intensive sectors in India. The steel industry will have to adopt low-carbon technologies and practices to meet the emission reduction targets and avoid penalties under the ICM. The steel industry will also have to compete with other sectors for the limited supply of carbon credits. Additionally, the ICM will create opportunities for the steel industry to access new sources of finance, innovation, and market access. The steel industry can also leverage the ICM to enhance its competitiveness and reputation in the global market, especially in light of the emerging carbon border adjustment mechanisms in the EU and other regions. The ICM will incentivise the steel industry to invest in advanced technologies, such as green hydrogen and carbon capture, utilisation and storage (CCUS), which will allow for deep decarbonisation of steel production.

1.4.13. Taskforces by the Ministry of Steel

The previous section highlights the Government of India's initiatives and policies that can be leveraged by the steel industry for its decarbonisation. The existing policies cover the expanse of decarbonisation levers like energy efficiency, alternative fuels, renewable energy, and regulatory instruments such as the PAT and CCTS schemes. However, there are gaps that need to be bridged to incentivise and develop the ecosystem, fine-tuning existing policies to accelerate the decarbonisation of the sector and identifying avenues to support the transition.

In response to India's climate commitments and in a bid to create a globally competitive, sustainable steel industry in India, the Ministry of Steel constituted 14 task forces that cover the pertinent aspects of decarbonisation of the steel industry. Figure 1.23 summarises the task forces created by the Ministry of Steel and the corresponding groups they belong to. Each of the task forces was headed by chairpersons of eminence, with extensive experience in the domain of the designated task forces. The members comprised of stakeholders from the industry, technology providers, experts, academia, think tanks, innovators, other ministries, departments, etc. The composition of Taskforces is given in Annexure(1). The initiative focuses on three key pillars: incentivisation and ecosystem development for green steel, levers to enable decarbonisation and support needed for the transition.

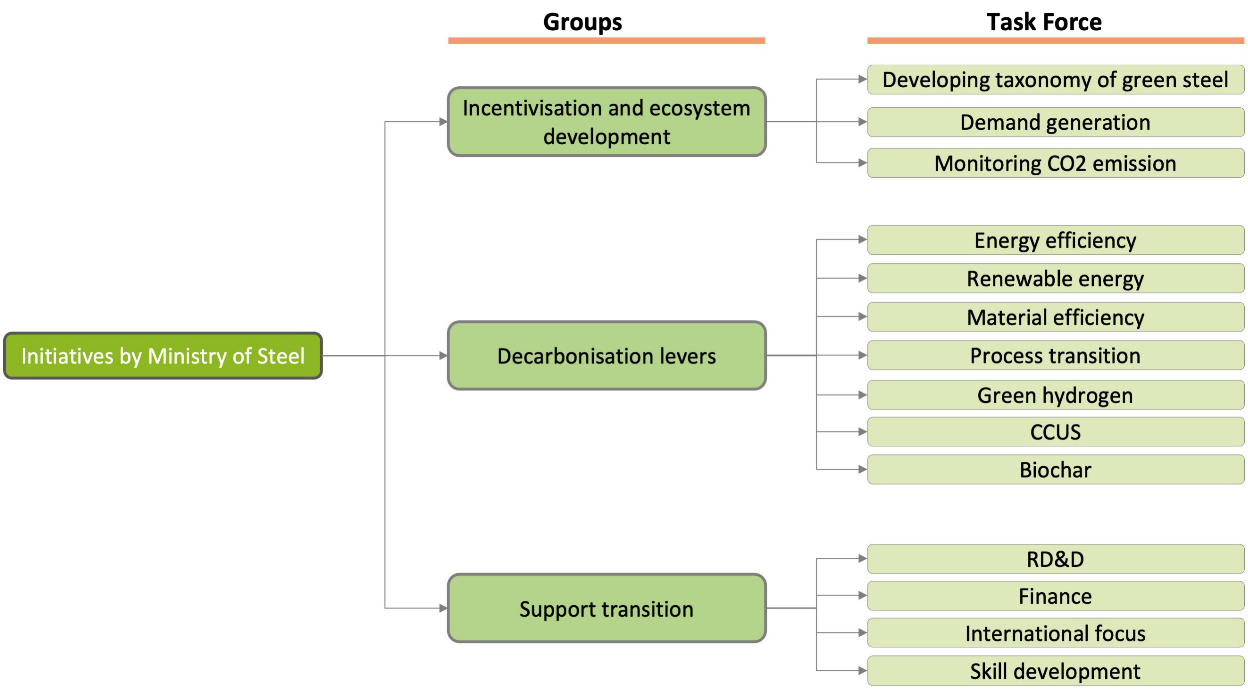


Figure 1.23: *List of task forces constituted by the Ministry of Steel*

Incentivisation and ecosystem development include key aspects like formulating a definition and creating demand for green steel along with a mechanism for measurement, reporting and verification (MRV) of emissions in the steel plants. These are essentially are 'pull' side levers.

In the short term, decarbonisation levers like energy efficiency, material efficiency and renewable energy can reduce the carbon footprint of the Indian steel industry. In the medium term, process transition is essential to use natural gas as a bridge fuel, which can be gradually replaced with new-age fuels like green hydrogen. The uptake of alternative fuels like biomass can also help abate emissions from the Indian steel industry in the medium term. However, in the long term, deep decarbonisation of the legacy steel capacity can only be achieved through the use of green hydrogen and carbon capture, utilisation and storage (CCUS) pathways. These levers, thus create a 'push' effect for the transition.

To enable this transition, accelerating the development of technologies through research and pilot studies is essential. This will eventually lead to the creation of domestic original equipment manufacturers (OEMs) who can provide access to technologies at scale and affordable prices. Ensuring energy transitions in the steel sector would also require access to large amounts of affordable finance and the development of an international collaborative network of stakeholders to mobilise financial and technological resources. Moreover, this transition can only be accelerated by strong focus on Research, Development and Demonstration. The transition will also need the support of a skilled workforce while simultaneously upskilling and reskilling the existing workforce to ensure a just transition. These levers thus act as 'facilitators'.

A brief discussion of the key objectives and findings of the 14 task forces is provided below. The terms of reference (ToR) of these task forces can be found in Annexure 1.

1. **Taxonomy of green steel**

Defining green steel is the first step in developing the ecosystem for steel sector decarbonisation in India. There is no globally accepted definition of green steel that accommodates multiple factors and constraints arising from the use of varying types of raw materials, fuels and production processes. The task force assessed various definitions of green steel globally and proposed guiding principles for defining green steel in the Indian context.

2. **Emissions monitoring**

Reliable data on emissions intensity of steel will be critical for decarbonising the sector. This task force proposed the methodology and institutional mechanism for monitoring, reporting and verification (MRV) of the carbon emissions from the steel sector after a detailed study of international standards and methodologies.

3. **Demand Generation**

Green steel will likely be available at a premium over conventionally produced steel. Therefore, demand generation is especially important for a price-sensitive market like India. This task force studied the current demand for steel in India across various end users, evaluated future trends in steel demand in India and studied international efforts for green procurement. Finally, the task force identified mechanisms for creating the demand-side pull for green steel in India through green public procurement (GPP) and private commitments.

4. **Energy Efficiency**

Energy efficiency is a low-hanging fruit for mitigating emissions from the steel sector. This task force identified the best available technologies (BAT) for the steel sector, evaluated their penetration levels and identified solutions for accelerating their deployment in the steel industry. Further, the task force identified solutions to encourage the adoption of energy efficiency measures for ISPs and SSIs.

5. **Renewable energy transition**

Switching from captive/grid power to renewable energy does not require any change to the existing steel production process. This task force evaluated the process-wise power requirement for the steel industry, studied the penetration level and identified challenges faced by the industry in adopting RE. Finally, the task force prepared an action plan for accelerating the uptake of RE in the steel industry.

6. **Material Efficiency**

This task force evaluated the role of material efficiency measures like beneficiation, pelletisation and scrap use in mitigating emissions from the steel sector. The task force identified the current level of beneficiation and pellet uptake by the steel industry, assessed the impact of utilising beneficiated material on carbon emissions and prepared a roadmap and action items for facilitating increased uptake of beneficiated ore, pellets and scrap in the sector.

7. **Green hydrogen**

Green hydrogen offers an avenue for fossil-free steelmaking. This task force identified and reviewed the global status of utilisation of green hydrogen in the steel industry, assessed the potentiality of its adoption across various production pathways in India, evaluated the techno-economic implications and emissions reduction benefits from its use in the industry and explored the possibilities for international cooperation for accelerating its uptake in the sector.

8. **Carbon capture utilisation and Storage (CCUS)**

CCUS will be imperative for deep decarbonisation of the existing pathways for steel production in India. This task force collated various international and national efforts on CCUS in the steel sector, evaluated the techno-economic aspects and suggested a roadmap for its deployment in the country. It also recommended hubs and clusters for piloting CCS projects across the industrial and power sectors.

9. **Process Transition from Coal based DRI to Gas Based DRI**

Natural gas is a bridge fuel for green hydrogen in the steel sector. This task force evaluated the possibility of shifting away from rotary kilns to shaft furnaces for a seamless transition to green hydrogen. The task force assessed the steel industry's appetite for natural gas and identified measures to accelerate the process transition through other options like industrial off-gases, syngas, and coal bed methane.

10. **Research Development & Demonstration (RD&D)**

As with any technological endeavour, new research in science and technology will be pivotal to decarbonising the Indian steel industry. This task force enlisted the Indian research institutes involved in the development of green technologies, studied the international scenario and alternative routes for steelmaking and the feasibility of their adoption in India. Further, the task force identified the RD&D and pilot projects for the sector and also evaluated the corresponding budgetary requirements.

11. **Finance**

Sustainable finance would be the key to enabling transition in the steel sector. This task force identified various innovative financing mechanism for fulfilling the investment requirements in the industry, especially for SSIs. Further, the task force suggested measures for increased adoption of green finance in the steel sector.

12. **International Focus**

International collaboration can help accelerate the transitions in the steel sector. This task force identified global initiatives for decarbonising the steel sector and proposed strategies for engaging with these efforts across various dimensions.

13. **Skill Development**

Skill development would be critical for a just transition in the steel industry. This task force proposed a framework for reskilling and upskilling of the workforce involved in the steel sector, especially SSIs. The task force suggested solutions for filling the gaps through trainings, development of course curriculum and infrastructure requirements.

14. **Biochar and relevant products**

Biomass and relevant products like biochar can play a significant role in mitigating emissions from the steel sector. It can also help reduce India's dependence on imported fossil fuels while creating jobs and enabling economic growth in the rural parts of the country. This task force evaluated the role of biomass in the steel sector by assessing its uptake potential across various production pathways, techno-economic evaluation and emissions mitigation potential. The task force also recommended strategies and pathways for accelerating its uptake in the sector.

This report is an outcome of the key findings from the 14 task forces and contains a harmonised action plan for steel decarbonisation in the country.

1.5. Initiatives by the Indian steel industry

The Indian steel industry has taken multiple initiatives to decarbonise its production process. Table 1.9 lists the net-zero goals of large ISPs in India as well as the initiatives taken by the major steel producers to decarbonise their production processes.

Table 1.9: *Net zero goals of major Indian steel producers*

Sr. No	Company name	Emission intensity (tCO_2/tcs)	Climate goals and sustainability initiatives
1	JSW steel	2.36	• JSW Steel has set a target of reducing the emissions intensity of steel by 42% till FY 2030 from the base year of 2021 and achieve net zero by 2050. • JSW has set a target of achieving 20 GW of renewable energy capacity and 40 GWh of storage capacity by 2030. • JSW is also focusing on raw material beneficiation, scrap-based steel and green hydrogen uptake in the steel sector. • JSW has implemented a pilot-scale carbon capture unit in the DRI plant in Dolvi, at 100 TPD.
2	JSPL	2.59	• JSPL aims to achieve 35% reduction in carbon emissions by 2030 and to become net-zero by 2047. • JSPL's decarbonisation strategy focuses on carbon minimisation, carbon avoidance and carbon circularity, carbon capturing, routes of carbon utilisation/sequestration, carbon sequestration/sink. • JSPL is operating 2000 TPD carbon capture unit across its syngas plant and 1500 TPD carbon capture unit in the DRI section.

Sr. No	Company name	Emission intensity (tCO_2/tcs)	Climate goals and sustainability initiatives
3	JSL	2.1	• JSL has committed to be net zero emissions steel company by 2050. • JSL is underway to achieve a 300 MW combined renewable energy capacity by 2026-27. • JSL has inaugurated a plant to produce green hydrogen, currently to be used for annealing, with view to expand applications across production chain.
4	AM/NS	2-2.5	• AM/NS targets reducing emissions intensity of steel by 20% by 2030 • AM/NS has focused on energy efficiency measures such as new nozzles were added to water spray to enhance cooling effectiveness, developed a chemically modified organic binder suitable for pelletising high alumina iron ore from Odisha • Use of novel beneficiation techniques to reduce gangue contents in ore.
5	Tata Steel	2.32	• Tata Steel has committed to reducing its emissions intensity below 1.8 tCO_2/tcs by 2030 and achieve net zero by 2045. • Tata Steel is implementing technologies such as coal bed methane (CBM) injection, hydrogen injection in blast furnaces, and commissioning of carbon capture plants.
6	SAIL	2.49	• SAIL has committed to reducing its emissions intensity to less than 2 tCO_2/tcs by 2030. • SAIL is focussing on deploying energy efficiency measures to mitigate emissions from the steelmaking process.
7	Kalyani steel	0.19	• Kalyani Steel offers 'Kalyani FeRRESTA' and 'Kalyani FeRRESTA PLUS' steel products that have very low carbon emissions intensity. • Kalyani Steel uses 100% RE and more than 70% recycled scrap material to produce low-carbon emissions steel.

CHAPTER 2

DEVELOPING TAXONOMY FOR GREEN STEEL

2.1. Introduction

The definition of green steel is a prerequisite for developing a coherent policy for decarbonising the sector and creating demand for products with green attributes. A clear, credible and standardised taxonomy provides a common language and framework for producing low-carbon emission steel, differentiating the market for green steel from conventional steel and enabling its procurement. Further, a green steel taxonomy is essential for drawing in financial support for the production of greener steel. It is also important to foster international collaboration and cooperation in advancing sustainable steel production and trade. While developing the definition of green steel is not a direct tool for reducing carbon emissions in the steel sector, it is a crucial enabler of the transition that supports 'push' and 'pull' factors for decarbonisation.

India has a functioning market for the trade in Energy Savings Certificates (ECerts) arising from the success of the PAT scheme. The BEE regularly collects data regarding plant-level energy consumption, which can be used for measuring emissions intensity of steel. The Government of India has notified the Carbon Credit Trading Scheme (CCTS) that will enable the creation of Indian Carbon Markets (ICM). BEE is already developing sectoral and plant-level targets for decarbonising the steel sector. Further, ISPs in India voluntarily disclose data regarding their emissions intensity in their sustainability reports and as a part of Worldsteel's Climate Action Data Collection[1]. However, a crucial gap remains due to the absence of an accepted and robust definition of 'green steel' in India. This lack of clarity creates challenges in comparing the environmental performance and decarbonisation initiatives of different steel producers. It hinders effective policy implementation, thus leading to uncertainty for producers seeking to invest in green technologies and consumers seeking environmentally friendly options.

Globally, there is no common, accepted definition of green steel yet, although multiple organisations and various countries are working on developing one. With this background, the chapter discusses various efforts taken across the globe, assesses their suitability to India and lists possible approaches for defining green steel in the Indian context to enable transitions in the sector and catalyse the green steel market in the country.

2.2. Developing taxonomy for green steel

Developing a taxonomy for green steel involves multiple components, from coining an accepted terminology to having a reliable certification system. This section briefly discusses the steps for developing a green taxonomy in India.

1. **Terminology:** It is important to coin the correct terminology to enable trade in green steel. Multiple terminologies like low-carbon steel, green/sustainable/responsible steel, net-zero/carbon-neutral steel, low(er) embodied carbon steel, near-zero steel, zero-carbon steel, and fossil-free steel have been discussed globally. However, there is no globally accepted terminology yet. The first step towards developing a taxonomy would be finalising the terminology. In the absence of a globally accepted taxonomy, "green steel" has been used as a terminology for decarbonised steel in this report. The word "Green" does not indicate near-zero emissions. It is, however, indicative of incremental efforts to decarbonise the steel sector.
2. **Definition:** This is the most critical step in defining green steel. Multiple definitions of green (or any related terminology) steel have been proposed globally. Given the heterogeneity, India's national climate commitments, and challenges related to fuel, raw material, scrap, power availability, etc., faced by the Indian steel industry, it would be important to develop a green steel definition for the Indian context.
3. **Benchmarking:** This step involves establishing the current emissions intensity of steel, at sectoral and

plant levels. Further, based on India's climate commitments, the next step would be to identify emissions intensity milestones for intermediate years to ensure that the sector is on track to reducing its carbon emissions.

4. **Scoping of emissions:** The scope of emissions - scopes 1, 2 and 3 - should be decided while setting up targets on the emissions intensity of steel. Establishing a level playing field for all steel plants across various production pathways is important. For example, one steel plant might source beneficiated raw material from an external supplier, while the other might have an in-house beneficiation unit. Consequently, if the scope of emissions intensity is decided purely based on the physical plant boundaries, then it might be unfair for the steel plant with an in-house beneficiation unit. Therefore, establishing an emissions boundary will be integral to this effort.

5. **Monitoring, reporting, and verification (MRV):** A well-functioning market for green steel can only be developed based on transparency related to the emission intensity of steel. A robust MRV framework and methodology, along with accredited agencies capable of implementing it, will be instrumental in developing investors' and stakeholders' confidence in decarbonising the sector.

6. **Certification:** Green steel will most likely be available at a premium over the conventionally produced steel. Therefore, the end-consumers of green steel will need a guarantee of the green attributes of the product. Certification from accredited agencies through a proper governance structure for the steel industry would be imperative for creating the demand side pull in the sector. Certification of green steel would include identifying certification bodies in India, developing mechanisms for banking green steel certificates, labelling products, etc.

2.3. Review of suggested green steel definitions across the globe

This section of the report summarises the major definitions of green (or any other related terminology) steel. Table 2.1 lists the key definitions of green (or other terminologies) steel that are evolving globally and identifies the challenges in directly adopting them in India. A detailed description of these definitions can be found in the references provided in Table 2.1.

Table 2.1: *Summary of key definitions of green (or other terminologies) steel globally*

S. No.	Organisation / Consortium	Critical review in the India Context
1	International Energy Agency (IEA)	The International Energy Agency (IEA) is a Paris-based international intergovernmental organisation of 29 industrialised countries under the Organisation for Economic Development and Cooperation (OECD). IEA follows the sliding scale methodology for the emission intensity of steel. The targets for the intensity of steel emissions are set based on the percentage of scrap steel used for steelmaking. As per this definition, a steel plant with a higher scrap share will have to meet a lower emissions intensity target than a plant that has lower scrap use. Essentially, this definition negates the use of scrap as a decarbonisation lever and intends to create a level-playing field between the primary and scrap-based steel producers. Further, the IEA definition also quantifies the amount of low-emission steel produced based on the actual emissions intensity and targeted intensity per the sliding scale.

S. No.	Organisation / Consortium	Critical review in the India Context
		A globally accepted sliding scale will benefit a scrap-deficient country like India. Countries that, on average, have higher scrap share will have to meet stringent emissions intensity targets compared to India. However, a challenge with global acceptance of this definition arises from different national commitments to achieve net zero goals. India has committed to achieving net zero by 2070, whereas developed countries plan to reach net zero by 2050. Therefore, having an equivalence between countries with varying net zero targets might be a challenge for global acceptance of this methodology. Another challenge with the sliding scale approach is that it does not differentiate between various processes and fuels used for producing steel. For example, the targets on emissions intensity for coal-based blast furnaces, rotary kilns and natural-gas-based shaft furnaces will remain the same if they use the same share of scrap. Steel plants located in a few countries might have access to affordable natural gas, while Indian steel plants do not have access to it. Consequently, coal-based Indian steel plants might not be able to compete with gas-based DRI plants located in the developed world for the same emissions intensity values (assuming similar scrap uptake) and risk losing market share. This will be detrimental to the interest of Indian steel plants. Therefore, a globally acceptable definition of green steel should account for the disparity in resource availability across countries to ensure a just and equitable transition in the steel sector. The IEA definition differentiates the emission intensity targets based on the quantum of scrap use. Given that scrap is a key decarbonisation lever, especially in a country like India, where its availability is limited, it is important that steel scrap may not be disincentivised. Further, in India, scrap-based IFs are operated by smaller players that have limited avenues to decarbonise.
2	Responsible Steel	ResponsibleSteel, headquartered in Australia, is a global, not-for-profit organisation created to maximise steel's contribution to a sustainable world. ResponsibleSteel has proposed a sliding scale for emission intensity targets of steel. Similar to the IEA approach, ResponsibleSteel considers scope 1, scope 2, and upstream scope 3 emissions to estimate the overall emission intensity of steel[2]. However, unlike the IEA approach, ResponsibleSteel does not quantify the amount of low-emission steel produced. The challenges with ResponsibleSteel's approach to setting targets on emissions intensity are similar to the sliding scale proposed by IEA. Further, the inclusion of upstream scope 3 emissions in accounting is also challenging given that India is significantly import-dependent on coking coal and natural gas, the emissions of which cannot be directly attributed to steel produced within India. It might also be challenging to measure the emissions intensity of fuels and raw materials produced in another country.

S. No.	Organisation / Consortium	Critical review in the India Context
3	ArcelorMittal	ArcelorMittal is a Luxembourg-based multinational steel manufacturing corporation headquartered in Luxembourg City. ArcelorMittal has identified six bands (A-E) of steel based on the targetted emissions intensity and scrap share[3]. The approach is based on the sliding scale principle proposed by IEA and ResponsibleSteel, which negates the effect of using scrap as a decarbonisation lever. However, unlike the IEA definition that quantifies the amount of green steel produced, the ArcelorMittal definition only proposes bands. The challenges with ArcelorMittal's approach to setting targets on emissions intensity are similar to the sliding scale proposed by IEA and ResponsibleSteel. Further, a band-based approach has additional challenges, given that there is no incentive for an industry to reduce its emissions intensity if it reaches a particular band. For example, there is no incentive for a steel plant to reduce its emissions intensity within band D of the proposed definition unless it wants to meet the criteria set for band C.
4	HYBRIT	HYBRIT – Hydrogen Breakthrough Ironmaking Technology – is a joint venture, based out of Sweden, between SSAB, LKAB and Vattenfall, aiming to replace coal with hydrogen in the steelmaking process. The HYBRIT project defines 'fossil-free' steelmaking as using non-fossil sources like green hydrogen and renewable energy to produce steel[4]. However, given that green hydrogen is significantly expensive today, such 'fossil-free' steelmaking can only be considered in the medium-to-long term after the cost of green hydrogen reduces.
5	Industrial Deep Decarbonisation Initiative (IDDI)	The Clean Energy Ministerial - Industrial Deep Decarbonisation Initiative (IDDI) is a global coalition of public and private organisations that are working to stimulate demand for low-carbon industrial materials. It is co-led by the UK and India, and current members include Canada, Germany, Japan, Saudi Arabia, Sweden, the United Arab Emirates (UAE), and the United States. IDDI proposes to directly adopt the IEA definition for low emission and near-zero steel production as a robust starting point[5]. IDDI is now focussing on harmonising Product Category Rules (PCRs), refinement and extension of IEA definitions along the value chain, the GHG emission boundary definition for each product stage, and the data quality requirements on the use of facility-specific GHG reporting data and background data.

S. No.	Organisation / Consortium	Critical review in the India Context
6	First Movers Coalition (FMC)	First Movers Coalition (FMC) is an initiative by the Geneva-based World Economic Forum (WEF) that aims to advance the most critical, emerging climate technologies by leveraging members' collective purchasing power. FMC[6] followed the sliding scale methodology proposed by IEA to define near-zero emissions steel. As per FMC definition, near-zero emissions steel has an emissions footprint of <0.4 t (with 0% scrap inputs) to <0.1 t (with 100% scrap inputs) of CO_2 per tonne of crude steel produced. The approach adopted by FMC does not incentivise incremental decarbonisation but focuses on achieving absolute near-zero emissions of steel production. Achieving near-zero emissions, irrespective of the corrections on the emissions intensity targets with scrap share, will be very challenging in India due to the presence of coal-based blast furnaces and rotary kilns that significantly depend on the CCUS route for deep decarbonisation. The CCUS ecosystem is still evolving in India and will take time to achieve scale and commercialisation.
7	Global Steel Climate Council (GSCC)	The Global Steel Climate Council (GSCC) is a Canada-based non-profit association organised to advance climate strategy by establishing standards and advocating for carbon emissions reductions by members of the steel industry. The GSCC standard provides a set of criteria for evaluating and certifying flat and long steel products based on their carbon intensity. GSCC has proposed different emissions reduction trajectories for long and flat products[7] for 5 years from 2022 to 2050. According to this definition, the long products have a more stringent emission intensity target. In India, the long products are produced by the DRI+IF route, which is dominated by the smaller players. It might be challenging to the smaller players to have a lower emissions intensity target as they might not have the wherewithal to meet the stringent emissions intensity targets. Further, the smaller players cannot compete with ISPs in terms of production costs, primarily due to higher scrap costs.
8	Kloeckner Metals Corporation	Kloeckner Metals Corporation is one of North America's largest metals manufacturing, supply, and service companies. Kloeckner Metals defines six categories of finished steel based on absolute carbon emissions intensity[8] starting with 1.75 to 0.4 tCO_2/t finished steel product. This definition considers scopes 1, 2, and 3 emissions and is based on the absolute emission intensity of steel. There is an analogous system for stainless steel and aluminium. A challenge with the category or band-based approach is that a steel industry at the extreme ends of a particular band will command the same premium in the market. For example, as per the proposed methodology by Kloeckner Metals, steel plants with an emissions intensity of 1.41 tonnes CO_2/tcs and 1.01 tonnes CO_2/tcs will be categorised under the same band 'step'. Consequently, there is no incentive for the industry at 1.41 tonnes CO_2/tcs to move to a lower value until it reduces enough to move to the next band.

S. No.	Organisation / Consortium	Critical review in the India Context
9	SteelZero	SteelZero is a global initiative by the London-based Climate Group that aims to bring together leading organisations to speed up the transition to a net-zero steel industry. The STEELZERO[9] initiative has adopted ResponsibleSteel's sliding-scale methodology for setting decarbonisation targets.
10	World Steel Association (WSA)	World Steel Association (WSA) is a Brussels-based international industry association for the iron and steel sector. WSA has discussed multiple definitions of decarbonised steel, such as low-carbon, near-zero, carbon neutral, fossil-free, clean, carbon-free steel, etc. However, no single definition has been proposed or adopted by WSA[10].

2.4. Indian scenario of green taxonomy

Bharat Stage Emission Standards (BSES) for automobiles: BSES are a set of regulations implemented by the Government of India to control the output of air pollutants from internal combustion engine vehicles and equipment. Modelled after the European emissions standards, they establish limits on the emission of pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (HC), and particulate matter (PM). The implementation timeline of BSES is as follows:

1. **Bharat Stages I and II:** Introduced in 2000 and 2001 respectively, to target initial reductions in vehicle emissions.
2. **Bharat Stage III and IV:** Implemented progressively from 2005 to 2017, with BS IV covering the entire country by 2017.
3. **Bharat Stage VI:** BS VI was directly enforced on April 1, 2020, setting more stringent emission limits comparable to Euro 6 standards.

Ongoing enhancements in emission standards are expected as India continues to align its regulations with global practices and pursues further reductions in vehicle-related pollution.

Star labelling of consumer appliances by BEE: The Star Labelling Programme, launched by the Bureau of Energy Efficiency (BEE) under the Government of India, is a voluntary initiative that rates the energy efficiency of appliances on a scale from 1 to 5 stars. Categorization of the ratings is done on the basis of-star rating, energy efficiency ratio, product details and BEE registration number. This labelling system guides consumers in choosing energy-efficient appliances by highlighting their potential for energy savings and cost reduction. The program, which was developed through a collaborative and consensus-driven process, involves active participation from various stakeholders to ensure its effectiveness.

2.5. Challenges

There are challenges for fossil-free and near-zero emission steel production concerning the scalability of technologies and avenues for achieving near-zero emissions in the sector. There are also challenges to developing a globally acceptable definition of steel. This section deliberates on these challenges and identifies the bottlenecks for driving sustainability practices in the steel sector.

2.5.1. Challenges for fossil-free and near-zero emission steel production

1. **High cost of fossil-free steel:** Green steel should have near-zero emissions, which is only possible with green hydrogen and renewable power-based steel production technologies today or other alternative direct electrolysis technologies that are currently at lower TRL levels. However, steel produced through such cleaner technologies is significantly more expensive than conventionally produced steel due to the high cost of green hydrogen, making it unviable for domestic steel manufacturers. Green hydrogen is still an evolving market in India. Therefore, there are challenges to the availability of green hydrogen at competitive prices for scaling up such a concept in India today. Consequently, until over-the-horizon technologies become commercially viable, an alternative definition of green steel will be needed.
2. **High cost of near-zero emissions steel from coal-based production processes:** There are challenges in achieving near-zero emissions with the current technology mix used for producing steel in India. The domestic steel industry is constrained to operate with coal-based blast furnaces and rotary kilns due to a lack of access to natural gas at competitive prices and sufficient scrap availability. In addition, the steel plants in India plan to add capacity through these coal-based processes. Decarbonisation measures like energy efficiency, renewable energy and alternative fuels cannot achieve near-zero emissions from the blast furnaces and rotary kilns. Further, deep decarbonisation of these coal-based production routes can only be achieved through the carbon capture, utilisation and sequestration (CCUS) route. CCUS ecosystem is still developing in India. Therefore, achieving near-zero emissions with the current steel production routes will face significant technical and cost-related challenges.

2.5.2. Challenges for defining green steel

Given the challenges of producing fossil-free and near-zero emissions steel, there is a need to find avenues for incremental decarbonisation of the steel sector. The sliding scale proposed by IEA incentivises the incremental decarbonisation of the sector by setting limits on the emission intensity of emissions on steel and quantifying the low-emission steel. However, there are many challenges in defining green steel, especially developing a globally accepted definition. These challenges are discussed below:

1. **Accounting for disparity in resource availability across various countries:** The cost of steel is expected to increase with reduced emissions intensity. A few countries have access to low-cost natural gas. Steel production through natural gas route has significantly lower emissions than coal-based blast furnaces and rotary kilns. Therefore, if there are the same targets for the emission intensity of steel for coal and natural gas-based technologies, coal-based processes might be disadvantaged for trade in green (or any other related terminology) steel. A globally accepted definition of green steel should account for the disparity in resource concerning fuels, iron ore quality, emissions intensity of grid power, etc.
2. **Accounting for different milestone years across countries for achieving net zero emissions:** There are challenges to a globally acceptable definition of low-emission or green (or any other related terminology) steel, given different targets for achieving net zero emissions. Most developed countries have committed to net zero by 2050. Therefore, the decarbonisation trajectories for the intermediate years and the amount of low-emissions steel produced will be based on the 2050 net-zero trajectory. India has committed to net zero by 2070. Therefore, there is a need to consider these challenges while formalising the globally accepted definition of green steel.
3. **Accounting for heterogeneity in steel production pathways:** There is a wide range of emission intensities of steel production across different pathways in India. There are challenges in developing a just and fair green steel definition and setting up an emissions intensity trajectory so that all production pathways bear a similar transition burden. It is also challenging to ensure that not one particular sector or sub-sector is put at a disadvantage due to the transitions in the steel sector.

4. **Ecosystem challenges:** Operationalising the definition of green steel will require a well-developed ecosystem. However, there are challenges regarding monitoring, reporting and verification (MRV), green steel certification and registry of green steel certificates as the ecosystem does not exist in India today.

2.6. Guiding principles for defining green steel in India

Five guiding principles can be used to define green steel in the Indian context. These guiding principles account for the current emissions intensity and existing production pathways in the steel industry and align the emissions reduction trajectory with India's overall climate goals and the upcoming Indian carbon markets. These guiding principles are discussed below:

1. **Alignment with India's climate goals**

   India has set ambitious climate goals that include achieving net zero emissions by 2070. It has also set intermediary milestones for 2030 that will require a significant reduction in emissions intensity of GDP and an increase in non-fossil fuel-based power generation capacity. The steel sector contributes to 10-12 percent of the total national emissions and meeting India's climate goals will also require reducing emissions from the steel sector. Therefore, the green steel definition in India is expected to align with and support India's larger climate goals.

2. **Synchronisation with CCTS targets**

   BEE is developing Indian carbon markets under the CCTS scheme to meet India's climate goals. The ICM will set targets for the emission intensity of steel for all industries covered under the scheme. It is expected that the definition of green steel n in India will align with the targets set under ICM to accelerate the decarbonisation of the steel sector.

3. **Suitability to domestic steel industry**

   As discussed in the introduction chapter, the Indian steel sector is heterogeneous and heavily reliant on coal-based production pathways. About 93% of the total iron and 75% of total steel production in India is through coal-based processes. Therefore, a green steel definition in India should consider the sector's heterogeneity and reliance on coal-based production processes.

4. **Accounting for current emission intensity levels**

   The average emissions intensity for steel in India is 2.54 t-CO_2/tcs which is significantly higher than global average of 1.91 t-CO_2/tcs. Therefore, the green steel definition in India is envisaged to account for the current emissions intensity levels in the sector, which are higher than the global average.

5. **Robust MRV framework and certification process**

   The implementation of the green steel definition will require developing a robust MRV framework to provide guarantee on the greenness of the product. Further, the certification system also needs to be developed that will have a registry of green steel certificates along with an inventory.

2.7 Design considerations for defining green steel in India

India will consider all definitions proposed globally to evolve a definition suitable to its needs. The Indian steel industry is heterogeneous and consumers are price sensitive. This demands the development of a green steel definition that meets the requirements of the domestic steel sector. Further, the targets on emissions intensity for defining green steel cannot be too steep for the industry to not provide the desired nudge for decarbonisation or cannot be too loose to not achieve significant reductions in emissions. Given these challenges, this section discusses the design considerations for evolving green steel in India.

1. **Scrap-agnostic or scrap-centric definition:** A scrap-agnostic approach for defining green steel would be based on the absolute emissions intensity of steel that recognises the role of material efficiency as an important decarbonisation lever. A few proposed definitions, like the one proposed by Kloeckner Metals or GSCC, follow this approach. An issue with the scrap-agnostic approach is that steel produced through the scrap-based IFs or EAFs will automatically have lower emissions intensity than primary steelmaking without much decarbonisation efforts. Therefore, such an approach might only benefit scrap-based IFs or EAFs, and there will be a limited incentive for primary steel producers to invest in cleaner technologies and decarbonise faster.

   The sliding-scale methodology developed by IEA and ResponsibleSteel negates the effect of utilising scrap as a decarbonisation lever. India is and is likely to remain a scrap-deficient country. Global adoption of the sliding scale methodology might help India overcome the challenges associated with steel decarbonisation as it permits higher emissions intensity targets for lower scrap use. This might enhance India's export competitiveness if due consideration is given to India's goal of achieving net zero by 2070. However, unlike the large steel players that produce primary steel, the secondary steel sector in India is significantly dependent on scrap use for producing steel and might not have the wherewithal to meet the steep decarbonisation targets that higher scrap consumption needs. Moreover, disincentivising scrap use may negatively affect the country's efforts to improve scrap recycling. Given this context, it would be important to balance disincentivising the use of scrap as a decarbonisation lever and the challenges faced by the secondary steel sector in India.

2. **Production route agnostic or production route centric definition:** India has significant heterogeneity in iron (BF, NG and coal-DRI) and steel (BOF, EAF, IF) production pathways. Therefore, there is a need to assess whether the emissions intensity targets across various production routes should be the same or different. There are conflicting opinions globally. The IEA sliding scale approach follows an approach which is independent of the production process. The GSCC approach sets a lower emission intensity target for long products than flat products. It should be noted that very few countries globally have a heterogeneity that parallels the Indian steel sector.

   The various decarbonisation measures for the steel sector are energy efficiency, material efficiency, renewable energy, alternative fuels like natural gas, biomass and green hydrogen and carbon capture, utilisation and storage (CCUS). The impact of these decarbonisation measures on the emissions intensity of steel and the cost of CO_2 abatement differs across various production processes. Therefore, having the same emissions intensity targets across various production pathways might affect the cost-competitiveness of some production pathways and consequently impact their market share.

   Having different emissions targets also has its own set of challenges. For example, although the natural gas-based production route has lower emissions intensity than coal-based blast furnaces and rotary kilns, it will have to adopt decarbonisation measures like energy efficiency and renewable energy per this approach. These measures might increase the cost of producing steel through the gas-based route and further disincentivise steel production through this route, notwithstanding the current challenges regarding access to cost-competitive natural gas.

   Therefore, before defining green steel in the Indian context, it is necessary to properly weigh the benefits and challenges of each approach.

3. **Quantified or banded approach for defining green steel:** The IEA sliding scale quantifies the amount of low-emissions steel produced based on the absolute emissions intensity of steel and the scrap usage. Other definitions, like those by ArcelorMittal and Kloeckner Metals, follow a banded approach. While the banded approach allows some flexibility for meeting the emissions intensity targets, it does not incentivise emissions reductions within the band. Therefore, there is a need to properly weigh the benefits and challenges of quantified and banded approaches for defining green steel in India.

4. **Dynamic or static targets on emissions intensity:** In the past, India had set targets on specific energy consumption (SEC) in the steel sector through the PAT scheme. The reduction in SEC can be achieved by using energy efficiency technologies that reduce energy consumption and the cost of producing steel. On the other hand, the cost of producing steel is expected to increase with a reduction in emission intensity beyond a certain range. Therefore, setting up targets on emissions intensity is more challenging than setting targets for the SEC. So far, India has no experience setting up emissions reduction targets.

   Static targets imply setting up fixed targets on emissions intensity for future years that cannot be changed even if intermediate targets are not achieved. Dynamic target setting implies changing emission intensity targets for the coming year based on the progress achieved in the intermediate years. A green steel definition should strike a balance between the static and dynamic methods for setting targets on the emission intensity of steel. A balanced approach in India could be setting up a static target for 2030 that allows time for an interim review. Based on the progress made till 2030, the static targets for future years can be set up. This is expected to significantly reduce anxiety regarding decarbonisation in the steel industry without substantially compromising the reduction of emissions in the sector.

5. **Near-zero and fossil-free steel or low-emissions steel:** There is a need to incentivise steel players that are significantly below the mandated emissions intensity. Incremental decarbonisation implies setting targets on the emissions intensity of steel and incentivising industries to reduce emissions below the target. This approach ensures the decarbonisation of the sector without sudden technological and financial challenges. It also enables the development of a market for green products within the country without facing a steep price increase for the consumers. The IEA sliding has a mechanism to reward such steel players as it quantifies the amount of low-emissions steel produced. The low-emissions steel thus produced can fetch a premium in the market. This approach is expected to incentivise incremental but accelerated decarbonisation of the steel industry.

   Another approach to producing green steel could be to achieve absolute decarbonisation by producing near-zero emissions steel in the existing production pathways through various decarbonisation options like energy and material efficiency, renewable energy, alternative fuels and CCUS. Alternatively, near-zero or fossil-free steel can also be produced using over-the-horizon technologies like green hydrogen-based steelmaking. There might be a need to incentivise steel production through these pathways to accelerate decarbonisation efforts. A possible approach to this effect could be having a fixed quota for procuring near-zero or fossil-free steel production that can fetch a higher premium in the market. These factors may be considered when deciding on the definition of green steel in India.

6. **Product-level emissions intensity or emissions intensity only till crude steel:** Most definitions of green steel proposed globally focus on measuring emissions intensity only till crude steel production. This is done to create parity across various production pathways that converge at crude steel production and subsequently have different processes for producing finished steel. However, steel is not used as crude steel in end-use applications. The end-consumers of steel, like automobile or construction projects, might need disclosure on their scope 3 emissions. Therefore, there might be a need for an MRV or mandates on the product level emission intensity of steel. A green steel definition in India would consider these factors and have guidelines for measuring product-level emissions intensity.

7. **Globally aligned or India-specific green steel definition:** The definition for green steel can be developed by aligning with a consensus-based global definition or catering specifically to the Indian steel industry. While multiple global definitions for green steel (or associated terminology) currently exist (as seen in Table 2.1), there is no globally accepted definition yet. Nevertheless, efforts are underway to establish a consensus, and India might actively participate in these efforts to help shape and define a globally accepted definition of green steel. This collaborative approach can ensure smooth trade in green steel across various countries. However, it is also important to acknowledge the challenge of reaching a consensus. It could take a significant amount of time, or the efforts could fail to achieve acceptance amongst participants. Also, since the Indian steel sector is unique and very different from the other parts of the world, the adoption of global definition might not suit domestic Indian interests. In such cases, having an India-specific definition of green steel could be beneficial for creating an ecosystem within India for its domestic market. In contrast, industries seeking to export green steel from India to various countries could adhere to the importing country's definitions and standards. Similar parallels exist in the green hydrogen space, where no globally accepted definition of green hydrogen exists. However, India has its own definition.

8. **Linking green steel definition with Indian carbon markets:** The Bureau of Energy Efficiency (BEE) is developing sectoral targets on emissions intensity for the steel sector based on India's NDCs and also to develop the carbon markets in the country. This provides a potential opportunity to intrinsically link the definition of green steel to the targets being set up by BEE. Steel plants that are a certain percent below the targeted weighted average emissions intensity of steel in India can benefit by qualifying a proportional share of their annual steel production to be called green. The methodology for computing the amount of green steel can be similar to the approach identified in IEA's sliding scale for computing the quantity of low-emissions steel. Steel plants, especially small-scale industries, that might be outside the scope of Indian carbon markets can be part of the green steel initiative by voluntarily registering for it.

   A challenge with this approach is that steel produced through the scrap-based IFs will automatically have lower emissions intensity than primary steelmaking without much decarbonisation efforts. Therefore, such an approach might provide disproportionately higher benefits to scrap-based IFs, and there will be limited incentive for primary steel producers to decarbonise faster. This challenge could potentially be addressed by having process-specific targets on emissions intensity.

9. **Limited scope 3 or complete scope 3 emissions:** Most proposed definitions of green steel include the entire life cycle emissions for steel production in setting up emissions intensity boundaries. It is seen that typically, scope 3 emissions constitute less than 10%[11] of the total emissions from steel production. India imports a significant share of raw materials and fuel for steel production. Including scope 3 emissions as a part of the accounting process will need significant efforts to measure them in another country. However, a few Scope 3 emissions, such as raw material agglomeration and coal beneficiation, should be accounted for, especially since they have varying impacts amongst different production pathways. Therefore, it would be important to identify the scope 3 emissions boundary for emissions accounting while defining green steel in the Indian context.

The task force constituted by the Ministry of Steel is working on developing a green steel definition for India, considering these design considerations. Irrespective of the final definition developed or adopted in India, it is envisaged that green steel production will involve emissions reductions through actual decarbonisation measures in the plant. Emissions reductions through carbon offsets or by buying credits from the carbon markets will not qualify for green steel. However, from the discussions in this chapter, it is also clear that all design considerations have their advantages and limitations. It is unlikely that any approach will find universal acceptance amongst all steel plants in India. Therefore, it is essential to develop an equitable and just green steel definition that incentivises all production pathways to reduce their emissions intensity without a significant advantage or disadvantage to any particular sub-sector.

2.8 Oversight Body for MRV, Green Steel Certification Mechanism and Registry

As the demand for green steel grows, end-consumers will require assurances regarding the emissions intensity and environmental friendliness of the product. To meet this need, a robust Monitoring, Reporting and Verification, certification, and registry of green steel must be established. It is anticipated that in some instances, green steel may not be physically traded, with only the certificates being purchased by the end consumer. Therefore, the creation of a certification mechanism and registry for green steel certificates in India is imperative

BEE is already developing an MRV framework for the Indian carbon markets covering the steel sector. Therefore, it is envisaged that BEE shall be the oversight body responsible for developing the MRV mechanism that will be used to certify green steel. Further, BEE shall also be responsible for green steel certification and maintaining the registry of green steel in India.

2.9 Action Plan

1. **Developing a definition of green steel:** Ministry of Steel to evolve the definition of green steel in the short-term horizon in consultation with all relevant stakeholders while following the guiding principles as outlined in this chapter

2. **Developing an MRV framework and creating a registry for green steel certificates:** Bureau of Energy Efficiency is to be designated as the oversight body for green steel certification; and for developing of an MRV framework and creating of a registry to enable the trade of green steel certificates.

CHAPTER 3

MONITORING CO_2 EMISSIONS

3.1. Introduction

To achieve net-zero carbon emissions in the steel industry, a stringent and well-defined approach to monitoring Carbon Dioxide (CO_2) emissions is essential. The role of monitoring standards becomes pivotal in steering the industry towards sustainable practices and compliance with global decarbonisation goals. Effective CO_2 monitoring involves accurately measuring emissions and ensuring that these metrics are standardised across the industry to facilitate comparison, enable effective regulation, and drive improvements in environmental performance.

The Necessity of Robust Monitoring Systems

Monitoring CO_2 emissions in the steel industry involves a complex interplay of site-specific measurements and product-level assessments. This dual approach offers a comprehensive understanding of both direct emissions from production processes and indirect emissions associated with the purchased material, energy and life cycle of steel products. Such detailed monitoring is underpinned by various international methodologies, offering frameworks for accurate and transparent reporting. These frameworks are crucial for comparing emissions across facilities globally and aligning with net-zero goals.

Facilitating Decarbonisation Through Standardised Monitoring

The standardisation of CO_2 emission monitoring plays a critical role in decarbonisation. By establishing uniform metrics and methodologies, the industry can benchmark performance, identify best practices, and push for continuous improvement. Implementing these standardised methodologies supports compliance and reporting and drives technological innovations and operational efficiencies aimed at reducing the carbon footprint of steel production.

Strategic Importance of CO_2 Monitoring

In the broader context of climate strategies, the role of CO_2 emission monitoring extends beyond regulatory compliance. It serves as a critical tool for corporate environmental responsibility, allowing companies to transparently communicate their sustainability achievements. Investors and consumers increasingly make decisions based on environmental considerations, positioning Greenhouse Gas Management (including CO_2 monitoring) as a strategic component in business operations.

As the steel industry aims for a sustainable and low-carbon future, the role of CO_2 monitoring standards becomes increasingly significant. They enforce accountability and drive innovation and efficiency in production processes. For India, adopting and adapting these international standards to local needs and conditions is a vital step towards achieving its decarbonisation goals. The development of a coherent, robust, and consistent CO_2 emissions monitoring and reporting protocol suitable for a net-zero-compliant iron and steel industry, is imperative.

3.2. Global Scenario

Emissions measurement methodologies fall into two broad categories- the ones specific to steel production or products; and others that are for general emissions reporting but can be applied to steel production. Product-level standards are often associated with detailed life cycle assessment (LCA) methodologies that factor in a range of environmental and other impacts, beyond just greenhouse gases (GHG). Production-level standards are used more frequently for performance benchmarking between facilities and often require less granular data than existing product-level standards.

There are many methodologies for CO_2 emission monitoring in the world, covering various aspects like measurement methodology, boundaries, direct/indirect emissions scope, and coverage according to adoption level. Five of the most adopted methodologies in the world are:

1. World Steel Association (WSA) CO_2 methodology[1]
2. WSA Life Cycle Inventory methodology[2]
3. ISO 14404 series (1/2/3/4) – Measuring CO_2 emissions from steel production[3]
4. ISO 20915:2018 ISO Life cycle inventory calculation methodology for steel products (LCI methodology)[4]
5. Responsible Steel (International Standard V2.0 (principle 10))[5]

The methodology, scope, and coverage of the above are summarized in Table.

Table 3.1: *Summary of the widely CO_2 emission monitoring methodologies across the world*[6]

	WSA CO_2 Methodology	WSA LCI Methodology	ISO 14404	ISO 20915 (LCI Methodology)	Responsible Steel International Standard V2.0 (principle 10)
Measurement methodology	Total emissions from a site are calculated by adding the quantity of different fuels and materials being used at a facility or purchased as intermediate products (such as coke or sinter), multiplied by their respective emission factor, including process emissions. This is divided by the crude steel production to derive an average CO_2 intensity.	A methodology for measuring the environmental impact from the production of a number of steel products. As part of the environmental impact assessment, GHG emissions can be calculated, alongside all other impacts, such as acidification, ozone depletion and resource depletion.	This includes the BF-BOF route (part 1), scrap EAF route (part 2), and the DRI-EAF route (part 3) and emission intensity from steel production (part 4).	Was developed using the World steel LCI methodology difference being impact of scrap processing is outside the scope and boundary and uses credits for process gases, based on the savings from replacing the marginal energy.	Relies on existing emissions accounting guidance, including ISO standards (14404, 14064, 20915), the world steel LCI methodology, the GHG Protocol and EN 19694
Coverage	Current database (22) includes data from more than 220 sites. Representing approximately 485 MT of steel production, or 25% of steel production. Has potential for calculation of 1600 MT capacity (if all members submit data).	Currently collects data from more than 160 sites. Representing approximately 400 MT of steel production, or 25% of steel production. Has potential for calculation of 1600 MT capacity (if all members submit data).	ISO/TC 17 has 27 participating members and 40 observing members. Would cover around 1750 MT (90%) of steel production	ISO/TC 17 has 27 participating members and 40 observing members. Would cover around 1750 MT (90%) of steel production	Currently, 56 sites belonging to 7 member companies have valid certificates, covering 106 MT of steel production, of which 36% are scrap EAF and 64% are BF-BOF sites

	WSA CO_2 Methodology	WSA LCI Methodology	ISO 14404	ISO 20915 (LCI Methodology)	Responsible Steel International Standard V2.0 (principle 10)
Emissions scope-Direct	Fossil fuel use in ironmaking, steelmaking and iron ore agglomeration, producing reducing agents; and downstream, on-site processes, e.g., rolling and direct-off gases.	Fossil fuel use in ironmaking, steelmaking and iron ore agglomeration, producing reducing agents; and downstream, on-site processes, e.g., rolling, direct-off gases.	Fossil fuel use in ironmaking, steelmaking and iron ore agglomeration, producing reducing agents, and downstream, on-site processes, e.g., rolling, direct-off gases	Fossil fuel use in ironmaking, steelmaking and iron ore agglomeration and producing reducing agents; and off-gases	Fossil fuel use in ironmaking, steelmaking and iron ore agglomeration and producing reducing agents and direct-off gases
Emissions scope-Indirect	Electricity, heat and hydrogen; raw materials manufacture; fossil fuel transport and supply, e.g., upstream fugitive methane.	Electricity, heat and hydrogen; fossil fuel transport and supply; raw materials manufacture; raw materials transport and supply; and waste treatment and associated processes.	Electricity, heat and hydrogen; indirect raw materials manufacture. Indirect fossil fuel and raw materials supply are not included.	Electricity, heat and hydrogen; indirect fossil fuel and raw material supply; and waste treatment and associated processes.	Electricity, heat and hydrogen; and indirect fossil fuel and raw material supply.
Greenhouse Gases Covered	This only includes CO_2.	All GHG emissions, including CO_2, CO, CH_4 and N2O.	This only includes CO_2.	All GHG emissions, including CO_2, CO, CH_4 and N2O.	All GHG emissions, including CO_2, CO, CH_4 and N2O

In addition to the above, the other methodologies in vogue[7], internationally are:

1. The Greenhouse Gas Protocol (GHG Protocol) – The Corporate Accounting and Reporting Standard
2. Monitoring and Reporting requirements under the Emissions Trading System, e.g., EU ETS
3. Monitoring and Reporting requirements under the EU – Carbon Border Adjustment Mechanism (CBAM)
4. Science Based Targets initiative (SBTi)
5. Sustainable Steel Principles
6. Climate Bonds Initiative (CBI) Steel Criteria
7. ISO 14064-1 - Specification with guidance at the organization level for quantification and reporting of GHG emissions and removals

Verification methodologies (global)

Considering the urgent need to decarbonise the iron and steel sector to avert climate change, efforts are being made to develop standard protocols for measurement as well as verification of emission data. The development of globally acceptable standards for verification is gaining importance as some countries have begun monitoring the intensity of carbon emissions of various products being imported into their country. One such regulation is CBAM, which was issued by the European Union. However, transparency in monitoring, reporting and verifying CO_2 emission data is crucial. The verification processes, both at the facility and corporate levels, play an important role in meeting the market requirements.

The type and granularity of data required under these standards must consider both availability and confidentiality concerns. Obtaining reliable information associated with raw materials and feedstock is challenging and may cause difficulties in verification. In some cases, relevant data might include contain business confidential information, and steelmakers may not want to provide competitors or commercial partners with access to the information.

Some organisations have already begun voluntarily declaring their carbon emissions as a part of their environmental, social, and governance (ESG) compliance to minimise risk, reduce the cost of production, and improve brand image besides promoting themselves as a socially responsible organisation. Since significant green funds are available and the banks and investors are giving priority to industries committed to reducing carbon footprints, the verification of emission data will be crucial and may become an important tool in future.

Applicable Standards for carbon footprint (CFP) Verifications

Some of the ISO standards already developed for carbon footprint monitoring and verifications are:

- ISO 14064-1:2018 Greenhouse gases — Part 1: Specification with guidance at the organisation level for quantification and reporting of greenhouse gas emissions and removals
- ISO 14064-2:2019 to identify and monitor emission reductions and improve GHG removals
- ISO 14067:2018 to calculate the carbon footprint of products
- ISO 14064-3: 2019 Greenhouse gases- Specification with guidance for the validation and verification of greenhouse gas assertions
- ISO 14065:2020 requirements for verification and validation bodies
- ISO 14066:2011 that specifies competence requirements for validation teams and verification teams

It is reported that the ISO 14064-3 verification process has been developed using the best practices derived from financial accounting techniques and environmental auditing as well as verification experiences from emerging GHG schemes and programs such as the Kyoto Protocol's Clean Development Mechanism and the EU ETS. ISO 14064-3 establishes "fundamentals" for verification, such as the level of assurance, objectives, criteria, and scope. These elements serve as points of reference regarding the expectations and level of effort required by the verification process. The fundamentals of verification also include the definition of materiality under the verification. A GHG assertion verification under ISO 14064-3 provides for the performance of assessments in three areas: review of the GHG information system, evaluation of the GHG data, and comparison of the assertion against verification criteria.

Global CFP Verification/Auditing Companies

Some of the major international companies involved in carbon footprint verification are:

1. British Standards Institution (BSI)
2. GEP Environmental Ltd., UK
3. DQS, Germany
4. TUV SUD
5. Bureau Veritas Certification
6. UL Solutions

3.3. Indian scenario

Emission monitoring methodologies

In India, emissions monitoring of steel plants is supported by a combination of standards, methodologies, and institutional and legal mechanisms to ensure environmental compliance and sustainable production. The Central Pollution Control Board (CPCB) and state pollution control boards have set emission standards for various pollutants emitted by steel plants. These standards define permissible limits for pollutants such as particulate matter (PM), sulphur dioxide (SO2), nitrogen oxides (NOx), and carbon monoxide (CO). Steel plants in India use Continuous Emissions Monitoring Systems (CEMS) and periodic stack emissions testing to monitor and measure air emissions. CEMS provides real-time data on key pollutants, while stack emissions testing involves collecting samples and analysing them in accredited laboratories. However, CO_2 emissions are not covered under this mandate. Thus, it necessitates a standard and common CO_2 monitoring methodology be applied across steel industries for effective monitoring.

Some of the CO_2 emissions monitoring systems adopted by the Indian steel industry are:

1. **World Steel Association (WSA) CO_2 methodology-** The WSA CO_2 methodology is an approach defined by WSA to monitor CO_2 emissions at a facility level and is voluntary in nature. This initiative aims to collect and report CO_2 emissions data on a site-by-site basis to give an overall emission intensity for the production of steel at that site, irrespective of the final products being made. This approach has been in place since 2007, and more than 200 sites report the data through this approach on an annual basis. It is also currently followed by many large Iron and Steel producers in India, including the Integrated Steel Plants (ISP). The World Steel methodology follows the principles suggested by the GHG Protocol (relevance, completeness, consistency, transparency, and accuracy) in its definitions whilst adapting them

to make the methodology accessible to a wide range of site structures and processes. It is transparent about exclusions, e.g., excluding mining operations from the from scope 3 emissions, as well as the exclusion of other non-CO_2 GHG gases, such as Methane (CH_4), Nitrous Oxide (N2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulphur Hexafluoride (SF6). Further, it adopts the concept of scopes 1, 2 and 3 to account for emissions, although it adds the ad hoc scope 1.1 concept to handle process gases exports. For scope 3, the boundaries encompass aspects from Category 1. Purchased goods and services and, Category-3 Fuel and energy-related activities (not included in Scope 1 or Scope 2) from the GHG Protocol Scope 3 categories.

2. **PAT Energy declaration formats:** Under the Perform Achieve and Trade (PAT) scheme, an energy efficiency-based market mechanism by the Government of India, large energy consumers defined as designated consumers (DCs) in energy-intensive sectors are required to achieve specific energy consumption reduction targets from the baseline. The DCs are issued energy saving certificates (ESCerts equivalent to 1 tonnes of oil equivalent) for exceeding their targets, which could be traded on the energy exchange, while the DCs who are not able to achieve their targets would be required to purchase the energy savings certificates and thus facilitating trade of ESCerts between the consumers. Till now, the data is collected for the energy consumption covering direct and indirect energy consumption, including specific energy consumption. The PAT scheme is transitioned to the Carbon Credit Trading Scheme (CCTS), where these DCs are expected to be given targets in terms of GHG emission intensity; the PAT forms are being modified to collect the CO_2 emissions data for every process in a particular manufacturing facility boundary. Though this will be at the facility level, it will help find the emission for each product after every process. There are separate forms for energy and emissions data for ISPs and SSIs (Secondary Steel Industry).

3. The CCTS notified on June 28, 2023, has set up the regulatory and institutional framework for the Indian Carbon Market (ICM). The CCTS defines the two mechanisms namely, compliance mechanism (mandatory) and offset mechanism (voluntary). Under the compliance mechanism of ICM Framework, the Central Government shall specify targets (for designated consumers who are termed as obligated entities) in terms of ton of carbon dioxide equivalent (tCO_2e) per unit of equivalent product after considering all relevant aspects including available technologies and likely cost of their implementation. The obligated entities shall comply with the prescribed GHG emission reduction targets on an annual basis and shall monitor, report and submit and verified emission details to the Government. The obligated entities who are able to reduce their GHG emission intensity below the prescribed GHG emission intensity targets shall be eligible for issuance of Carbon Credit Certificates. The entities who are not able to achieve the target will be required to surrender/purchase an equivalent number of certificates based on the shortfall. The current PAT Scheme (an energy efficiency-based market mechanism) will be transitioned gradually (for the relevant sectors and entities) to the compliance mechanism under CCTS, thereby providing more opportunities for decarbonisation.

A National Steering Committee for Indian Carbon Market (NSCICM) was established for this purpose. Although NSCICM and BEE will be responsible for target and trajectory setting, the targets and emission norms will be notified to the industrial sectors by the Ministry of Environment, Forest and Climate Change (MOEFCC) under the Environmental Protection Act (EPA), 1986.

One of the critical aspects of the compliance mechanism under the CCTS is that BEE, in its capacity as administrator, will be publishing the Compliance Procedure for the obligated entities which will direct the monitoring, reporting and verification requirements at the obligated entities or at facilities level. The monitoring and reporting aspects will cover in detail the emission sources to be covered and the development and implementation of the monitoring plan. Further, it will also cover collection of activity data, application of emission factors, fuel quality testing to determine emissions factors, calculation of absolute emissions and intensity emissions, verification procedure and requirements. The BEE is developing this procedure and detailed Monitoring, Reporting, And Verification (MRV) guidelines will also be developed basis this procedure for individual sectors including Iron & Steel.

Indian CFP Verification/Auditing Companies

Some of the major companies involved in carbon footprint verifications in India are:

1. Bureau Veritas India Pvt. Ltd.
2. TUV India Pvt Ltd.
3. KBS Certification Services Ltd.
4. Carbon Check India Pvt. Ltd.
5. TUV SUD South Asia Pvt. Ltd.
6. DNV Business Assurance India Pvt. Ltd.

3.4. Challenges

1. **Reporting challenges (Scope 1,2 & 3) -** The iron and steel companies in India are measuring and reporting Scope 1 and Scope 2 emissions on a voluntary basis using different methodologies such as those proposed by WSA, ISO and others. The Indian iron and steel plants are reducing their Scope 1 emissions—those under their direct ownership—with operational efficiency, predictive maintenance, etc. Strategies to address the reduction of Scope 2 emissions by these industries include power purchase agreements and a mix of renewable energy sources. However, Scope 3 emissions, including upstream (procurement of raw materials, shipping) and downstream (transport, warehouse management, scrap processing) emissions, are complex due to lack of data and clarity and thus, Scope 3 emissions are not fully adopted internationally.

2. **Monitoring challenges -** Further, there are a number of challenges for monitoring CO_2 emissions in the Indian iron and steel industry. These include a complex network of supply chain partners without visibility into operations, lack of reliable, accurate, and specific data required for GHG calculations. Further, primary data sources, often maintained on multiple platforms (interoperability) within the organisation are not integrated or accessible to all stakeholders. The other major challenges for small enterprises include lack of adequate infrastructure for measuring and monitoring the data, lack of skilled experts who can perform carbon measurement, life cycle analysis, data management and established data quality processes. These challenges need to be addressed to ensure a robust CO_2 monitoring and verification system for the Indian iron and steel industry.

3.5. Proposed approach

The Government of India, under its compliance mechanism of CCTS, is developing a comprehensive MRV requirements for various sectors, including the iron and steel sector. This evolving MRV framework is aimed at enhancing the accuracy and transparency of GHG emissions data, enabling effective participation in carbon credit markets.

As the MRV framework aims at developing emission reporting and monitoring requirements for obligated entities, the approach under CCTS would be particularly suitable for the CO_2 monitoring within the iron and steel sector in India. This approach ensures that:

1. **Standardisation:** It provides a standardised methodology for measuring and reporting emissions, ensuring consistency across the sector.

2. **Efficiency:** It supports the efficient collection and verification of emissions data, reducing administrative burdens and improving data accuracy.

Though there might be some alignment necessary with international requirements, these elements can be additionally added, such as reporting emission intensity in crude steel or finished goods, inclusion of other Scope 3 categories to the MRV framework as when required.

3.5.1. Emission Measurement Methodology

The current MRV procedure (under development) under CCTS for the iron and steel sector encompasses several critical aspects:

1. **Types of Gases Covered:** The MRV framework currently focuses exclusively on monitoring of CO_2 emissions.

2. **Boundary Setting Requirements:** It specifies the necessary boundary settings for accurate emissions accounting.

3. **Emissions Coverage:** The framework covers both direct and indirect emissions.

4. **Energy Source Exclusions:** It includes provisions to exclude renewable energy sources such as biomass or renewable energy (power), which can benefit overall emissions reduction and accounting.

5. **Monitoring Plan:** Provisions for developing a robust monitoring plan are included.

6. **Activity Data Collection:** Requirements for the collection of activity data, emission factors, and fuel/material testing are detailed.

7. **Reporting Requirements:** The framework outlines the procedures for reporting GHG emissions, including the submission of reports and e-forms.

8. **Verification Procedures:** It mandates verification procedures that align with international standards. While the current MRV framework aligns with many international standards, certain areas may require further development to ensure full compliance with global requirements from iron and steel sector perspective, which can be addressed over time:

9. **Expanded Source Coverage:** The MRV framework can be expanded to cover additional energy sources, such as process emissions from lime kilns, and include limited scope 3 emissions as per WSA or ISO standards.

10. **Harmonisation of Procedures:** The current approaches differ between ISPs and secondary steel producers. Over time, these procedures can be harmonised to ensure consistency across the sector.

By addressing these areas, the MRV framework for the steel sector in India can achieve greater alignment with international standards, thereby enhancing the sector's capability to participate effectively in global carbon markets.

3.5.2. Verification of Data

One of the critical aspects defined under the CCTS compliance mechanism is the requirement for yearly verifications. As part of the compliance procedure, the verification process is being developed to ensure rigorous and credible emissions reporting. This verification must be undertaken by a third-party entity accredited as an Accredited Carbon Verification (ACV) Agency.

In its role as the administrator of CCTS, the BEE is developing the criteria and procedures for accreditation which will be approved by the NSCICM. This is expected to align with international standards such as ISO 14065, ISO 14064-3, and ISO 17029. As part of the scheme, BEE will empanel and accredit third-party carbon verifiers. An inter-ministerial accreditation advisory committee (ACC) will evaluate and give recommendation to BEE to accredit the verification agency (ACV). The Ministry of Steel is also expected to be part of the accreditation committee, guiding the BEE in accrediting such agencies.

In addition to the above, the BEE is also developing the verification procedure on how verification is to be conducted by the verification agency and the verification process will be defined as per ISO standards, including several key elements.

Additionally, there are specific team requirements. For example, if the verification is conducted in the steel sector, there is a requirement that a steel sector expert (process) be part of the verification team. This approach ensures that the verification process is guided by relevant industry expertise, thereby enhancing its accuracy and credibility.

1. **Pre-Contract Review:** Initial assessment to understand the verification requirements.
2. **Strategic Analysis:** Evaluation of the organisation's structure and emissions sources.
3. **Appointment of Team:** Selection of a qualified verification team.
4. **Site Visit Requirements:** Conducting on-site inspections to gather data.
5. **Agreement on Scope and Objectives:** Defining the boundaries and goals of the verification process.
6. **Development of Verification Plan:** Creating a detailed plan for conducting the verification.
7. **Assessment of Data:** Evaluating the collected data for accuracy and completeness
8. **Verification and Evaluation of GHG Performance:** Analysing GHG performance against set benchmarks
9. **Submission of Verification Documents:** Compiling and submitting the verification report and supporting documents

The verification requirement for CO_2 monitoring in the steel sector can initially be voluntary but later it can be made mandatory for large to medium steel producers, with specific criteria defined at a subsequent stage.

3.5.3. Legal Mechanisms

Monitoring CO_2 emissions for the iron and steel industry in India will be carried out under the ICM, which is established under the purview of the Energy Conservation Act, 2001, and the Environment (Protection) Act, 1986. The Energy Conservation Act, 2001 empowers the Government of India to specify the CCTS, where any entity, including the designated consumers, registered for carbon credit trading scheme will be the "registered entity". The Act empowers the Central Government to issue the "Carbon Credit Certificates" to the registered entities under different mechanisms. The Environment (Protection) Act, 1986 empowers the Government of India to specify standards for emission or discharge of pollutants for the obligated sectors. The Central Government has notified the Carbon Credit Trading Scheme, 2023 vide S.O. 2825(E) dated 28th June 2023 under the powers conferred by clause (w) of section 14 of the Energy Conservation Act, 2001 (52 of 2001) which defines the ICM where a national framework is established with an objective to reduce or remove or avoid the greenhouse gases emissions from the Indian economy by pricing the greenhouse gases emission reduction through trading of the carbon credit certificates.

3.6. Action Plan

1. Ministry of Steel (MoS) may coordinate with BEE to develop protocol for measuring emissions from all the steel plants of the sector, including those not covered as Obligated Entities under CCTS and to incorporate the provisions in relevant law/rules.

2. MoS may coordinate with BEE to develop dataset for default emission values for all those input materials, where the data is not available, with the help of the industry stakeholders.

CHAPTER 4

DEMAND GENERATION

4.1. Introduction

It is a well-accepted fact that the decarbonisation initiatives of the steel sector would increase the cost of steel to recover the expense of deploying capital-intensive carbon mitigation technologies such as energy efficiency, renewable energy and green hydrogen[1]. While the investment in these technologies enables a supply-side push for mitigating emissions from the steel industry, there is also a need to create a demand-side pull for green steel in India. Chapter 2 details the possible framework for developing a green steel taxonomy for India. Irrespective of the final definition adopted for green steel in India, green steel is expected to be available at a premium over conventional steel. Therefore, developing a consumer base who can pay a premium for green steel is needed.

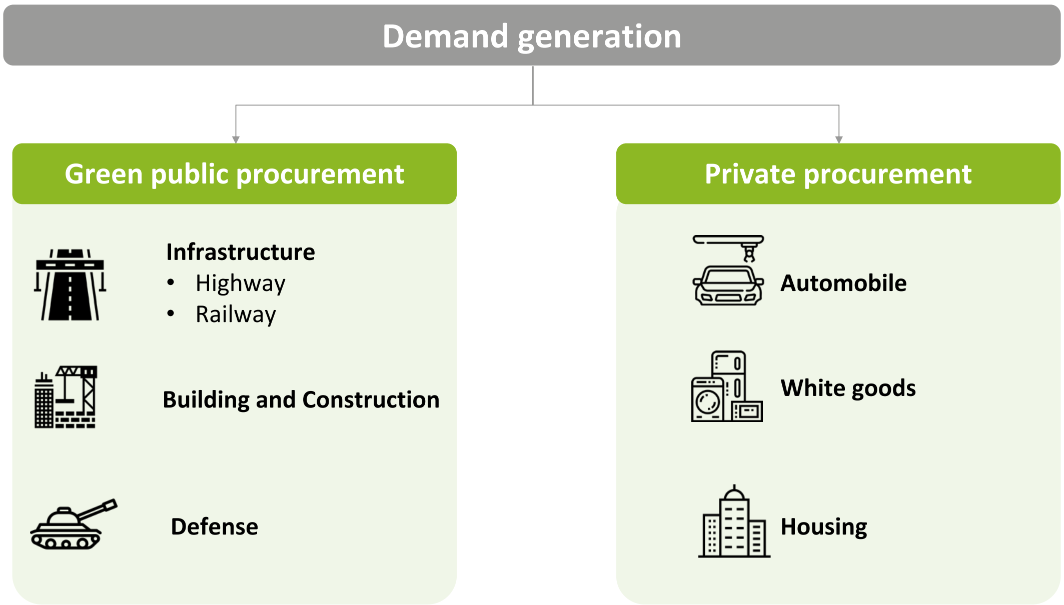


Figure 4.1: Mechanism for creating demand in the steel sector

Figure 4.1 shows the two potential mechanisms for creating the necessary demand-side pull for green steel in India. The government of India is a significant consumer of steel across infrastructure projects, housing schemes and the defence sector. Worldwide, the procurement activities of materials and services of national, state, and local governments, directly or indirectly, account for 15 %[2] of global greenhouse gas emissions. Capping such emissions could have a significant effect on accomplishing India's climate goals. By prioritising green steel in procurement policies, the government can send a strong signal to the market. This incentivises steel producers to invest in cleaner technologies and production methods for green steel, knowing there's a guaranteed demand. Moreover, through public procurement, the government can facilitate emission reduction to meet its own national climate goals. Further, by implementing green public procurement policies, the government acts as a leader and sets an example for private companies and other stakeholders, thus creating a ripple effect and encouraging wider adoption of green steel across different sectors.

The private sector is also a large consumer of steel, which is spread across sectors like auto, white goods, etc. The premium brand across these categories can potentially absorb the cost of green steel without significantly increasing product cost. Therefore, the private sector can support creating the demand-pull to nudge the industry to accelerate decarbonisation efforts.

This chapter highlights the need to develop a market for green steel through green public procurement (GPP) and private demand creation and the interventions that may be taken up.

4.2. Global and Indian scenarios

This section discusses the global and Indian scenarios for green public and private procurement.

4.2.1. Global scenario

Globally, there are multiple initiatives on green public procurement across various sectors of the economy. A few private sector initiatives are specific to the steel sector. This section expounds on the status of these public and private procurement initiatives and commitments globally.

4.2.1.1. Green public procurement

Many countries have a policy framework to facilitate and encourage green procurements across various sectors. However, there is no policy targeting emission reduction from the steel industry in particular, though many countries like Germany, Japan, etc., are deliberating upon such policies for steel. A snapshot of GPPP across various countries across different sectors is discussed below:

1. **European Union:** The European Union has a voluntary common Green Public Procurement Policy (GPP) to reduce the environmental impact of public purchases. GPP is within the framework of Strategic Public Procurement, together with Socially Responsible Public Procurement (SRPP) and Innovation Procurement. Governmental expenditure on goods and services is estimated to represent 14% of the GDP in the EU in 2016[3]; this represents significant buying power. The GPP policy consists of criteria for a set number of products and services like textiles, road transport, furniture, electronic devices like computers, data centres, electricity, office building design, construction and management, etc. The procurement benchmarks for these entities are decided based on life cycle analysis83. Steel is intrinsically embedded in these products, and a demand for low-carbon procurement might create a market for low-carbon emissions steel, even though there are no criteria for steel as a standalone commodity. The voluntary nature, high upfront procurement costs and lack of awareness regarding public procurement in member states have led to disparate adoption of green procurement. For example, from 2006 to 2017, less than 1 % of public procurement in Malta incorporated GPP criteria. In comparison, it was over 15 % for France[4]. Also, there is limited public information about the budgetary outlay for green procurement in the EU.

2. **Netherlands:** The Netherlands achieves CO_2 emission reductions below a certain threshold through its five-year procurement plan called the National Plan on Sustainable Public Procurement (SPP), with the current plan for 2021-2025. The bidders for public projects, like sustainable electricity and solar panels, are by law required to use a software called DuboCalc[5] that calculates the life cycle environmental effects of materials and energy, from extraction to demolition and recycling. SPP PIANOo[6], the Dutch Public Procurement Expertise Centre, provides tools and resources, including a private discussion platform, access to learning tools and best practices, implementation coaching, working groups, and a PIANOo Procurement Law Course. The intention is to stimulate sustainable procurement of goods and services.

   The central government, municipalities, water authorities, and provinces have a purchasing power of more than EUR 73 billion per year in the Netherlands. For about EUR 10-12 billion spent on government procurement in the Netherlands, a strategy called "Procuring with impact" has been developed. The national plan supports this strategy through the SPP criteria tool and the SPP Self-evaluation tool[7].

3. **Germany:** The German government uses the requirements from the EU directives, which state that public procurement decisions should be based on the life cycle costs of products and services[8]. The use of the German Blue Angel eco-label is encouraged[9] in federal procurement so products

meet stringent environmental criteria. Procuring agencies can seek assistance from the Centre for Sustainable Procurement.

In addition, The Federal Ministry for Housing, Urban Development and Building of Germany has formulated an assessment system for Sustainable Building (BNB), which provides a methodology for assessing sustainable and environmentally sound construction concepts. Since 2011, all federal-government-funded projects must consider five main criteria groups, which are: economic, socio-cultural and functional, ecological, technical and process qualities. The first four qualities are weighted at 22.5%, and process quality is weighted at 10 %. A minimum threshold of 65 %[10] has to be met, without which the project cannot proceed. However, there is no explicit mandate for the use of green steel under this assessment framework.

4. **USA:** The United States federal government is the largest purchaser in the world, with an annual purchasing power of over USD 630 billion for products and services, over one third of existing Federal contracts contain a sustainable purchasing requirement[11]. Many federal and state-led initiatives promote GPP, which are listed below:

   a. The Inflation Reduction Act (IRA) includes USD 4.5 billion in funding for the General Services Administration (GSA), Department of Transportation, and Environmental Protection Agency (EPA), to designate and use construction materials and products that emit significantly less greenhouse gas (GHG). The IRA also gives the Department of Energy (DoE) billions of dollars to invest in retrofitting industrial facilities, as well as tax breaks for clean technology manufacturers[12].

   b. The Buy Clean Task Force[13] is a partnership of agencies like the Department of Agriculture, Energy, Transport, Defence, State, Commerce, EPA, GSA, NASA, etc., that account for 90% of all federally financed and purchased construction materials nationwide. The Buy Clean Task Force is tasked with creating recommendations on policies and processes to expand consideration of embodied emissions in federal procurement. This includes:

      i. Prioritising lower embodied carbon (LEC) construction materials and products in federal procurement and funded projects, such as steel, cement/concrete, asphalt, and flat glass.

      ii. Increasing transparency of embodied emissions through supplier reporting of Environmental Product Declarations (EPDs) and providing incentives and technical assistance to domestic manufacturers to improve reporting and reduce emissions.

      iii. Launching pilot programs for construction materials and studying their real-world performance.

   c. Buy Clean California Act (BCCA)[14] act, enacted in October 2017, aims to reduce embodied carbon emissions associated with the production of structural steel, concrete reinforcing steel, flat glass, and mineral wool board insulation, particularly for publicly funded projects. It requires EPDs for public construction contracts above USD 1 million in California. The nodal agency for this act is the Department of General Services (DGS), which has set the maximum acceptable global warming potential (GWP) at the industry average for that material. Depending on the type of steel, the maximum acceptable GWP ranges from 890 kg CO_2eq. for a tonne of unfabricated concrete reinforcing steel bar to 1,830 kg CO_2eq. for one tonne of fabricated structural steel[15]. Consequently, this enables the creation of a market for commodities with a lower carbon footprint.

   d. In 2005, the Energy Policy Act[16] directed federal purchasers to procure ENERGY STAR (launched in 1992) – certified products. Since then, regulations, legislation, executive orders, policy documents, and agencies have raised the scope of green procurement programs. The purpose of EPA's ENERGY STAR[17] program is to highlight products with superior performance in energy use or embodied energy. The close connection between energy use and CO_2 emissions makes ENERGY STAR relevant to green procurement. ENERGY STAR is a voluntary programme and has achieved 4 billion metric tonnes of GHG reduction since its inception. This program's emphasis on the energy performance of cement, iron, glass, and steel manufacturing plants makes it especially relevant[18]. ENERGY STAR has a plant Energy Performance Indicator (EPI) tool that steel mills can use to compare themselves with similar mills in the US and Canada. The plant gets an ENERGY STAR rating for a score above 75 on a scale of 100. Plants can use ENERGY STAR Guidelines for Energy Management to build an energy management program and adopt best practices from the industry.[19]

e. The draft CLEAN Future Act[20] in the United States aims to achieve a 100% clean economy by 2050. According to this act, a federal Buy Clean Program is established to "steadily reduce the quantity of embodied carbon emissions of construction materials and products and promote the use of clean construction materials and products, in projects supported by Federal funds." The bill was introduced in 2021 with a budget outlay of USD 565 billion over ten years for deep decarbonisation and is in the subcommittee hearing stage.[21]

f. The U.S. Department of Energy (DOE)[22] in 2023 announced a corpus of USD 100 million for local governments and public utilities to purchase products derived from converted carbon emissions. This initiative aims is to accelerate the deployment of advanced carbon management technologies and create a market for environmentally sustainable alternatives in fuels, chemicals, and building products sourced from captured emissions from industrial and power generation facilities.

5. **Canada:** The Greening Government Strategy[23] was launched in 2017 by the Treasury Board of Canada Secretariat and updated further in 2020 and 2024. As part of the Strategy, the Centre for Greening Government is collaborating with various departments and agencies to green their procurement by implementing existing greening government initiatives like the Low Carbon Fuel Procurement Program, the purchase of clean electricity, the purchase of zero-emission vehicles, and the retrofitting of buildings with low or zero carbon materials. In addition, the agency is also developing new procurement requirements for products and services with a high embodied carbon footprint. The Government of Canada tracks and publishes its GHG emissions and declares information on electricity, green vehicles, and other procurements. The Treasury Board of Canada Secretariat reported a total CO_2 reduction of 731 kilo tonnes (40.6%) in scope 1 and 2 emissions across all 27 departments compared to the 2005–06 baseline.

6. **China:** The Chinese Ministry of Environmental Protection (MEP) has mandated the implementation of a program for labelling products based on their environmental friendliness[24]. The implementing agency requires all levels of state bodies, institutions, and organisations to prioritise purchasing environmentally labelled products and prohibit them from purchasing any products that harm the environment or human health. The list of products includes cement concrete products, fibre-reinforced cement products, lightweight construction materials and products, building ceramics, etc.

7. **South Korea:** South Korea spends 13.5 % of its GDP each year on public procurement. This purchasing power gives governments leverage in stimulating markets toward developing low-carbon goods and services[25]. The Korean Ministry of Environment and the Korea Environment Industry and Technology Institute introduced the green credit card system to monetise the impact of an individual's lifestyle. Green Credit Card users are rewarded with points that are converted into cash or can be donated to environmental funds when they buy eco-friendly products, use public transport, make paperless transactions, and consume less electricity, water, and gas. However, there is no specific policy targeting

the procurement of steel in the country.

8. **Japan:** The movement of green purchasing in Japan goes back to the late 1980s. In 1989, the Eco Mark Program was launched as a Type I environmental labelling scheme. In 1994, a local government started promoting its institutional green purchasing. Then, a non-profit organisation, Green Purchasing Network, was established in 1996 to support nationwide green purchasing activities. The Government of Japan enforced the Act on Promotion of Procurement of Eco-Friendly Goods and Services[26] by the State and Other Entities (Act on Promoting Green Purchasing) in 2001 to expand the market for environmentally friendly products. The Law Concerning the Promotion of Contracts Considering the Reduction of GHG Emissions by the State and Other Entities (Green Contract Law) was also enacted in 2007104. The law stipulates the green contracting requirements for elements of government agencies and public institutions in the purchasing contracts for electric power, automobiles, energy service company projects, and building designs. Even though the Green Contract Law focuses more on the GHG reduction aspect of specific products and services like transportation, delivery and printing, it complements the Act on Promoting Green Purchasing in establishing the Japanese legal framework for green public procurement.

   The Ministry of Environment (MOE) has developed the basic policy of the Act on Promoting Green Purchasing, including designated procurement items and evaluation criteria (evaluation criteria for 274 items in 21 categories does not specify steel as a standalone item) The act is mandatory for the central government and encouraged by local governments. In 2013, the Japanese government implemented GPP for 95 per cent of designated procurement items. The estimated CO_2 emission reduction from GPP is 0.21 MT of CO_2e. The act also increased the market share of environmentally friendly products.

9. **Industrial Deep Decarbonisation Initiative (IDDI)[27]:** IDDI is a global alliance of public and private organisations collectively working to create a market for low-carbon industrial materials. This initiative is led by the UK and India, with the United Nations Industrial Development Organisation (UNIDO) coordinating the effort. Through the development of a number of key definitions, tools, guidelines, and publicly accessible data, IDDI will enable the industry to conduct rigorous reporting and industry benchmarking comparisons in addition to defining common methods and understandings of what constitutes decarbonised steel and cement products. In addition, through the initiative's member country network, the IDDI advocates for governments to set procurement targets for purchasing decarbonised steel and cement, particularly for publicly funded major projects such as buildings, roads and bridges, given that this makes a significant share of purchasing power. Essentially, this creates an assured market for these low-emission products.

   Canada, Germany, the UK and the USA have announced a timebound four-level IDDI Pledge[28] to procure low-emission steel, cement and concrete and have set emission reduction thresholds for the whole project life cycle assessments to achieve net zero emissions in public buildings and built infrastructure. They also commit to supporting innovation and deploying breakthrough technologies by stimulating demand and commercialising near-zero emission materials.

10. **European Union-United States deal on decarbonised steel and aluminium**: The European Union and the United States have committed to finalising a deal on low-carbon steel and aluminium wherein the negotiating parties propose to create a favourable tariff arrangement that ensures a market for these low-carbon products[29].

4.2.1.2. Private procurement

A successful transition to green steel requires commitments from the private players in the key steel-consuming sectors to procure steel produced from less emissions-intensive pathways. Some key initiatives in the private sector are discussed below:

1. **SteelZero:** SteelZero is a global initiative which brings together leading organisations to speed up the transition to a net-zero steel industry[30]. To date, 43 global organisations have joined SteelZero and made a public commitment to procure 100% net zero steel by 2050 or 2040 and an interim commitment to procuring, specifying or stocking 50% of its steel requirement by 2030 or earlier. These organisations are spread across various steel-using sectors like construction and engineering, renewable energy, structural steel, real estate, and automotive. The entities part of the initiative and their commitments are summarised in Table 4.1.

Table 4.1: *SteelZero commitments*

S.No.	Sector	Organisation/company	Commitments
1	Shipping	A.P. Moller – Maersk	100% of steel requirement to be net zero before 2040 & to transition 50% of steel requirement to meet the SteelZero interim criteria by 2030.
2	Equipment supplier	GEA Group	
3	Real estate	Lendlease	
4	Renewable energy	Siemens Gamesa	
5	Construction and engineering	Walsh	
6	Construction & engineering	Robert Bird Group	100% its steel requirement to be net zero before 2045 & to transition 50% of steel requirement to meet the SteelZero interim criteria by 2030.
7	Real estate	Sir Robert McAlpine	
8	Construction	Mace Group	100% of steel requirement to be net zero before 2050 & to transition 50% of steel requirement to meet the SteelZero interim criteria by 2025.
9	Automotive	Polestar, Volvo Cars	100% of steel requirement to be net zero before 2050 & to transition 50% of steel requirement to meet the SteelZero interim criteria by 2030.
10	Construction	B+M Steel, Balguard Engineering Ltd, Blocotelha, Deconstruct UK, MetStructures, Multiplex Construction Europe, SKF	
11	Construction & engineering	B&K Hybrid Solutions Ltd., Buro Happold UK, John Sisk & Son, Kilnbridge, Smulders, Bourne Group	
12	Engineering	Trane Technologies, ViaCon Group, William Haley Engineering, William Hare, WSP UK	

13	Industrial design	Eiffage Métal	100% of steel requirement to be net zero before 2050 & to transition 50% of steel requirement to meet the SteelZero interim criteria by 2030.
14	Luxury	Chopard	
15	Real estate	British Land Company Plc, Grosvenor Property, Hang Lung Properties	
16	Renewable energy	Iberdrola, Orsted	
17	Retail & hospitality	Landsec	
18	Steel designing	BHC Limited	
19	Steel supplier	Barrett Steel Limited	
20	Structural steel	Severfield plc	
21	Structural steel contracting	Billington Structures Ltd, J&D Pierce Contracts Limited	
22	Supply chain	CIMC TCREA	
23	Wind energy	Vattenfall BA Wind	

2. **First Movers Coalition**[31]**:** FMC is a consortium of 98 members that intend to leverage their purchasing power to create early markets for innovative clean technologies across eight hard-to-abate sectors. These sectors include aviation, aluminium, chemicals, concrete, shipping, steel, trucking and direct air capture. The FMC has set ambitious commitments for steel consumers to procure at least 10% (by volume) of near-zero emission steel per year by 2030. 27 members have committed to meeting the targets set by FMC for the steel sector.

3. **H2 Green Steel**[32]**:** Private commitments are likely to drive the overall demand for green steel, resulting in investment flows in the sector. This is demonstrated by H2 Green Steel, a Swedish company headquartered in Stockholm that plans to undertake the global technological shift to produce steel with 90 % lower carbon emissions. The company will have an annual capacity of 2.5 MTPA in 2025 and has signed pre-contracts for 1.5 MTPA of green steel for 5 - 7 years from 2025. The company has listed Adient, BE Group, BILSTEIN GROUP, BMW Group, Electrolux, Kingspan, Klöckner & Co, Lindab, Marcegaglia, Mercedes-Benz, Miele, Mubea, Purmo Group, Roba Metals, Scania, Schaeffler, Zekelman Industries and ZF Group as customers who have pre-contracts[33].

4.2.2. Indian scenario

This section of the report documents the progress made in green public and private procurement in India. On GPP, Energy Efficiency Services Limited (EESL) has demonstrated the benefits of bulk procurement of energy efficiency and renewable energy technologies and the price reductions achieved through it. While private procurement of green products has not started in India, many private companies have set climate goals that will enable the uptake of green steel in the future.

4.2.2.1. Green public procurement

In India, numerous examples of public procurement programmes have had a significant impact; however, they are not specifically targeted towards steel procurement. In 2008, the Indian railways replaced Incandescent Lamps (ICL) bulbs with compact fluorescent lamps (CFLs) for 400,000 railway residential quarters[34] with a maximum of 4 CFLs each. The supplier recovered the cost through trading Certified Emission Reductions (CERs) (97% to the supplier and 3% to Indian Railways), and 0.09 MT of CO_2 was estimated to have been saved annually.

EESL has enabled consumers, industries and governments to manage their energy needs effectively through energy-efficient technologies. It has been implementing energy efficiency programmes across sectors like lighting, buildings, industry, electric mobility, smart metering, agriculture, etc. The list of initiatives implemented or under implementation by EESL is schematically represented in Figure 4.2. Under schemes such as UJALA[35], 36.86 core LED bulbs, 72.18 lakh LED tube lights and 23.59 lakh energy efficiency fans were distributed across the country, resulting in emission savings of nearly 40 MT of CO_2 per year. Further programmes such as the National Motor Replacement Program, Corporate Driven Programme, Retrofit of Air-Conditioning to Improve Indoor Air Quality For Safety And Efficiency (RAISE), and EESL's super efficiency AC program specifically focuses on innovative technology management solutions for increasing energy efficiency and performance of industrial motors, heat pumps, air conditioning, respectively.

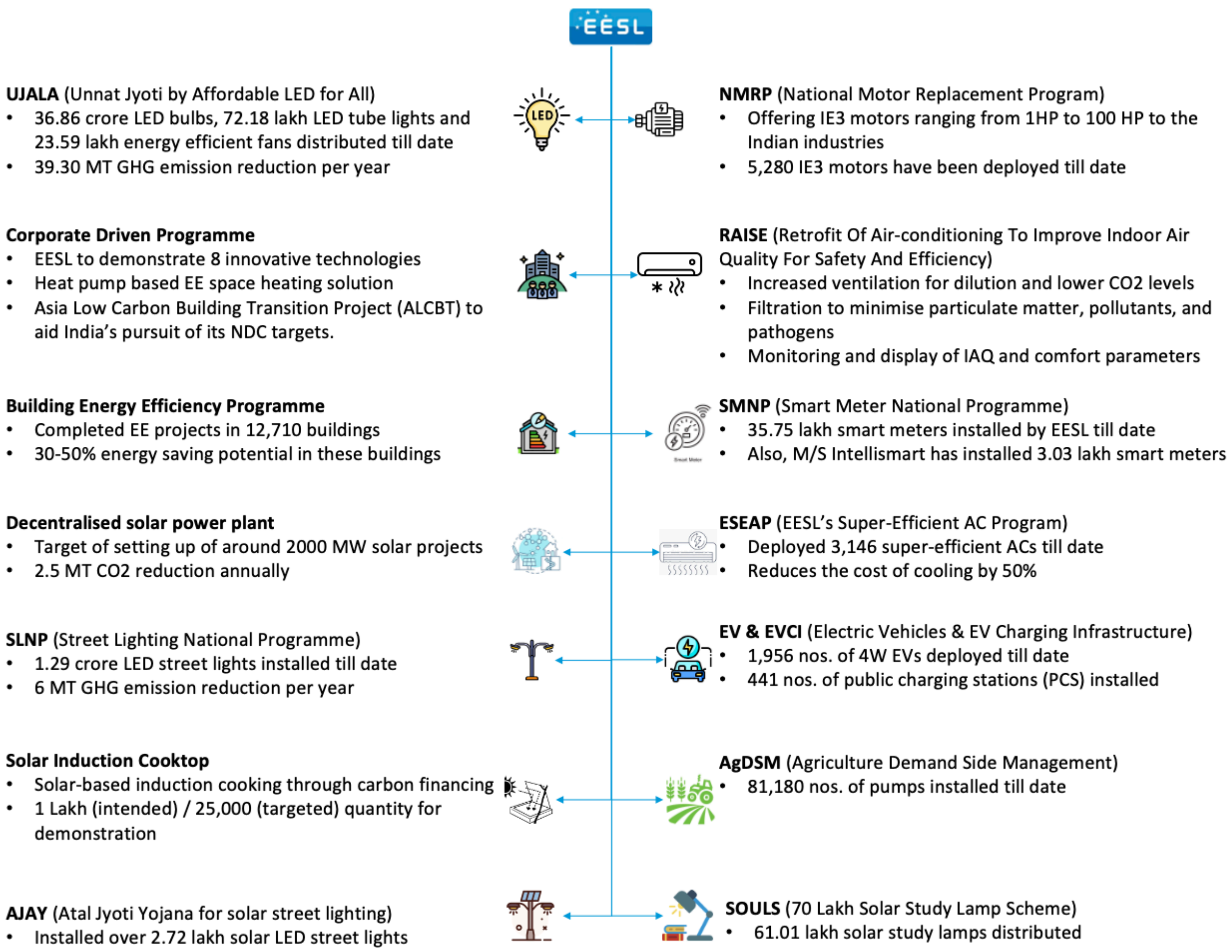


Figure 4.2: *EESL Green public procurement*[36]

4.2.2.2. Private procurement

A few companies like Siemens Gamesa, Mace, WSP, Volvo, SKF, Maersk, Severfield, etc., that have committed to the SteelZero initiative also have a presence in India. Further, five Indian companies are also a part of the FMC initiative. These include Bharat Forge, Dalmia Cement (Bharat), Mahindra Group, ReNew Power, and RMZ Corporation. Apart from these, a few private companies in India have also disclosed plans to achieve net zero emissions, which include scope 3 emissions, as a part of their ESG commitments. These companies consume steel to a significant extent for construction, infrastructure, capital goods and automobile production. A few commitments are listed below:

1. **Lodha group:** The Lodha group is a real estate developer that aims to achieve a 51.6% reduction in scope 3 emission intensities by 2030 and plans to achieve net zero by 2050[37].
2. **JLL India:** JLL India is a real estate developer that has committed to reducing absolute scope 1, 2, and 3 emissions by 51% by 2030 and 95% by 2040 from a 2018 base year[38].
3. **ABB:** ABB has set a target of reducing its scope 3 emissions by 25% by 2030 (compared to 2022) and 90% reduction by 2050 (compared to 2022)[39].
4. **Cummins India:** Cummins India has set a target of reducing its absolute lifetime scope 3 emissions by 25 % from newly sold products in 2030 and achieving net zero by 2050[40].
5. **Tata Motors:** Tata Motors has committed to reducing its Scope 3 emissions from purchased goods and services and use of sold products by 54% per car by 2030 from a 2020 base year[41].

4.3. Challenges

There are challenges associated with generating demand for greener products through public or private procurement due to the cost premium associated with it. There are also challenges on the supply side and ecosystem readiness that can potentially impede the creation of a market for green steel. These are discussed below:

4.3.1. Public Sector Challenges

There are challenges to green public procurement primarily due to the anticipated high cost of green steel that might have ripple effects on infrastructure and construction projects by the government. Further, the inherent complexities of government procurement procedures, coupled with a potential lack of understanding of the broader economic impacts of GPP, pose hurdles. Some of them are enlisted as:

1. **Potential impact on the pace of infrastructure deployment:** India is a developing country, and a significant amount of infrastructure has yet to be deployed. Any increase in the cost of steel is likely to increase the budget requirements for the infrastructure projects, which might slow the pace of infrastructure development in the country.
2. **Potential impact on social initiatives:** The government has many social initiatives like Pradhan Mantri Awas Yojana (PMAY) that aim to construct affordable housing complexes. Any increase in steel cost might directly impact the coverage of these social initiatives.
3. **Decentralised procurement:** India's decentralised public procurement system poses a challenge for widespread adoption of green steel through Green Public Procurement (GPP). While central ministries manage procurement at the national level, state governments also undertake numerous infrastructure and construction projects, leading to independent steel procurement at the state level.

Ensuring all central and state government ministries prioritize green steel requires a coordinated approach to GPP implementation.

4. **Macroeconomic implications:** The macroeconomic implications like inflation etc. due to premiums on green products are not very well understood for a developing country like India.

5. **Administrative Burden:** Implementing GPP policies might increase the administrative burden on procurement officials, requiring additional time and resources for evaluation and documentation.

4.3.2. Private Sector Challenges

The private sector is driven by the intent to maximise its profitability while capturing a higher market share. A green procurement at higher costs potentially conflicts with these objectives. The challenges with private procurement of green steel in India are discussed below:

1. **Price-sensitive market:** India is a price-sensitive market. Any increase in the cost of a white good or an automobile due to the procurement of green steel might affect the competitiveness of the manufacturer, and it risks losing market share. If the premium is not passed on to the end consumer, then it might affect the profitability of a company. This is a significant detriment to the private consumption of green steel in India.
2. **Lower per-capita income of the general population:** India is a developing country, and the per-capita income of the general population is significantly lower than that of the developed world. Any increase in the cost of end-use commodities or products will significantly impact the spending of an average family in the country. For example, any increase in the cost of a housing project will increase the Equated Monthly Instalment (EMI) of a house loan. Further, unlike the developed countries, India's population is still growing. Therefore, India needs to strike a balance between the aspirations of a young population and its climate commitments.

3. **Low market share of premium brands**: Luxury brands of automobiles, white goods and construction projects can be the first movers for buying green steel as the end-consumers can afford to pay a premium for green products. However, the market penetration of these luxury brands might not be significant enough to create a big market for green steel. The demand for luxury products is expected to increase with time as the country moves towards becoming Viksit Bharat.

4. **Lack of Awareness:** The consumer base of the end-use product needs to be made aware of its responsibility to purchase greener products so private demand can upscale. For example, unless people are sensitive enough to demand greener cars, automobile manufacturers will not demand green steel.

4.3.3. Ecosystem challenges

The ecosystem for green steel production is still evolving in India. The trade-in of green steel will largely depend on the definition of green steel, the MRV mechanism, the green steel certification mechanism and inventory management. BEE will do the MRV mechanism, green steel certification and registry under the ambit of Indian carbon markets. The Indian carbon market is under development, and therefore developing an ecosystem for trade in green steel might take more time. Clear and well-defined technical specifications for green steel are crucial to ensure its environmental benefits and performance.

4.3.4. Supply-side challenges

The emission intensity of steel produced in India is significantly higher than the global average due to multiple challenges like lack of access to decarbonisation technologies, high-grade input materials like iron ore, and low-carbon fuels like natural gas at affordable prices and scrap. A significant reduction in the emission intensity of existing steel capacity will only be possible through capital-intensive technologies like green hydrogen and CCUS, an ecosystem for which is yet to develop in India. While green hydrogen-based DRI can significantly reduce the emissions from greenfield capacity additions, its current cost is prohibitively high for use in the steel industry. Given these supply-side issues, the availability of green steel will also be a challenge in the short-to-medium term.

4.4. Evolution of GPPP in India

As seen, GPPP is the most essential policy lever for decarbonisation of the steel sector in the short term, as it nudges the producers to transition to expensive, cleaner technologies by meeting their extra cost burden as well as providing them with market signals for assured demand of green steel. However, as discussed, it is fraught with challenges, especially its monetary implications. The government must take a prudent approach to provide the right balance between incentives for the producers and the resultant cost escalation in government projects.

This section discusses important aspects of GPPP and gives the guiding principles for the evolution of GPPP in India. It also provides projections of steel demand in the public sector, sectoral distribution of steel demand, insights into the cost premium for green steel, projected uptake of green steel by the government, cost implications of GPPP on government infrastructural spending and a framework for GPP.

4.4.1. Guiding principles for GPPP in India

A GPP policy in India can be developed based on various guiding principles. These guiding principles are briefly discussed below:

1. **Share of Green Product in total procurement:** Establishing the right share of green steel in total steel consumption by the public sector, considering various factors like cost burden and decarbonisation, would be the key to striking a balance between sustainability and infrastructure development.

2. **Green steel mandates vs flexible targets:** GPP can be implemented through a mandate where a certain percentage of steel procurement has to be green every year, or there can be a broader mandate on total green steel consumption across a range of years that will provide flexibility on yearly consumption. Careful evaluation of mandates against flexible targets must be incorporated to achieve demand generation at optimum levels. Mandates as a percentage of total procurement can ensure steady demand and early kickoff of the supply, but they might be expensive initially. Flexible targets allow for adjustments over time as technology advances, economies of scale drive down costs, and demand for green steel increases. However, it also risks postponing green steel consumption in the public sector.

3. **Price discovery mechanism for green steel:** Another aspect to consider is the method for determining green steel prices. Options such as reverse bidding, first come, first serve, one-time bids and selecting the lowest bidder can be considered. Reverse bidding can ensure competition and low prices but also can lead to supplier manipulation. First-come-first-serve and one-time bids provide simplicity and efficiency but may not always result in the best value for money.

4. **Quota for near-zero emission steel:** Keeping quota in the procurement for near-zero emission technologies like green hydrogen-based steel production, or new technologies that capture carbon

can drive innovation in riskier and advanced methods of low-carbon steel in India. A balance between incremental and absolute decarbonisation would be critical to reducing the cost of green steel and promoting futuristic over-the-horizon technologies.

4.4.2. Current steel demand in the public sector and its growth projection

India's current total steel production capacity is approximately 179.5 million tonnes (MT)[42]. As per the National Steel Policy, 2017, the production capacity is to be roughly doubled by 2030 -31 to 300 MT[43]. The increased demand across various end-use sectors will primarily drive the growth in production capacity. Steel consumption in the Indian economy can be broadly classified into five buckets: construction, infrastructure, white goods, automobiles, and defence. Figure 4.3 provides public and private sector-wise steel consumption data for 2022-23 and estimates for 2030-31. It is seen that the construction and infrastructure projects together account for more than 2/3rd of the total steel consumed in India. The government primarily drives steel consumption in infrastructure and defence projects. Private sector consumption is dominated by construction projects, automobile and white goods segments.

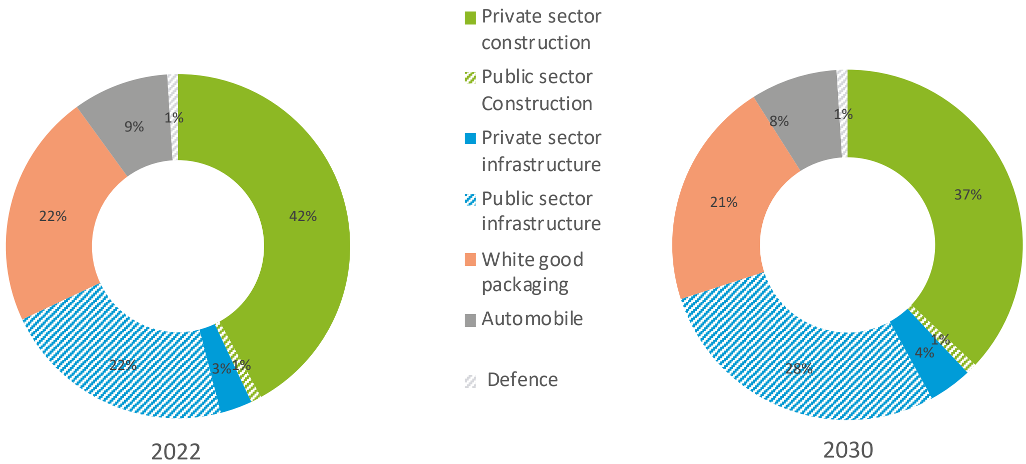


Figure 4.3: Sector-wise breakdown of steel consumption[44]

The growth in the public sector's steel consumption can be estimated using two methods. In the first method, public sector steel consumption growth can be linked to GDP growth and infrastructure investment as a share of GDP. In the second method, a simple CAGR can be used to project the steel consumption in the public sector across various years. This section discusses both approaches for estimating steel consumption in the public sector till 2030-31.

Approach 1: In the first method, infrastructure projects are expected to primarily drive the growth in steel consumption in the public sector. As shown in Table 4.2, infrastructure spending is 2-2.5% of the gross domestic product (GDP) in FY 2021-22 and FY 2022-23, based on actual expenses by the government. Even assuming a conservative 6.5%[45] real GDP growth rate, the total spending on infrastructure projects will be INR ~17 lakh crore by 2030-31 in a business-as-usual scenario. The government of India intends to boost the country's infrastructure development. Therefore, in an aggressive scenario[46], the infrastructure expenditure is expected to increase to INR ~18.8 lakh crore.

Based on the FY 2021-22 and FY 2022-23 data regarding steel cost and consumption in the infrastructure sector, it is seen that steel constitutes 18-21% of the total expense in infrastructure projects. Assuming that the cost of steel does not change and considering an average 20% share of steel in infrastructure projects by 2030-31, the total steel consumption is expected to be 62-68 MT by 2030-31. Further, the steel consumption in the defence and construction sector is expected to double from 2 MT to 5 MT by 2030-31. Therefore, the total steel consumption by the public sector is expected to be 67-73 MT by 2030-31.

***Table 4.2:** Budget for defining green steel in India*

S. No.	Parameter	Unit	2021-22	2022-23	2030-2031 Scenario 1 BAU for infrastructure development	2030-2031 Scenario 2 Aggressive infrastructure development
1	GDP (current prices)	USD trillion	3.385[47]	3.736[48]	7.1[49]	7.1
2	GDP (current prices)	INR Lakh crore	270.8	298.88	568.4	568.4
3	Infrastructure expense	INR Lakh crore	5.54[50]	7.5[51]	17.05	18.76
4	Infrastructure expense as share of total GDP	%	2.05%[52]	2.51%	3%	3.30%[53]
5	Steel cost as share of total infrastructure cost	%	21%	18%	20%	20%
6	Total cost of steel procurement	INR Lakh crore	1.19	1.36	3.41	3.75
7	Steel cost	INR/ tonne	52000[54]	55000	55000	55000
8	Total steel procurement in infrastructure projects	MTPA	23	25	62	68
9	Steel procured in defence and construction projects	MTPA	2	2	5	5
10	Total steel procurement by GoI projects	MTPA	25	27	67	73

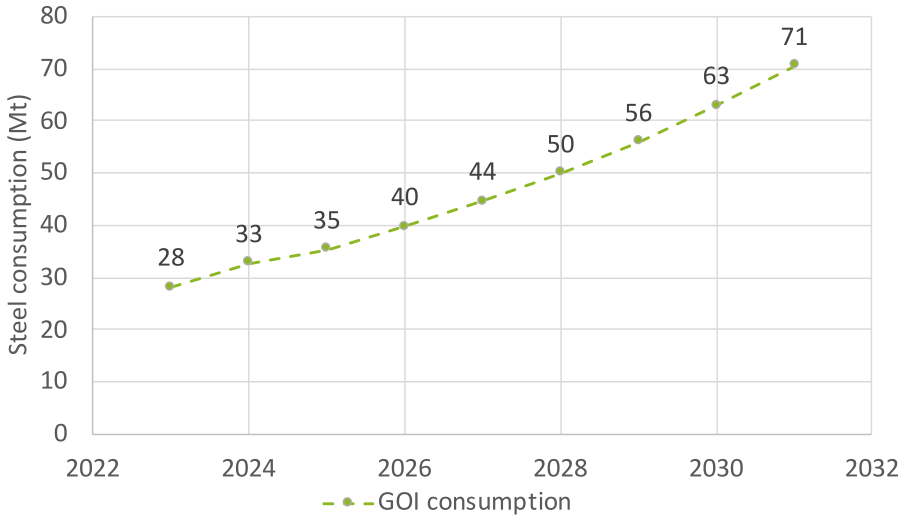


Figure 4.4: *Steel consumption in Government projects till 2030-31*

4.4.3. Potential cost impact of the GPP policy

Energy efficiency and renewable energy are the low-hanging fruits for decarbonising the steel sector. However, these technologies need significant capital investments. The use of these technologies also leads to an increase in the cost of steel production by about 10-15%. Further, energy efficiency and renewable energy can reduce the emission intensity of steel at best only by 25%[55] for the BF-BOF process and 30%[56] for the coal DRI-IF process. Further reduction in emissions intensity is only possible through other decarbonisation options like the use of alternative fuels and CCUS. It is seen that ~56%[57] of the total emissions from the current production pathways can be abated only through CCUS. Further, near-zero emissions steel produced through the BF-BOF pathway has a 20% - 68%[58] premium over conventionally produced steel for a CCS cost of USD 50-92/t-CO_2[59].

The use of green hydrogen to produce iron from iron ore coupled with renewable energy to power the EAF units can produce nearly zero emissions or even fossil-free steel. However, it is seen that green hydrogen-based steel has a 50-70%[60] premium over conventionally produced steel. This is expected to reduce to 20-29%[61] by 2030-31. Decarbonising steel production, irrespective of the existing technology mix or new technologies, has a premium attached. Therefore, it is important that this factor be considered while developing a GPP policy.

A premium on green steel is expected to potentially increase the budget of public procurement in India. This section deals with the potential budgetary impact due to a premium on green steel. The budgetary impact of green steel procurement for public sector projects is assessed in two ways. The first method assesses a broader potential impact on the overall infrastructure sector. Subsequently, a few project-specific potential impacts are assessed for a select few projects across infrastructure and construction segments. It is also important to note that infrastructure projects require other emission-intensive goods such as cement, aluminium, etc. If GPPP is adopted, then these construction materials will also be procured and mandated to be from low-emission producers. Thus, the additional expense of public procurement of green products should not be limited to that from green steel only. However, for the sake of easing analysis, the impact has been analysed only with respect to the procurement of green steel.

Figure 4.5 shows a possible trajectory for green steel procurement in the future. In this possible trajectory, it is assumed that that the share of green steel is 5% for FY27 and FY28, increasing to 10% for FY29 and FY30, and reaching 15% for FY31. The total GPP of steel from FY27 to FY31 could be 27.2 MT.

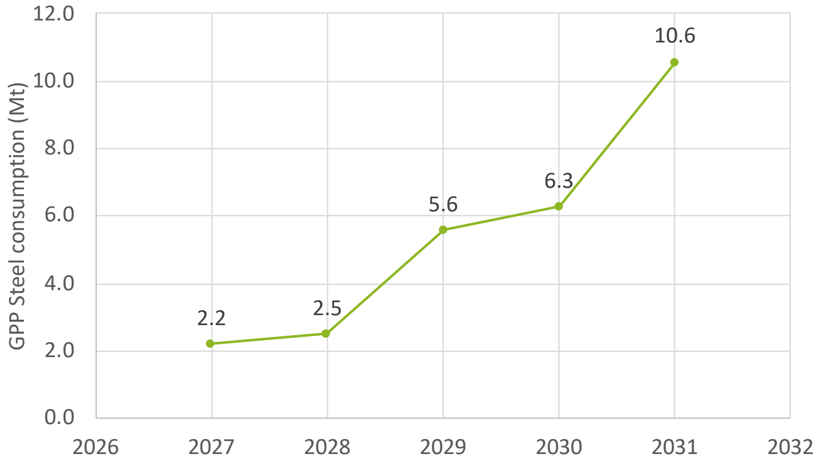


Figure 4.5: *Green public procurement trajectory from 2026-27 to 2030-31*

Figure 4.6 depicts the potential annual budgetary impact of GPP on government expenses. The premium on green steel will depend on its definition, which is being deliberated in the task force and will be finalised in the future. Therefore, the potential impact of GPP on government expenses is indicated for a 10% and 15% premium on green steel. At a 10% premium, the annual budgetary impact may increase from INR 1,223 crore in 2026 to INR 5,820 crore in FY31, resulting in a total outlay of INR 14,954 crore over the period. At a 15% premium, the impact may range from INR 1,834 crore in 2026 to INR 8,730 crore in FY31, with a total outlay of INR 22,431 crore.

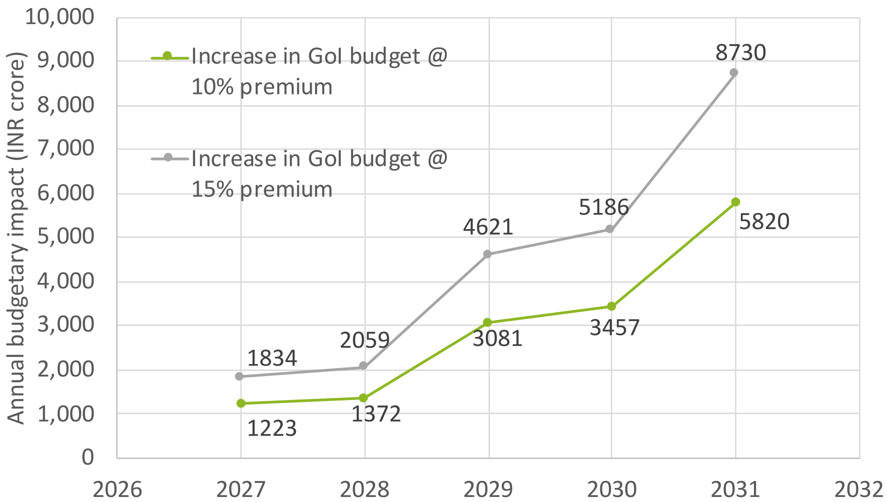


Figure 4.6: *Annual budgetary impact of GPP on government expenses*

4.4.3.1. Potential impact of GPP on infrastructure sector

Table 4.3 illustrates the budgetary impact of green steel procurement on infrastructure projects. The budgetary implications of GPP will depend on two factors - the premium on green steel and the percentage uptake of green steel in the infrastructure projects. As seen above, the premium on green steel varies significantly across different decarbonisation levers. However, it is expected that by 2030-31, levers like energy and material efficiency and renewable energy will mainly drive the decarbonisation efforts of the steel industry. Hence, for estimating the potential budgetary impact of green procurement, a green steel premium in the 10-30% range is being considered[62]. Further, it is assumed that 100% of the steel consumption across these projects will be replaced by green steel. For the analysis, the data related to steel cost, steel consumption, and infrastructure expenses are obtained from Table 4.2. Even with 100% green steel uptake, the average total budget of the infrastructure projects increases by only 1.83% -5.50%.

Table 4.3: *Budgetary Impact of public procurement of green steel*

	Unit	Base case (FY 2023)	With green steel premium @10%	With green steel premium @20%	With green steel premium @30%
Steel Cost	INR/tonne	55000[63]	60500	66000	71500
Government steel consumption for infrastructure in 2023	MT	25	25	25	25
Total cost of steel procurement	INR lakh crore	1.38	1.51	1.65	1.79
Infrastructure expense	INR lakh crore	7.5[64]	7.5	7.5	7.5
Steel cost as share of total infrastructure cost	%	18%	20%	22%	24%
Budget Impact	%		1.83%	3.67%	5.50%

It is unlikely that a GPP will have a mandate to uptake 100% green steel across various projects. Therefore, the budgetary impact will be lower for a lower uptake of green steel in the infrastructure projects. The graph in Figure 4.7 shows the increase in the project costs (as a percentage of total cost) as green steel procurement increases. For a 20% mandate of procurement of green steel in total average, the project cost increases by only 0.37 - 1.1 %, depending on the premium.

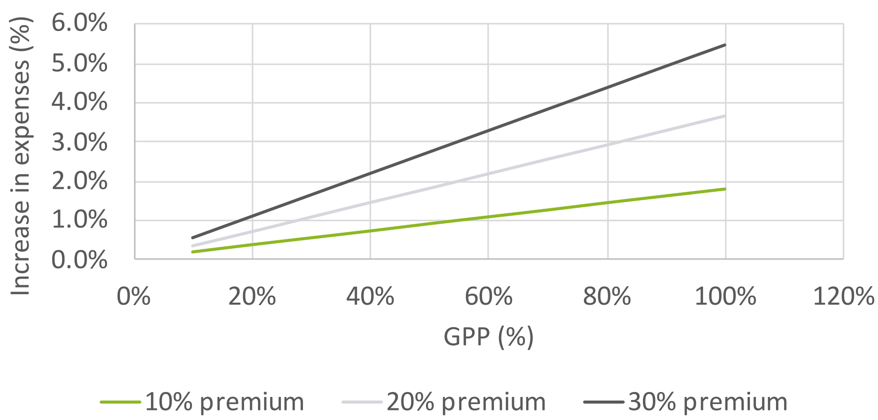


Figure 4.7: *Impact of Green Steel Procurement on Infrastructure Sector*

4.4.3.2. Potential impact of GPP for select few projects

The previous section discussed the sectoral impact of green steel procurement across infrastructure projects. This section illustrates the budgetary impact of green steel procurement for a select few infrastructure and construction projects listed in Table 4.4. The information related to the budget and steel consumption in these projects is available in the public domain[65]. These projects span across various types of infrastructure and construction initiatives by the Government of India. The total budget and steel intensity differ significantly across these projects; hence, an assessment can reflect the potential impact of GPP across various types of projects. As indicated in Table 4.4, these projects consume ~111 MTPA of steel and have a budget of INR 26 lakh crore. It is seen that, on an average, steel constitutes ~19% of the total project cost; the actual share varies depending on the project type.

Table 4.4: Green steel demand and cost escalation for infrastructure and construction projects

	Estimated steel consumption (MT)[66]	Current project cost (lakh crores)[67]	Green steel demand (MTPA)*	Steel cost (INR lakh crore)	Steel cost as % of total cost**	% increase in project cost for a premium of 10%	% increase in project cost for a premium of 20%	% increase in project cost for a premium of 30%
Bharatmala project	18.6	5.35[68]	18.6	1.02	19%	1.91%	3.82%	5.74%
PMAY (urban)	30	8.19[69]	30	1.65	20%	2.01%	4.03%	6.04%
PMAY (rural)	22.5	-	22.5	1.24	-	-	-	-
Dedicated freight corridor	6.2	0.81[70]	6.2	0.34	42%	4.21%	8.42%	12.63%
Jal Jeevan Mission	12	3.5[71]	12	0.66	19%	1.89%	3.77%	5.66%
UDAAN	8	-	8	0.44	-	-	-	-
Sagarmala project	14.1	8.5[72]	14.1	0.78	9%	0.91%	1.82%	2.74%
Total	111.40	26.47	111.40	6.13	19%	1.68%	3.36%	5.04%

**Assuming steel cost of INR 55000 per tonne

*Share of green steel in total procurement - 100 %

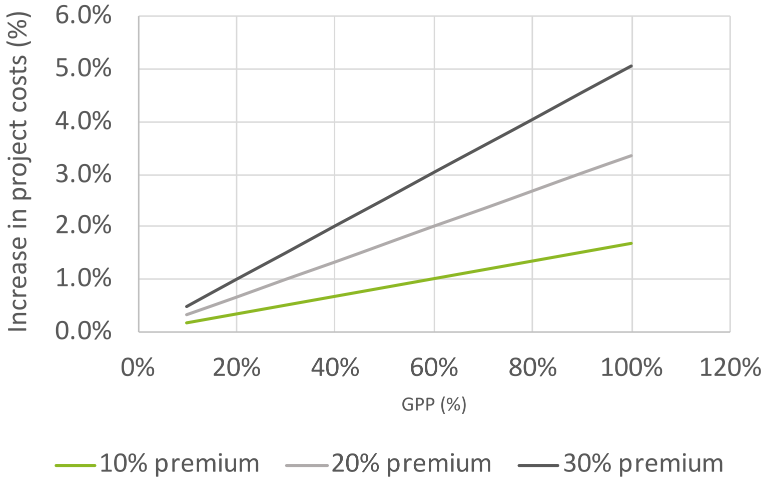


Figure 4.8: Impact of Green Steel Procurement on select few Infrastructure and Construction Projects

4.4.4. Proposed Framework for procurement of green steel in India

Figure 4.9 shows a potential framework for procurement of green steel in India. Following the success of the EESL model, it is envisaged to designate a central agency for bulk procurement of green steel. The agency will be responsible for aggregating demand from various end users of steel across the public and private sectors. Subsequently, the agency can opt for bulk procurement through a competitive reverse bidding mechanism from various steel players. MRV and certification of green steel will be instrumental in guaranteeing the greenness of steel. Therefore, the agency will coordinate with BEE or any other nodal organisation responsible for the certification of green steel. While this agency will be primarily responsible for GPP, private players will also be encouraged to procure green steel from the agency and benefit from guarantees on greenness and economy of scale due to bulk procurement. It is envisaged that this body will be a one-stop solution for buying and selling green steel in India.

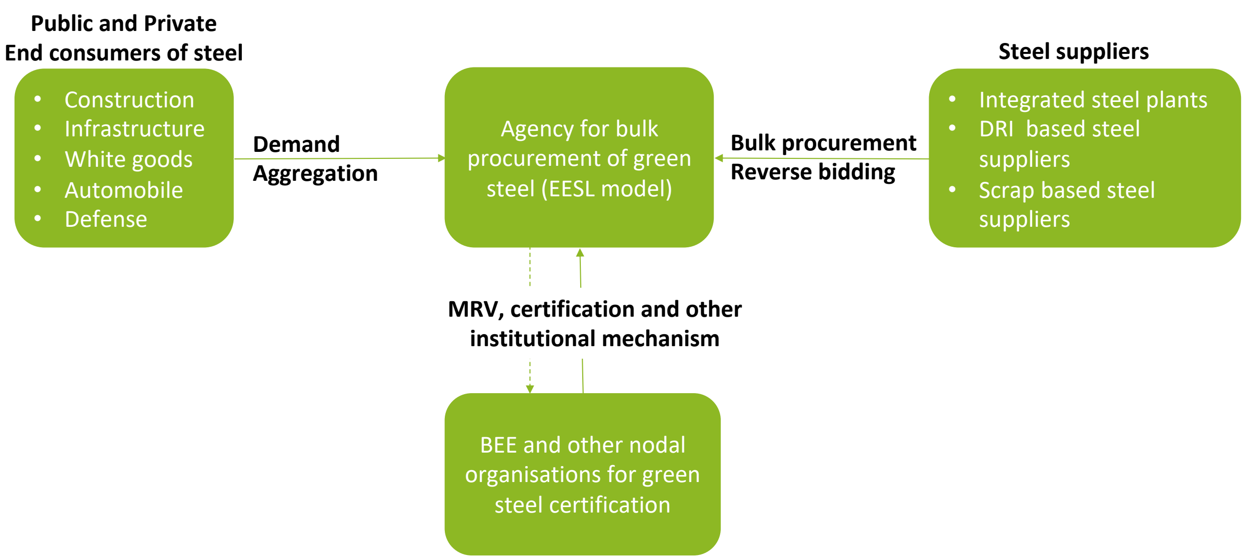


Figure 4.9: Potential framework for procurement of green steel in India

4.5. Measures to increase private demand for green steel

Given that India is an emerging economy, the demand for basic inputs like steel is expected to grow significantly in the private sector. As discussed earlier, the public sector consumes 20% of India's steel while the private sector consumes the remaining quantity. Private consumers across the building and construction sector, engineering, packaging and automobiles can potentially consume a significant share of green steel produced in India. These entities are, however, not the final consumers of steel as they produce some value-added goods that common people eventually consume. Consequently, an increase in the price of raw materials like steel will be eventually passed on to the end consumer.

It is seen that in the products produced by entities, steel makes up only a small share of the overall cost. Therefore, any increase in the cost of input materials like steel will not significantly affect the competitiveness of their products in the market. For example, if green steel is 15-40%[73] expensive than conventionally produced steel, the cost of a passenger automobile increases by only 0.5%[74] and white goods only by 1%[75]. The uptake of green steel by private entities will, therefore, play a crucial role in creating a sustainable market for green steel.

The automobile sector can play a key role in the uptake of green steel. As a first step, luxury car makers in India can start guaranteed uptake of green steel so that the premium is paid by a relatively affluent section of society. Later, as the cost of green steel reduces due to the economy of scale, manufacturers of all automobiles can start consuming green steel.

Premium housing societies in and around cities can use green steel for construction projects. These societies can advertise their houses as green, which can fetch a premium in the market. Similarly, premium white goods like mobile phones, laptops, and refrigerators can consume green steel and command a higher price in the market. For these commodities, the increase in cost due to green steel will be marginal as the bulk of the cost can be attributed to brand value and not actual material cost.

The following measures can increase the steel consumption in the private sector:

1. **Mandating disclosure of product emissions intensity, including scope 3 emissions:** The shift towards measuring, disclosing, and reducing scope 3 emissions reflects a growing recognition of the environmental impact across the entire supply chain. As the ecosystem prioritises sustainability goals and stakeholders demand more transparency, there's an inclination to seek out greener alternatives in all aspects of operations, including procurement of materials. This can be pivotal for creating a demand for green steel in sectors with high steel consumption.
2. **Higher ESG ratings for consumers of green products:** ESG ratings have also become pivotal in influencing financing decisions and market access for companies. A higher ESG rating signifies a commitment to responsible business practices, which can attract investors, lower borrowing costs, and unlock new market opportunities. For major steel consumers, integrating green steel into their supply chains presents a strategic advantage in operations.
3. **Including embodied emissions in green ratings of buildings:** Accounting for embodied emissions arising from construction materials like steel in green ratings of buildings would create demand for green steel. Green building certifications like LEED and Griha Rating have an instrumental role to play in this regard.
4. **Lower rates of tax or tax holiday on GST for green steel:** Taking cognisance of the higher price of green steel, when compared with the conventional form of steel, its consumption can be incentivised for private

procurement by having lower or no tax burden on green steel. Currently, GST on steel stands at 18%, and with the already high price of green steel, this would further impede the competitiveness of the final product. In this regard, considering a lower rate of tax or a tax holiday on GST for green steel procurement may increase the competitiveness of green steel and increase its uptake by private consumers.

4.6. Action plan

The government of India may take the following steps to further the uptake of green steel in the country.

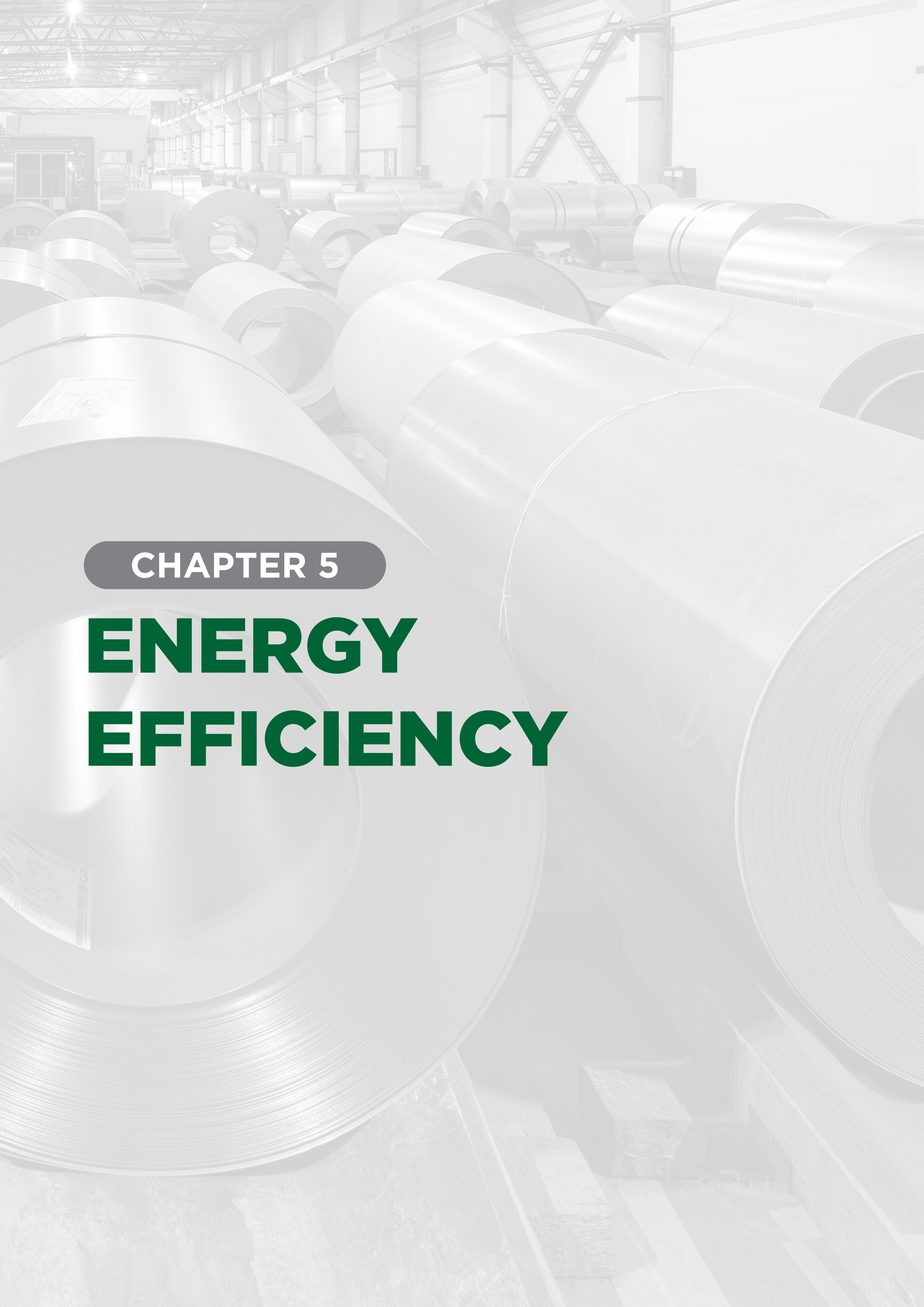
1. **Estimate premium on green steel:** The Ministry of Steel may take up a study to estimate the premium on green steel based on its definition and the technologies used for the transition. It may then aid in deciding the procurement targets for publicly funded projects.
2. **Development of GPPP for green steel:** In coordination with the Ministry of Finance, the Ministry of Steel may prepare a framework for Green Public Procurement (GPP) policy for the steel sector based on an extensive study of similar policies across the globe. The Ministry of Finance may then take up the framework for further development and action.
3. **Capacity Building and Training Programs:** Once the policy is in place, the Ministry of Steel, in coordination with relevant bodies, may organise Capacity-Building and Training Programs to equip procurement officials with the necessary knowledge and expertise to evaluate and compare green steel options effectively in tenders.
4. **Ease of buying and selling green steel:** Ease of buying and selling green steel may be important to create an enabling ecosystem for green steel consumption in India. This involves developing a robust measurement, reporting, and verification (MRV) system for emissions accounting, a registry of green steel production and consumption, and tracking of green steel certification. This may also involve developing an ecosystem for green steel certification. The Ministry of Steel may develop a one-stop solution for buying and selling green steel in India.
5. **Scope 3 emissions disclosure by end users:** The government may encourage voluntary disclosure of scope 3 emissions by end-users of steel, like the automobile industry and construction projects. Further, discussions on mandatory disclosure of scope 3 emissions for steel-intensive projects and goods may be initiated in consultation with all stakeholders. This may create awareness about scope 3 emissions amongst the end-users of steel in the country.
6. **Enhanced Environmental, Social and Corporate Governance (ESG) rating points:** It is important to ensure that ESG norms give higher ratings to private companies consuming green steel. Transparency and robust regulatory framework by government agencies like the Securities and Exchange Board of India (SEBI) for ESG ratings may push consumers to opt for green steel. Through relevant agencies, the government may strive for transparency in the ESG ratings of companies to include green procurement as an evaluation criterion.
7. **Setting up of agency:** The Ministry of Steel may set up an agency along the lines of EESL to facilitate bulk procurement of green steel in both public and private procurement. This may also closely work with the certification body.
8. **Tax Incentive for Green Steel:** The Ministry of Steel, in collaboration with the department of revenue and other relevant organisations, may introduce a tax incentive scheme for green steel. This scheme may include a reduced Goods and Services Tax (GST) rate or a complete tax holiday period for the procurement

of green steel. The objective is to lower the cost disparity between green steel and conventional steel, thereby enhancing the market competitiveness and enabling ecosystem for green steel.

9. **Raising Public Awareness:** The ministry may engage agencies to run awareness campaigns for consumers, nudging them to prefer to buy products with green steel. The label 'Green Steel Inside' should be developed and promoted.

Proposed studies: The Ministry of Steel may carry out the following studies to enable the decarbonisation of the steel sector.

10. **Impact of decarbonisation on end consumers:** There is a need to assess the change in the price of steel with decreasing emission intensity. The study may focus on assessing the steel production cost with varying emission intensity and evaluate its effect on the end consumers.
11. **Macroeconomic implications for the steel sector:** There is a need to assess the macroeconomic implications of steel decarbonisation, such as changes in demand, effects on inflation etc.
12. **Review of green buildings and associated codes and standards:** To incentivize end-users to consume green steel, a thorough review of green buildings and associated codes and standards may be conducted.



CHAPTER 5

ENERGY EFFICIENCY

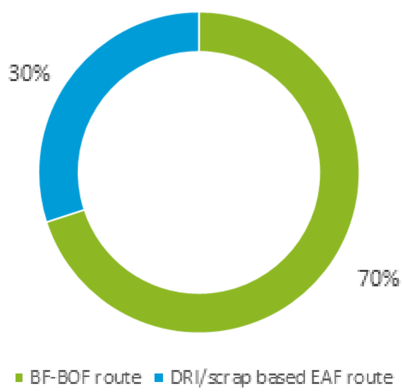
5.1. Introduction

Energy efficiency (EE) is one of the important tools for reducing GHG emissions and decarbonising the steel sector. The Indian steel industry has made significant efforts during the past two decades by implementing energy-efficient technologies and practices, which led to remarkable improvement in specific energy consumption and emission reduction. The average CO_2 emission intensity of the Indian iron and steel industry has reduced from 3.1 T CO_2/tcs in 2005 to around 2.55 T CO_2/tcs by 2022[1], predominantly owing to energy efficiency measures. With the widespread adoption of Best Available Technologies (BAT) and shifting towards scrap-based steelmaking, the Indian steel industry can further reduce the levels of energy consumption and emissions, substantially. However, due to several layout constraints and challenges, BATs have not been fully adopted. This reveals that there is significant energy saving potential to be realised. The Indian iron and steel sector, supported by government policies and other stakeholders, has the potential to accelerate its transition to energy-efficient production that is in line with global benchmarks.

5.2 Global Scenario

The total energy consumption of the steel sector globally was 36 EJ[2] in 2022. The sector accounts for approximately 20% of industrial energy use and 8% of total final energy use[3]. In the total energy consumption of the steel sector, coal has a major share of 74%, followed by gas at 9%, electricity at 14%, and other sources at 3% in global energy consumption of the steel sector. Coal is used as a reducing agent and fuel to meet the energy demand of various sub-processes in steel production. The steel-making process is energy intensive as energy constitutes a significant portion of steel production cost, accounting for 20-40%, depending on the production route, raw material and fuel quality, technology adopted, and operational practices followed.

Crude steel, globally, is produced by using two different routes, viz. (i) Blast Furnace – Basic Oxygen Furnace (BF-BOF) and (ii) Electric Arc Furnace (EAF). Globally, more than 70% of crude steel is produced using the BF-BOF route, and the remaining 30% is produced through the DRI/scrap-based EAF route[4] (figure 5.1).



The BF-BOF process uses coke as the reducing agent. Under the EAF route, there are two methods of steel production, namely, (i) EAF-scrap and (ii) Direct Reduced Iron (DRI)-EAF route. The scrap-EAF process uses electricity. The DRI-EAF process uses natural gas or gasified coal as a reductant and electricity to power the EAF. Thus, the global steel industry uses different energy sources as input for BF-BOF and EAF routes, and the share of energy sources[5] is given in Table 5.1.

***Table 5.1:** Share of energy sources in global steel production[6]*

Energy source	Share (%)	
	BF-BOF	EAF
Coal	89	11
Electricity	7	50
Natural gas	3	38

***Source:** Worldsteel*

As can be observed from the table, coal is the major source of energy (as a reducing agent and fuel) for the BF-BOF route, accounting for 89%, whereas electricity and natural gas constitute 88% of the EAF route of steel production. The specific energy consumption and emission intensity of the global steel industry for different routes of steel production are given in Table 5.2

Table 5.2: *Energy consumption and carbon emissions of global steel industry*

Process route	Direct CO_2 T/tcs	Direct and Indirect CO_2 T/tcs	Energy Consumption (GCal tcs)
BF-BOF	1.2	2.2	5.4
DRI (gas)-EAF	1.0	1.4	5.2
Scrap-EAF	0.04	0.3	1.2

Source: *Worldsteel*[7]

Among the processes, as seen from the above table, BF-BOF has high specific energy consumption and emission intensity, whereas the EAF route with scrap as raw material has the lowest specific energy consumption and emission intensity.

The global iron and steel sector has made significant strides in improving energy efficiency as a result of which energy intensity has improved by 60% since[8] 1960. Higher energy efficiency is achieved in global industry by adopting best available technologies (BATs), energy efficient processes and production technologies, and advanced electric arc furnaces (EAFs), resulting in lower specific energy consumption and emission intensity.

5.3 Indian Scenario

5.3.1 Energy use, consumption, and energy intensity of iron and steel sector

The high energy intensity of the sector is evident from the fact that energy constitutes 20-40% of steel's total manufacturing cost. The sector's overall energy consumption is over 70 million tonnes of oil equivalent (Mtoe) per annum[9]. Besides the existence of a mix of old and new production technologies, the inadequate adoption of technologies for harnessing waste heat/energy due to constrains and increased dependency on solid fossil fuels results in overall higher energy consumption and CO_2 emissions.

Scrap utilisation in steel production brings substantial energy and GHG reduction gains as it can avoid material preparation and iron-making processes. In India, scrap utilisation for steel production is low due to its non-availability; as a result, the majority of steel produced comes from hot metal and sponge iron. In India, scrap utilisation is limited to 10-12% in the BF-BOF route compared to that of 25-30% in the best operating BF-BOF plants globally. India has large steel assets, and scrap utilisation is expected to increase in the coming years.

5.3.2 Impact of Perform, Achieve, and Trade (PAT) Scheme on Energy Efficiency in the Indian iron and steel industry

The Perform, Achieve, and Trade (PAT) is a flagship scheme under The National Mission for Enhanced Energy Efficiency (NMEEE), which is one of the eight missions under the National Action Plan for Climate Change (NAPCC) and is being implemented by BEE. The PAT scheme, launched in 2012, includes the iron and steel sector to reduce specific energy consumption i.e., energy use per unit of production. The threshold energy consumption in the iron and steel sector was fixed at 30,000 tonnes of oil equivalent (toe) in 2007-08, and a total of 96 units were notified as designated consumers (DCs). In order to further increase the ambit of the sector, the threshold energy consumption was lowered to 20,000 tonnes of oil equivalent (TOE) in 2017 and a total of 270 units were notified as designated consumers (DC) till PAT cycle-VIII in 2023. As of date, the PAT scheme covers 100% BF-BOF and EAF units[10]. PAT scheme has been instrumental in driving energy efficiency efforts in the Indian iron and steel industry as the sector achieved total energy savings of 6.137 Mtoe[11] up to Cycle V (2021-22), exceeding the targeted energy savings of 4.575 Mtoe and contributed to 24% of total energy savings achieved in the country under the PAT scheme (table 5.3).

Table 5.3: *Energy savings targets and achievement in iron and steel sector under PAT scheme*[12]

PAT Cycle No.	Period	Energy savings target (Mtoe)	Energy savings achieved (Mtoe)	CO_2 Emission (MnT of CO_2/Year)
I	2012-15	1.486	2.10	6.51
II	2016-19	2.27	2.845	11.85
III	2017-20	0.457	0.572	1.691
IV	2018-22	0.193	0.357	1.414
V	2019-22	0.169	0.263	1.04
VI	2020-23	0.030	-	-
VII	2022-25	2.729	-	-
Total		**7.334**	**6.137**	**-**

As per BEE, the PAT scheme will transition to the Carbon Credit and Trading Scheme (CCTS) scheme - a regulatory framework for the Indian Carbon Market (ICM) - which was notified in June 2023. Thus, CCTS will succeed the PAT scheme in incentivising emissions reduction by providing a financial motive to decrease carbon emissions.

5.4 Benchmarking energy consumption of iron and steel industry

Benchmarking is an important tool for the iron and steel industry to drive energy efficiency improvement and enhance competitiveness. It enables us to learn from industry best practices within the industry and implement strategies to reduce energy consumption and costs. Furthermore, benchmarking helps companies demonstrate their commitment to sustainability and showcase their efforts to reduce environmental impact to stakeholders, customers, and regulators. Overall, benchmarking plays a significant role in driving energy efficiency improvement in the iron and steel industry, helping companies track trends in energy usage and optimise operations, reduce costs, and enhance their competitiveness in the market.

Energy consumption varies widely in the Indian iron and steel industry, and it is attributed to several factors such as the route of production, technology, quality of raw materials, size and vintage of the plant, and operational practices. While some of the plants have upgraded their technology and are operating at higher energy efficiencies, the other units are still using old equipment resulting in high energy consumption and emissions.

5.4.1 BF-BOF route

In India, more than 45% of steel production is through the BF-BOF route. The specific energy consumption data and other performance parameters of this route is summarised in Table 5.4.

Table 5.4: *BF-BOF route- Specific energy consumption and other performance parameters[13]*

BF Productivity t/m3/day	BF Coke Rate kg/thm	BF PCI/CDI kg/thm	Total fuel rate kg/thm	SEC Gcal/tcs
1.71 - 3.24	350-480	60-199	505 - 579	5.4 - 7.2

The analysis of the specific energy consumption data of all the BF-BOF plants in India indicates that the average specific energy consumption is 6.0-6.5 Gcal/tcs, and the average SEC of the inefficient plants is 7.1 Gcal/tcs whereas the global average SEC is the range of 4.5-5.0 Gcal/tcs[14]. However, theoretical SEC for the BF-BOF plant is 4.0 Gcal/tcs[15] (figure 5.2)[16]. This shows that there is potential for reducing SEC of Indian BF-BOF plants from the current level of 6.5 Gcal/tcs to 4.5 to 5.0 Gcal/tcs through the implementation of BATs in different sub-processes.

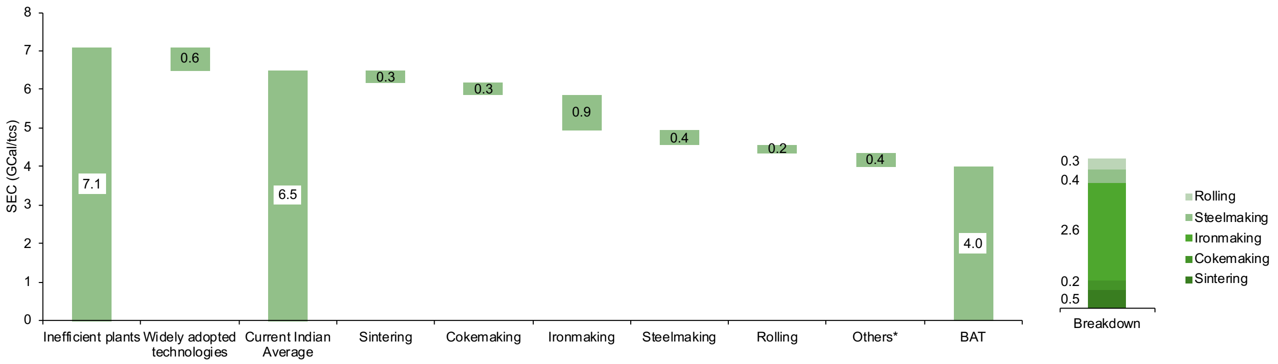


Figure 5.2: *Energy efficiency improvement potential for BF-BOF route*

Below is the list of process-wise BATs that can help reduce the SEC of the BF-BOF route from 6.5 Gcal/TCS to the desired level of 4.5 Gcal/TCS. Table 5.6 gives the recommended BATs for the BF-BOF route along with their energy-saving and CO_2 reduction potential.

Sintering 1 Sinter waste heat recovery for steam generation

Coke Making 2 Coke Dry Quenching (CDQ), Stamp charging

Iron Making 3 Top Pressure Recovery Turbine (TRT), Pulverised Coal Injection (PCI) in Blast Furnace, Dry gas cleaning plant (GCP) with bag filter, Hot Stove waste heat recovery

Steel Making 4 Dry gas cleaning (GCP) with bag filter, Low NOx regenerative burner system for ladle preheating

Rolling 5 Regenerative burner in reheating furnace, induction heating

Others 6 VVVF Drives (for pumps, fans), Energy efficient motors, Industry 4.0

5.4.2 DRI-EAF/IF route

India is one of the largest producers of DRI in the world. In India, DRI is produced using either coal or gas. Coal-DRI accounts for 78% of the total DRI produced due to the non-availability of natural gas. The DRI is relatively energy-intensive and has higher emissions.

The specific energy consumption of the coal DRI process is influenced by factors such as plant capacity, coal quality, iron ore quality, etc. Coal DRI plants vary over a wide range in size and capacity and can be divided into three main categories of plant capacity, viz. 100 tpd, 350 tpd, and 500 tpd. As the DRI plant capacity increases, the specific coal consumption reduces. Another factor that affects specific coal consumption is fixed carbon in coal and ash content. For this reason, specific coal consumption is high for Indian coals and low for imported coals. Accordingly, the SEC varies from 4.5 to 6.1 Gcal/t depending on the source of coal and plant size. Specific electrical energy consumption also reduces with an increase in the plant capacity and is 120 kWh/t for 100 tpd, 100 kWh/t for 350 tpd and 80 kWh/t for 500 tpd plant. The specific energy consumption and other parameters of DRI plants are given in Table 5.5.

Table 5.5: *Specific energy consumption of coal DRI plants in India*

Sl. No.	Description	DRI kiln capacity		
		100 TPD	350 TPD	500 TPD
1	Specific coal consumption, t/t	0.8 - 1.5	0.8 - 1.3	0.8 - 1.3
2	GCV of imported coal, Kcal/kg	5,500	5,500	5,500
3	Ash content of imported coal[17], %	10-20	10-20	10-20
4	GCV of Indian coal, kcal/kg	3,000 – 4,000	3,000 – 4,000	3,000 – 4,000
5	Average Ash content of Indian coal[18], %	25-45	25-45	25-45
6	Fixed carbon on dry basis % in imported coal	50 - 55	50 - 55	50 - 55
7	Fixed carbon on dry basis in % in Indian coal	35 - 45	35 - 45	35 - 45
8	Specific Thermal Energy (Gcal/t)	4.5 - 6.0	4.5 - 5.85	4.5 - 5.85
9	Specific Electrical energy (kWh/t)	120	100	80

Source: *BEE*

The average SEC of Indian coal DRI-EAF/IF plants is 7.0 Gcal/tcs vis-à-vis the theoretical SEC of 5.3 Gcal/tcs[19] (figure 5.3) for the average DRI-EAF plant. Significant reduction in SEC can be achieved by implementing the BATs across different sections of the steelmaking process, as can be observed from the figure 5.3.[20] The major areas of energy efficiency improvement are pelletising, steelmaking, and rolling.

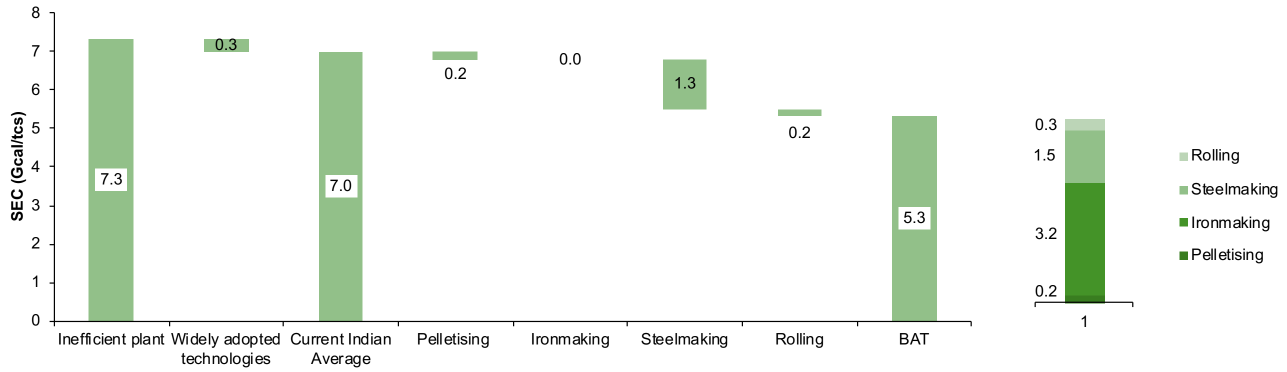
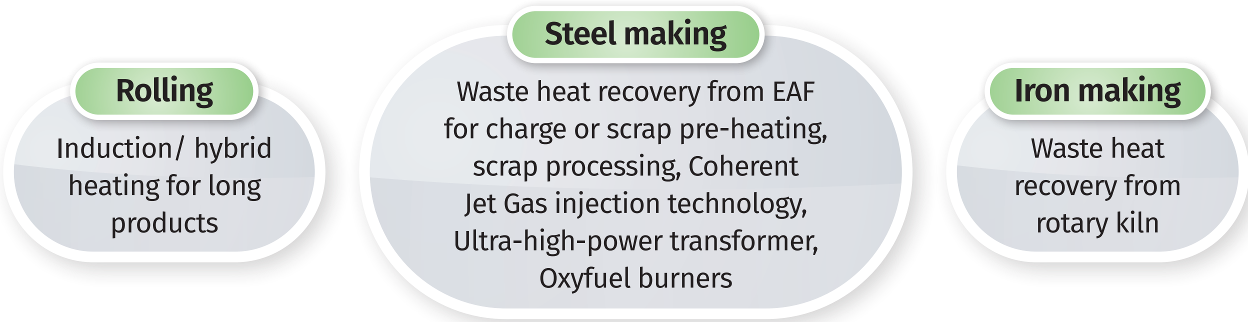


Figure 5.3: *Energy efficiency measures for the coal-based DR-EAF/IF route*

In the above figure, it is considered that many of the existing coal-DRI plants have installed waste heat recovery (WHR) systems for horizontal rotary kilns for power generation and use the power generated for captive consumption. However, the implementation of WHR systems doesn't help increase the energy efficiency of the rotary kiln, as it does not impact the input energy consumption of the kiln.

The list of BATs for sub-processes of DRI-EAF route, that can help reduce the SEC to the desired level of 5.3 Gcal/tcs, is given below.



5.4.2.1 Electric arc furnaces (EAF)

There are 34 EAFs with a total installed capacity of 36.61 Mt. The production through the EAF route was 28.20 Mt in 2022-23, registering about 77% capacity utilisation of the sector and contributing to 22% of total steel production. The major energy form used in EAF is electricity followed by chemical energy. A few EAF units have installed an oxy-fuel burner system that provides additional thermal energy through gas firing and electrical energy input. The SEC of the EAFs was observed to be in the range of 420 to 775 kWh per tonne of liquid steel. Large variations in the SEC are attributed to various factors such as the grade of steel produced, composition of raw materials, size of the furnace, capacity utilisation, temperature of liquid metal, and operating practices. The SEC of the furnaces tends to decrease with an increase in furnace capacity and vice versa. The EAF units in India use scrap or a mix of scrap and DRI as the raw material. Due to the non-availability of scrap, scrap utilisation is limited to 40-80%, and the balance is

DRI[21]. A major energy input (75-80%) to EAFs is met through electrical energy and the balance (20-25%) in chemical energy. Compared to India, the lower SEC of international EAFs is attributed to preheating of scrap for steel production coupled with adoption of energy efficient EAFs of large capacity. The average SEC of the Indian EAFs is about 480 kWh per tonne of liquid metal, whereas the SEC of international EAFs is about 350 kWh per tonne[22]. The lower SEC of international EAFs compared to India is attributed to preheating of scrap for steel production coupled with adoption of energy efficient EAFs of large capacity. Significant improvements in the energy efficiency of the Indian EAFs can be achieved by adopting a range of BAT technologies and best practices covering furnace design, furnace operation and practices, charge management, and auxiliary systems (table 5.7).

5.4.2.2 Electric Induction Furnace (EIF)

There are around 1032 EIF units in India with a total installed capacity of 68.8 Mt. The production through the EIF units is 50.4 Mt registered a capacity utilisation of 73% and contributed to 35% of crude steel production in India. Continuous technological developments and the availability of bigger-size furnaces enabled EIFs to contribute to steelmaking in India. The furnace capacity ranges from 8 tonne to 60 tonne. EIF mainly uses scrap or a mix of scrap and DRI as raw material due to a shortage of scrap. Electrical energy is the source of energy input in EIF. As in the case of EAFs, the SEC of EIFs varies over a wide range owing to a number of factors such as grade of steel produced, raw material composition, size of the furnace, capacity utilisation, and operating practices. Significant improvement in energy efficiency can be achieved in EIFs by adopting BATs. The average specific electricity consumption of EIFs is about 680 kWh per tonne of liquid steel, with SEC ranging from 580 kWh to 800 kWh per tonne for different capacities of furnaces[23]. Substantial improvements in energy efficiency of the Indian EIFs can be achieved by adopting a range of BAT technologies and best practices, as mentioned in Table 5.7.

5.5 Best Available Technologies for the iron and steel industry

Over the years, the Indian steel industry has reduced its energy intensity and carbon emissions substantially with the widespread adoption of BATs in all stages of iron and steel production, starting from raw material preparation, coke making, sinter or pellet making, iron making, steel making and rolling/finishing processes. As a result of these significant efforts by the industry, the average CO_2 emission intensity of the Indian steel industry has reduced from around 3.1 tonne of CO_2 per tonne of crude steel in 2005 to around 2.55 tonne of CO_2 in 2022[24]. The iron and steel industry has been adopting the best available, state-of-the-art technologies inter-alia for optimisation of production processes, harnessing waste heat/ energy, and catching up with the global benchmarks by enhancing productivity and energy efficiency, thereby reducing CO_2 emissions. With these initiatives, the technological profile of the Indian steel industry, particularly the ISPs, has been changing resulting in much improved techno-economic parameters that are coming close to the global benchmarks. However, there is still a long way for the Indian iron and steel industry to fully adopt BATs and realise the full potential of energy savings and CO_2 emission reductions. Table 5.6 provides major BATs for ISPs with energy saving and CO_2 reduction potential.

Table 5.6: Best Available Technologies (BATs) for Integrated Steel Plants

S. No.	Best Available Technology (BAT)	Energy Savings Potential		CO_2 Reduction potential	Remarks
		Electrical energy saving potential	Thermal energy saving potential		
			Sintering		
1	Sinter Plant Heat Recovery (for steam generation)	Not applicable	0.251 GJ/t-sinter	23.86 kg-CO2/t-sinter	The device recovers sensible heat in the hot air from sinter cooler to generate steam
2	High Efficiency (COG) Burner in Ignition Furnace for Sinter Plant	Not applicable	0.010 GJ/t-sinter	0.44 kg-CO_2/t-sinter	The multi-slit burner can form a successive and uniform frame in the ignition furnace using coke oven gas
			Coke Making		
3.	Coke Dry Quenching (CDQ)	Not applicable	1.9 GJ/t-coke	97.5 kg-CO_2/t-coke	The heat recovered by inert gas from hot coke is used to produce steam, which may be used on-site or to generate electricity
		150 kWh/t- coke	Not applicable	135.45 kg-CO_2/t-coke	
4.	Coal Moisture Control (CMC)	Not applicable	0.29 GJ/t-coke	27.55 kg-CO_2/t-coke	CMC uses waste heat from COG to dry the coal used for coke making. Coal moisture is reduced from 8-9% to 3-5%, which reduces fuel consumption in the coke oven
			Iron Making		
5.	Top Pressure Recovery Turbine (TRT)	50 kWh/t-pig iron	Not applicable	45.15 kg-CO_2/t-pig iron	This system generates electric power by employing blast furnace top gas to drive a turbine generator. Blast furnace gas passed through TRT is used as a fuel in iron and steel making processes.
6.	Dry gas cleaning plant (GCP) with bag filter	9.26 kWh/t-pig iron	Not applicable	8.36 kg-CO_2/t-pig iron	This system cleans the blast furnace gas that goes into TRT power generation system through removing dust and water drops using bag filter

S. No.	Best Available Technology (BAT)	Energy Savings Potential		CO_2 Reduction potential	Remarks
		Electrical energy saving potential	Thermal energy saving potential		
7.	Pulverized Coal Injection (PCI) System	Not applicable	1.55 GJ/t-pig iron	147 kg-CO_2/t-pig iron	Pulverized coal is directly injected through the blast furnace tuyeres as a partial substitute for the coke used in the blast furnace
8.	Hot Stove Waste Heat Recovery	Not applicable	83-125 MJ/t hot metal	7.89 kg-CO_2/t-CS	The device recovers the sensible heat of the flue gases generated in the hot stove and the heat is used in preheating fuel and combustion air for the hot stoves
Steel Making					
9.	Low NOx regenerative burner system for ladle preheating	–	0.2 GJ/t-CS	12.62g-CO_2/t-CS	Has high energy saving potential with automation. Fuel Direct Injection (FDI) Combustion is adopted
10.	Dry gas cleaning plant (GCP) with bag filter	9.26 kWh/t-crude steel	Not applicable	8.36 kg-CO_2/t-crude steel	This system cleans the blast furnace gas that goes into TRT power generation system through removing dust and water drops using bag filter
Rolling					
11.	Regenerative Burner Total System for Reheating Furnace	Not applicable	0.19 GJ/t-CS	10.66 kg-CO_2/t-CS	While one of the burners is burning, the other burner will work as an exhaust outlet. The combustion air will be preheated to a superhigh temperature.
12.	Induction/hybrid heating for long products	Not applicable	To be established	To be established	This technology allows utilising electricity-based heating (induction heating) replacing fully or partially the existing system coal/NG firing

Source: *India Technology Customised List for BF-BOF and EAFs, recommended technologies for energy saving, environmental protection and recycling in Indian iron and steel industry, The Japan Iron and Steel Federation, 2022*

 # European Commission JRC Reference Report – "Best Available Techniques (BAT) Reference Document for Iron & Steel Production" – year 2013 **OEM input*

The comprehensive list of BATs for the secondary steel industry (DRI, EAF, and IF) are given in Table 5.7.

Table 5.7: BATs Secondary Steel industry

S. No.	Best available Technology (BAT)	Energy Saving potential	Remarks
1	Waste heat recovery from DRI kiln for power generation (2x100 tpd DRI kiln)	23.5 million kWh/ year (4 MW plant)	The high sensible heat in off-gases can be recovered using a WHR boiler to generate high-pressure steam for power generation
2	Waste heat recovery from DRI kiln for iron ore preheating	15%	The off-gases from rotary kiln flow through the rotary preheater in a counter-flow arrangement and transfer heat directly to incoming iron ore, resulting in lower coal consumption. The preheated iron ore at about 650°C enters the rotary kiln instead of being fed at ambient temperatures.
3	Mullite-based kiln lining for reducing DRI kiln surface heat losses	1.5%	High-alumina low-cement castable refractories used as inner lining in rotary kiln to withstand a temperature of close to 1050°C, can be replaced with mullite-based high alumina castable refractory. It has excellent high-temperature strength and high resistance to thermal shock, oxidation, and abrasion
4.	Ultra-high-power Transformer for EAF	5.0%	Long arc by high voltage and low ampere operation; water cooled wall-panel to protect refractories
5.	Oxy-fuel burner for EAF	3.0%	Supersonic or coherent burner; accelerate scrap melting during melting stage; facilitate slag foaming during refining stage over the bath
6.	Continuous Scrap preheating in EAF	12.0%	It has air-tight structure; high temperature scrap preheating (over 700C); automatic process control by using data logging; and post-combustion of generated CO gas.

Sources: *1) Ghosh, A.M., Vasudevan, N. and Kumar, S. 2021. Compendium: Energy-efficient Technology Options for Direct Reduction of Iron Process (Sponge Iron Plants), TERI*

2) Compendium: Energy Efficient Technology Packages for Electric Arc Furnace, TERI, UNDP

3) #OEM inputs

In addition to the BATs for ISPs and the secondary steel industry, there are a few common BATs applicable for the iron and steel plants, which are listed in Table 5.8.

Table 5.8: Common BATs for the iron and steel industry

S. No.	Energy efficient technologies	Energy Saving Potential
1.	Variable frequency drives (VFD) for pumps, fans, etc.	5%
2.	Energy monitoring and management system (EMMS)	5-10%
3.	Star Rated equipment in utilities and process (distribution transformers, chillers, ceiling fans)	Not available

Source: *Will Hall, Thomas Spencer, Sachin Kumar2020: Towards a Low Carbon Steel Sector:Overview of the Changing Market, Technology and Policy Context for Indian Steel (TERI)*

The industry may thrive on these low-carbon relevant BATs, which may be modified and partly or fully replaced by alternate green technologies as and when developed or available.

Industry 4.0 plays a pivotal role in driving decarbonisation and improving energy efficiency within the steel industry. By integrating digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), Machine Learning (ML) and advanced analytics, steel manufacturers can optimise processes to reduce carbon emissions and enhance energy utilisation. Furthermore, Industry 4.0 facilitates the implementation of energy management systems that optimise the overall energy usage across the steel production process. In essence, Industry 4.0 serves as a catalyst for decarbonisation and energy efficiency in the steel industry by enabling data-driven decision-making, process optimisation, and the deployment of innovative technologies aimed to reduce environmental impact while enhancing competitiveness and sustainability. Adopting these new digital technologies may also propel the steel industry to meet India's honourable Prime Minister's target of reaching net zero emissions before 2070. The iron and steel industry in India is currently using Industry 4.0 for predictive maintenance, thus improving the efficiency of equipment and making digital twins of complex equipment like blast furnaces and optimising it for better energy efficiency and operational performance. Major ISPs are working on this front.

Also, an Energy Management System (EMS) has been implemented in SAIL's Burnpur unit (with the help of NEDO) to optimise the usage of export gases from the Blast furnace, Coke ovens, and Steel melting shops.

5.5.1 Adoption level of BATs in the Indian iron and steel industry

The Indian iron and steel industry has been adopting BATs in BF-BOF and DRI-EAF/IF routes and reducing specific energy consumption and CO_2 emissions over the past decade. While there is no available information about the status of the adoption of BATs in ISPs and SSI, a study conducted by JISF in the past has documented the adoption level of major BATs in seven ISPs, as shown in figure 5.4.[25] As can be seen from the figure, while some BATs have higher adoption rate in the industry (e.g., PCI), there is significant potential for enhancing the adoption rate for other BATs.

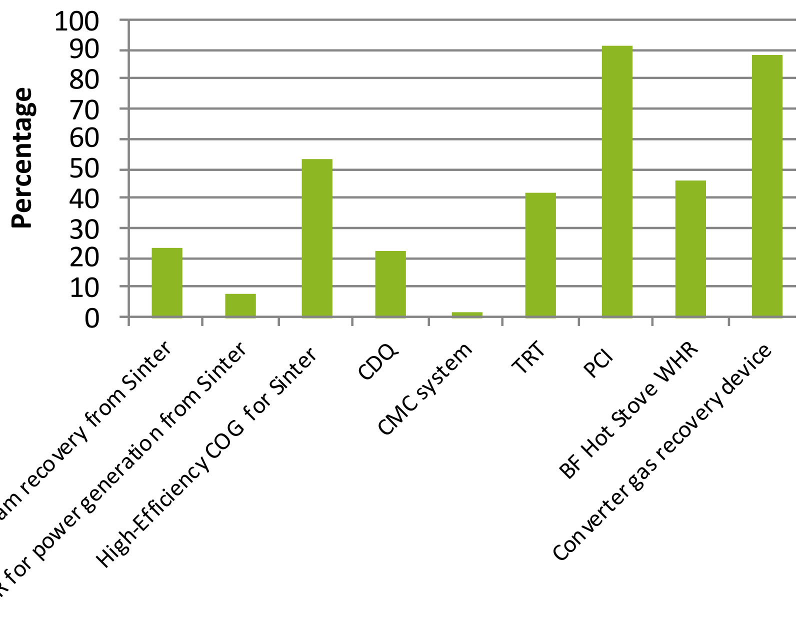


Figure 5.4: *Diffusion rate of BATs in 7 major companies (percentage)*

Source: *India Technology Customised List for BF-BOF and EAFs, recommended technologies for energy saving, environmental protection and recycling in Indian iron and steel industry, The Japan Iron and Steel Federation, 2022*

However, similar data on the adoption rate of BATs is not available for the SSI sector, which needs to be studied.

PCI has a high adoption level, as shown in the figure, which means most of the ISPs have introduced PCI injection to reduce the coke rate. However, there is scope for increasing the PCI rate from the current level of 50-150 kg PCI/tonne to 180-200 kg PCI/tonne to fully exploit the energy saving potential in BF-BOF. Site conditions, plant layout, and age of the facility are major constraints for adopting most of the BATs in ISPs, whereas lack of awareness, technical information, and capabilities are the major constraints for the SSI. Apart from the BATs mentioned in section 5.5, some of the steel plants have adopted best practices to lower their energy consumption and the same are listed in annexure 5.1 (source BEE). A study is needed to revise the adoption rates of BATs in the steel industry.

5.6 Major constraints for adopting energy efficient technologies and technology upgradation projects

The Indian iron and steel industry has successfully reduced energy and emission intensity during the past two decades by implementing various EE technologies and best practices. However, there are constraints for wide-scale adoption of BATs, which are highlighted below:

1. **Site conditions:** Retrofitting issues prevail in some of the ISPs and SSI units due to layout/ space constraints within the existing plant configuration
2. **Lack of awareness:** There is a lack of awareness or understanding about the potential benefits of energy efficiency measures among stakeholders in the industry
3. **Technological obsolescence:** The iron and steel industry in India comprises many small and medium-sized enterprises (SMEs) that lack access to the latest energy-efficient technologies.
4. **High initial investment:** Many BATs require a significant upfront investment. This initial cost is a barrier to adoption for the iron and steel industry, especially smaller units.
5. **Access to affordable financing:** The industry faces a major challenge in accessing financing to implement energy efficiency measures. Limited access to affordable financing options hampers the adoption of energy-efficient technologies.
6. **Lack of skilled workforce:** Implementing energy-efficient technologies often requires specialized knowledge and skills. The shortage of trained personnel in the industry is a barrier to adopting energy-efficient practices.
7. **Competitive pressure:** In a highly competitive market, companies prioritize short-term gains over long-term investments in energy efficiency. The pressure to remain competitive can deter firms from investing in energy-saving technologies or processes.
8. Besides the above-mentioned constraints, there are challenges faced by the industry as highlighted below:
   g. Poor quality of raw materials viz. high ash coal/coke, high Silica/alumina iron ore
   h. Lower use of prepared burden (sinter, pellet)
   i. Availability of 'quality' and sized scrap at affordable cost
   j. Poor operational practices viz. low hot blast temperature in blast furnaces

The ministry shall make concerted efforts to bring all stakeholders (government, industry, financial institutions, service providers, experts, technology providers) to create an enabling environment for adopting energy efficiency measures in the Indian iron and steel industry. Providing incentives, improving access to financing, raising awareness, strengthening regulations, and investing in R&D and skill development are some of the actions that need to be focused on the ground.

5.7 CAPEX required for implementing BATs

The total capex required for implementing BATs across the ISPs and SSI is estimated at Rs23,257 Crore. The breakup of the estimate for ISP and SSI is given below.

Category	Capex, Rs Crore
ISPs	12,711
SSI	10,546
Total	23,257

The capex has been estimated using the penetration levels of BATs and the project cost of each BAT.

5.8 Action plan

This section discusses the action plan for enhancing energy efficiency in the iron and steel sector.

Scaling up implementation of BATs and other EE technologies across ISPs and SSI

1. Making the implementation of certain BATs mandatory for brownfields as well as existing ISPs is necessary and crucial for increasing energy efficiency, thereby reducing CO_2 emissions in the steel sector. The BATs recommended for mandatory implementation are i) Stamp charging, ii) Sinter waste heat recovery, iii) CDQ, iv) TRT, and v) PCI (increasing the PCI rate from the existing level to at least 180 kg/thm). These BATs have been proven, established, and implemented by some of the ISPs successfully and the same can be replicated by the existing units and the brownfield projects. In this regard, MoS will work with MOEFCC to include these BATs as part of the consent to operate (CTO)/EC in the compliance category.
2. The iron and steel industry has significantly reduced its energy and emission intensity over the past two decades by implementing various BATs (in addition to the BATs recommended above for mandatory implementation). The adoption rate of these BATs is low, particularly in the SSI sector. The Ministry will work with BEE/MoEFCC to formulate clear guidelines for wider adoption of the BATs by the existing ISPs and SSI units. Further, the Ministry will work with the industry to address the pain points identified earlier and address them. The list of BATs suggested for implementation is provided in section 5.6 of this chapter.
3. The Ministry may work with BEE to mandate the mandatory implementation of star-rated equipment as per the Standards & Labelling program (e.g., distribution transformers, chillers, LED lights, ceiling fans), variable frequency drives (VFDs), and energy-efficient motors to reduce electrical energy consumption in iron and steel plants.
4. The Ministry will promote the adoption of Industry 4.0 or a newer/updated version of Industry 4.0, encompassing EMS/automation/digital technologies for ISPs and SSI, through a policy initiative.

5. The ministry may conduct a study to assess and evaluate the status of implementation of BATs across the technologies in SSIs and ISPs and understand the challenges for implementation. This comprehensive study may provide insights for policy formulation and help facilitate wide-scale adoption of BATs.

6. The BATs are not static but dynamic and may continuously evolve with technological developments and innovation. The ministry may periodically review, revise, and update the list of BATs and periodically notify the same for implementation by the industry.

Benchmarking of energy consumption and mandatory energy audits

7. Currently, there is no benchmarking of energy consumption of the iron and steel industry in India. Benchmarking energy consumption and setting energy-saving targets for different routes of steel-making are vital for periodically tracking the progress made in energy efficiency and taking appropriate steps. Under the PAT scheme, BEE has extensively worked on baseline assessment for different routes and processes and issued targets for individual plants. In this regard, MoS will work with BEE to set benchmarks and energy-saving targets for different routes of steelmaking (EU Energy Efficiency Directive 2023 has set energy-saving target of 11.7% reduction[26] in energy consumption by 2030[27]).

8. MoS, in consultations with BEE, will examine the possibility of making Energy audits mandatory (under the EC Act 2001) for the iron and steel sector. The mandatory energy audits can be conducted periodically to help the industry review its performance and identify measures for reducing energy consumption. With the introduction of the CCTS scheme, the PAT scheme will end, but the energy audits should be continued to maintain energy efficiency in the units.

9. Multiple steel plants continue to operate beyond their optimal lifetime, resulting in excessive resource consumption and emissions. The Ministry may devise a mechanism to monitor such plants and encourage them to replace the old, inefficient plants with greener steelmaking routes.

Enhancing the coverage of steel plants under CCTS scheme

10. Currently, the PAT scheme has a total of 270 designated consumers (DCs) from the iron and steel sector (covering 100% of BF-BOF and EAF facilities and the majority of medium/large coal-DRI facilities). As the PAT scheme is transitioning to the CCTS, shifting the focus from specific energy consumption targets to specific GHG emission (SGE) targets, the ministry may work with BEE and MoEFCC to increase the number of obligated entities (OE) of the iron and steel industry under the CCTS scheme from the present level. This initiative may ensure that a majority of the small and medium coal-based-DRI facilities and other secondary steel industries are covered under the CCTS scheme and stand to benefit from it.

Technical support to SSI units and strengthening the institutions

11. Strengthening the national institutions/organisations such as National Institute of Secondary Steel Technology (NISST) and Biju Patnaik National Steel Institute (BPNSI) to provide technical support and handholding of SSI (SSI accounts for 30-35% of steel production in the country) is crucial for improving energy efficiency. The SSI sector faces major challenges, such as a lack of technical capabilities and capacity, lack of credit worthiness, and lack of awareness and information, and this necessitates handholding support for implementing energy efficiency measures. The ministry will draw out a plan to strengthen the above institutions.

12. The Ministry intends to devise a scheme to extend technical consultancy services at free-of-cost or subsidised cost to small SSI units covering a range of services, including conducting energy audits,

identifying appropriate energy efficiency measures, preparing DPRs, and identifying suitable financing schemes for implementing measures. NISST, being an Empanelled Energy Auditing agency by BEE, may be a mandated through BEE to conduct frequent audits at subsidised cost and hand-holding in implementing the energy-efficient technologies and improving process efficiency. This support may go a long way in addressing the challenges of the lack of technical capacity and capabilities faced by the small SSI units in improving energy efficiency. It may help realise the potential savings and encourage them for technological upgrades and improved work practices, leading to reduced carbon emissions.

Incentivising coal DRI plants

13. A large number of medium and large-sized coal-based DRI plants are yet to install WHR power plants, resulting in wastage of energy. Considering this, the ministry intends to incentivise WHR implementation in coal DRI plants to improve energy efficiency and carbon footprint.

14. Coal DRI facilities of 350 TPD and above are proven to be more energy efficient compared to the smaller plants having capacity of 200 TPD and below. The ministry will consider restricting the growth of new small capacity coal DRI plants and will examine the possibility of incentivising the capacity upgradation through a policy initiative.

Financial incentives

15. It is understood that lenders have been reluctant to fund energy efficiency projects due to the ingenuity of various technologies being implemented. This is also established by the lack of interest shown by the industry in implement energy efficiency projects. The lenders perceive the credit risk to be high in energy efficiency projects and the creation of security has remained a challenge for EE financing. Therefore, it is important to provide credit/risk guarantee support for energy efficiency lending to mitigate the credit risk. Further, the high capital costs of some of the BATs will increase the burden on the industry, resulting in longer payback period. Financial incentives such as interest subvention or such suitable initiatives can address these challenges faced by the industry in implementing capital-intensive BATs. Such a scheme will improve the viability of BATs and facilitate faster deployment by the industry. The ministry may work with the concerned ministry/department(s) to extend the financial support to the iron and steel sector.

RD&D

16. R&D initiatives may be initiated and supported by the Ministry targeting to improve energy efficiency in various stages of steelmaking, including raw material preparation, heating, refining, and casting, advanced control systems, and heat recovery technologies. The ministry will review the possibility of R&D Institutions such as RDCIS, SRTMI, and CSIR-CIMFR coming together to work with the industry for the indigenous development of technologies. At present, BATs are sourced internationally with implications of high capex resulting in a longer payback period. The ministry may initiate R&D projects in partnership with industry and academia to help the development of BATs and equipment indigenously, thereby reducing the investment costs.

CHAPTER 6

RENEWABLE ENERGY TRANSITION

6.1. Introduction

Renewable Energy (RE) has evolved over a decade and is a mature market-driven ecosystem in India today. India's installed renewable energy capacity (*excluding large hydro*) has grown from 63 GW in December 2017 to 134 GW in December 2023[1,2]. With innovation further bringing down the cost of RE power and focusing on clean energy in the future, RE uptake in industrial production seems obvious.

For the steel industry, integrating renewable energy would be one of the easiest ways to reduce emissions intensity and achieve decarbonisation in the sector. The emissions intensity of Indian steel plants is amongst the highest in the world today due to the over-reliance on the higher emissions intensity grid and captive power plants (CPP) to meet their electricity demand. As per the estimates, the penetration of RE electricity in the steel sector is very low at about 7.2%, i.e., 5.6 TWh out of the total electricity requirement of 78 TWh (excluding the electricity generated from waste heat recovery in FY 2021-22[3]. Thus, despite the low cost of RE and improvement in the overall RE ecosystem, the uptake of RE by steel players has been at a slower pace due to the ground-level challenges. This chapter discusses different measures to enhance the penetration of green electricity in the steel sector.

6.2. Global Scenario: Renewable Energy

Renewable energy (solar and wind only) capacity stands at 1952 GW globally as of 2022, which is around 23% of the total electricity generation capacity of 8511 GW, where solar stands at 1053 GW (12%) and wind at 899 GW (11%)[4,5]. As per the IEA's 'Renewables 2023' report, an unprecedented surge of renewable energy capacity addition was observed in 2023 with an addition of ~483 GW, almost 60% higher than in the previous year owing to favourable policies with sustainability concerns on the rise and decreasing prices of renewable energy acting as a tailwind[6]. In 2022, solar and wind energy contributed to around 12% (3,444 TWh) of total electricity generation, with solar share 4.5% (1,284 TWh) and wind share 7.6% (2,160 TWh)[7].

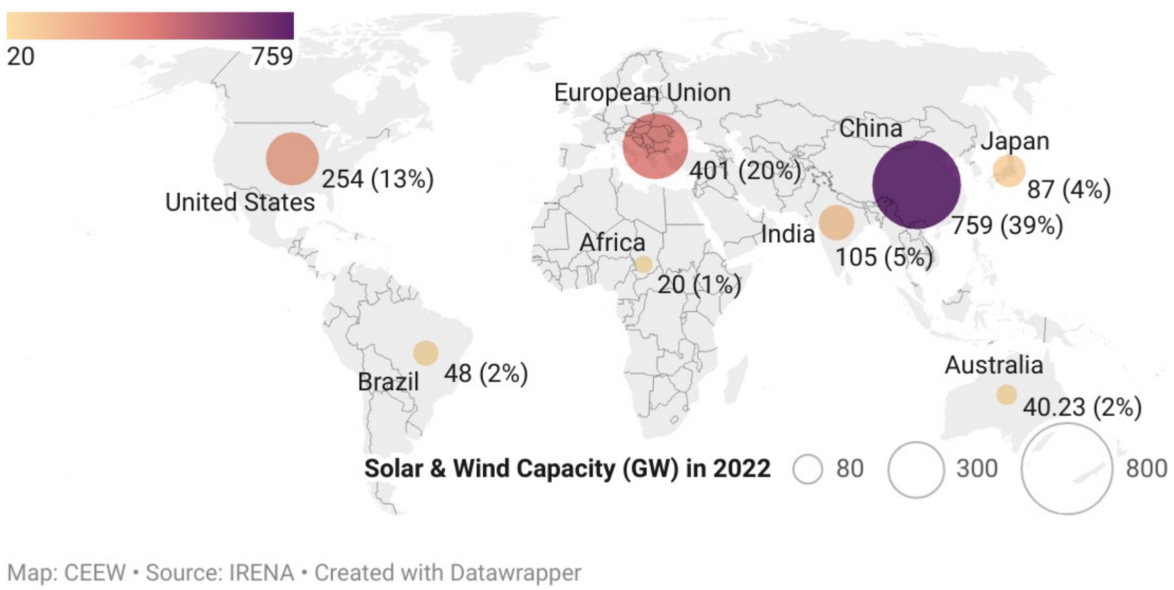


Figure 6.1: *Global Scenario: Solar and Wind Installed Capacity (GW) in 2022*

***Note:** The % in bracket (%) represents the share of a country's solar and wind capacity in the global solar and wind capacity.*

6.3. Indian Scenario: Renewable Energy

6.3.1. State of Renewable Energy in India

India targets to install 500 GW of non-fossil fuel-based capacity by 2030. Currently, India ranks 4th in renewable energy installed capacity in wind power capacity and 5th in solar power capacity globally[8]. As of December 2023, India has around 180 GW of installed RE capacity *(*RES[9] including large hydro),* which is 42% of the country's total installed capacity and contributes to 20% of energy generation[10], with solar and wind capacities of 73.3 GW and 44.7 GW respectively[11].

RE capacity addition in FY 2022-23 has led to a 13% reduction in the grid emission factor from 0.823 tCO_2/MWh to 0.713 tCO_2/MWh[12]. The Iron and steel sector has a captive power installed capacity of 16 GW. These captive power plants generated 58 TWh of electricity in 2021-22 and around 0.23 TWh (0.39%) was generated from captive RE sources[13].

6.3.2. India's Current RE Policy Landscape

1. Renewable Purchase Obligation (RPO)

Renewable purchase obligation (RPO) is a mandate for the obligated entities, i.e., DISCOMs, open access consumers, and captive consumers to ensure specified percentage of their total electricity consumption from renewable energy sources. The Ministry of Power has notified the RPO trajectory with 43.33% compliance by 2030[14]. State Electricity Regulatory Commissions (SERCs) are empowered to fix the RPO targets for the respective states[15].

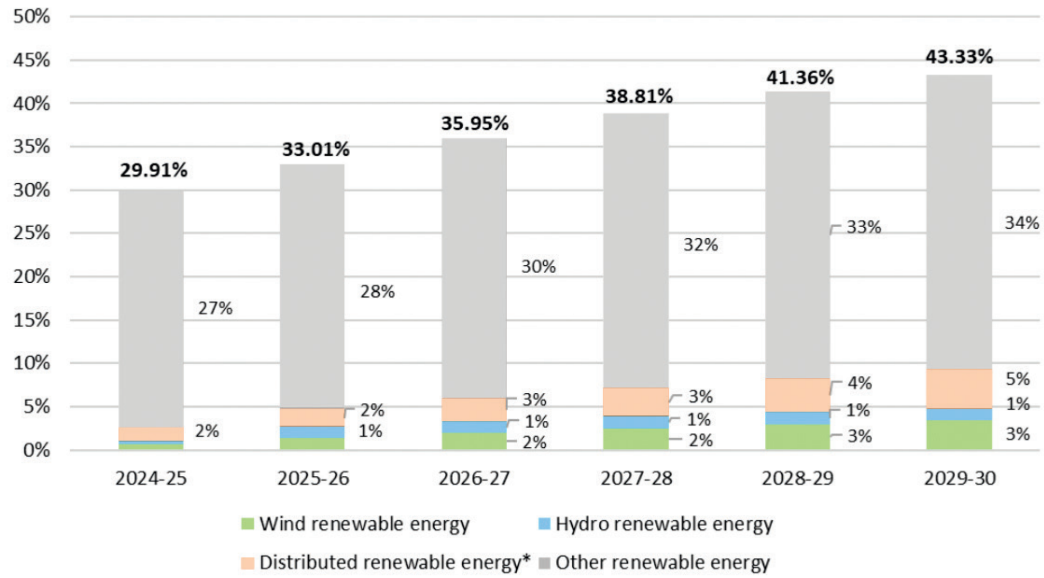


***Figure 6.2:** RPO Trajectory till 2029-30[16]*

***Note:** HPO stands for Hydro power Purchase Obligations, DRE stands for Distributed Renewable Energy*

**DRE component shall be met only from the energy generated from renewable energy projects that are less than 10 MW in size and shall include solar installations under all configurations (net metering, gross metering, virtual net metering, group net metering, behind the meter installations and any other configuration) notified by the Central Government.*

2. ISTS Waiver for RE Open Access

A 100% waiver of Inter-State Transmission System (ISTS) charges for inter-state sale of RE power, wind and solar for projects commissioned by June 2025 for 25 years with a provision of gradual phasing out of waiver for projects commissioned from July 2025 onwards[17].

Table 6.1: *Phasing out plan of waiver for ISTS charges*

Sr. No.	Period of Commissioning	Inter-state Transmission Charges
1	01.07.2025 to 30.06.2026	25% of the applicable ISTS charges
2	01.07.2026 to 30.06.2027	50% of the applicable ISTS charges
3	01.07.2027 to 30.06.2028	75% of the applicable ISTS charges
4	From 01.07.2028	100% of the applicable ISTS charges

Source: *MoP Notification*

Various charges related to Open Access (OA)

Transmission Charges & Losses:

Transmission charges and losses include:

State transmission charges charged by the state transmission utility at both injection and drawal states

State transmission losses that are expressed as a regulated percentage of the total power transmitted

Central transmission charges charged by the central transmission utility (Currently waived up to June 2025, the level of waiver will be gradually reduced)

Central transmission losses that are expressed as a regulated percentage of the total power transmitted

For intrastate projects, only the concerned state transmission charges and losses will apply.

Wheeling Charges & Losses:

Wheeling charges and losses include:

Wheeling charges charged by the discom at both injection and drawal states

Wheeling losses that are expressed as a regulated percentage of the total power transmitted

These would apply only if the transmission of power involves the use of the discom network

Cross-subsidy Surcharge and **Additional Surcharge** are applied by the discom on third-party open access projects.

Cross subsidy surcharge is payable by OA consumers to subsidise the subsidised consumer category of agriculture and domestic

Additional surcharge is payable to make up the losses incurred by the discoms due to the stranded of existing power purchase agreements.

3. PLI Scheme for manufacturing of solar modules

To achieve high-efficiency solar PV modules, the Government of India has introduced a Production Linked Incentive (PLI) scheme to establish large-scale, efficient modules and solar PV cells, with an outlay of INR 24,000 crores.

4. **Priority Sector Lending by RBI**

Reserve Bank of India has identified Renewable Energy sector as the priority sector to provide easy finance to RE projects. The project developers can get loans extended by banks up to INR 30 crore to set up RE projects like solar, wind, biomass, and RE-based public utilities under the Priority Sector Lending classification[18].

5. **Solar Park Scheme**

As of February 2023, the government had approved 57 Solar Parks with an aggregate capacity of around 40 GW. Solar parks offer a good option for developers as land, connectivity, and access to the evacuation network are easily available, which is otherwise the major issue faced by the developers[19].

6. **Transmission Infrastructure**

Central Electricity Authority's (CEA) Plan for Transmission System for 500 GW RE Integration by 2030: Considering the longer gestation period of transmission systems compared to RE generation projects, CEA laid out the plan for 537 GW of Transmission system to evacuate the 500 GW of renewable power to the load centres by 2030[20].

Green Energy Corridor (GEC): The GEC Project aims to synchronise the electricity produced from various renewable energy sources, like solar, wind, etc., with conventional grid power. The Intra State Transmission System (InSTS) Phase-I project was sanctioned in 2015-16 for the evacuation of around 24 GW of renewable energy in eight RE-rich states and phase-II of InSTS was approved for the evacuation of around 20 GW of RE in seven states by 2026[21].

7. **PSUs acting as Renewable Energy Implementing Agencies (REIA/Nodal Bidding Agencies)**

Four Central Public Sector Undertakings (CPSUs), namely, Solar Energy Corporation of India (SECI), National Thermal Power Corporation (NTPC), National Hydroelectric Power Corporation (NHPC), and Satluj Jal Vidyut Nigam (SJVN) have been designated as Nodal Bidding Agencies. These Nodal Agencies aggregate the demand from consumers such as DISCOMs, etc., and procure the power from RE developers through transparent bidding. These CPSUs have tripartite arrangements with RBI and State Govt. to ensure timely payment by DISCOMs. Therefore, they can procure power at a lower rate to mitigate therisk of default/ delay in payment to the developers.

8. **Incentives for Storage**

ISTS Waiver for RE Storage: A 100% waiver of ISTS charges has been granted for 25 years from the date of project commissioning for Pumped Storage Plant (PSP) and Battery Energy Storage Systems (BESS) commissioned by December 2030. Later, they will be subjected to graded transmission charges. This step encourages storage systems, which will help to address the intermittency issue related to RE by making them available round-the-clock.

PLI Scheme for Battery Storage: The government has launched the PLI Scheme for Advanced Chemistry Cell (ACC) Battery Storage to achieve 50 GWh of ACC to build India's manufacturing capacity with an outlay of around INR 18,000 crores. This initiative aims to ensure that the cost of battery manufacturing in India is competitive globally[22].

Viability Gap Funding (VGF) Scheme for Development of Battery Storage: The government has introduced the VGF scheme for the development of a Battery Energy Storage System (BESS) with a capacity of 4000 MWh and a budgetary outlay of INR 3760 crore. Under this scheme, the projects will be approved over a period of 3 years (2023-24 to 2025-26) with VGF provision of up to 40% of the capital cost[23].

9. Notification of Green Energy Open Access Rules, 2022

The *Green Energy Open Access Rules, 2022,* notified in June 2022, promotes the generation, purchase, and consumption of green energy[24]. These rules lay down model rules and regulations to promote the direct sale of RE power from developers to commercial and industrial consumers via open access. Most of the state regulators have either adopted these regulations or are in the process of adopting them.

10. Must Run Status for RE Power Plants

REGs (RE Generating Stations) have been granted the must-run status as per the *Indian Electricity Grid Code* (IEGC) formulated by the *Central Electricity Regulatory Commission* (CERC) and, thus, are not to be subjected to curtailment except for technical constraints or grid security considerations. In case of curtailment due to other reasons, the procurer must compensate, the RE developer, as per the agreement.[25]. This step mitigates the risk of the RE suppliers/developers by ensuring a 100% offtake of produced RE power.

11. Launch of Green Power Market

MNRE launched the Green Term Ahead Market (GTAM) in 2020 and Green Day Ahead Market (GDAM) in 2021, i.e., the sale of Green power through power exchanges to provide more flexibility to power markets as compared to long-term PPAs, which are rigid and inefficient.

12. 100per cent FDI in RE

The government has allowed Foreign Direct Investment (FDI) up to 100 per cent under the automatic route in the Renewable Energy sector, i.e., no prior Government approval is required for investment in the RE sector[26]. This step will attract more investment in the RE sector. The FDI equity inflow in the RE industry has been around $14 billion from April 2000 to March 2023[27].

Recent Developments in the RE space

Environment Social Governance

ESG was first recognized in India in 2011 by the Ministry of Corporate Affairs (MCA) through the National Voluntary Guidelines on Social, Environmental and Economic Responsibilities of Business (NVGs)[28].

Later, SEBI formulated the Business Responsibility Reports (BRR), mandating that the top 100 listed companies file the BRR annually and in 2021, SEBI replaced the existing BRR reporting requirement with the Business Responsibility and Sustainability Report (BRSR), a more comprehensive integrated mechanism[29]. The market capitalization of ESG-compliant industries is higher than that of non-compliant industries. The cost of energy transition for the steel industries can be offset by this increase in the market valuation due to ESG Compliance by the industries. Also, ESG-compliant organisations have lower cost of raising capital, both via debt as well as equity and get access to cheaper finance.

Carbon Credits Scheme

In June 2023, the Ministry of Power notified the Carbon Credit Trading Scheme[30]. The Indian Carbon Market will be governed jointly by the MoEFCC and the MoP and administered by the Bureau of Energy Efficiency (BEE). Steel players can monetise the RE integration in their units by participating in the carbon market, and trading/selling carbon certificates/credits. This will help the sector reduce its carbon emissions.

Time-of-Day (ToD) Tariff

Recently, MoP has issued a notification, 'Electricity (Rights of Consumers) Amendment Rules, 2023'. According to this, the ToD tariff will apply to C&I consumers (Load>10 kW) from April 2024. As per the amendment, during solar hours, the tariff is lower than the normal tariff, and the tariff during peak hours will be higher. With the growing share of renewables in the generation mix, the introduction of the ToD tariff will effectively integrate RE into the grid. Aligning the load profile of steel industries with the solar hours will help reduce the cost of power by taking advantages of the ToD tariff. This will improve the grid stability due to better demand-side management.

6.4. Electricity Requirement of the Steel Sector

6.4.1. Electricity Requirements in different Steel Manufacturing Processes

The entire process of steel manufacturing can be divided into three key stages - production of iron from iron ore, conversion of iron to steel, and, finally, finishing of steel. While integrated steel plants (ISPs) have all the three stages, smaller scale steel plants may have only one or two of these stages and, accordingly, source or sell the intermediary products. The specific electricity consumption and electricity requirement for each stage is elaborated in the table below.

As shown in Table 6.2 below, the specific electricity consumption of finished steel in FY 2021-22 is estimated to be around 786 kWh/ton. Of this, the most power-intensive stage is the conversion of iron to steel, which accounts for 62% of the total electricity consumption. Further, it can be observed that in the steel production routes, the induction and electric arc furnaces use more electricity than basic oxygen furnaces. Based on the current values of steel production and specific power consumption for each process, the total electricity requirement for steel manufacture is around 94 TWh (1 TWh = 1,000 MU = 10^9 kWh).

Table 6.2: *Electricity Requirements in different Steel Manufacturing Processes in FY 2021-22*

Sr.No.		Production (million tonnes per annum)	Specific electricity consumption (kWh / tonne of product)	Total Electricity Requirement (MU) in 2021-22
1	**Iron Production (2+3+4)**	**123.69**		21,853
2	Sponge Iron - Coal DRI	30.33	100.00	3,033
3	Sponge Iron - Gas DRI	8.87	120.00	1064
4	Hot Metal & Pig Iron	84.49	210.17	17,756
5	**Steel Production (6+7+8)**	**120.29**		58,803
6	BOF	54.49	174.09	9,503
7	EAF	30.50	664.00	20,251
8	IF	35.21	825.00	29,049
9	**Steel Finishing (10+11)**	**113.60**		13,632
10	ISP	65.06	120.00	7,807

Sr.No.		Production (million tonnes per annum)	Specific electricity consumption (kWh / tonne of product)	Total Electricity Requirement (MU) in 2021-22
11	SSI	48.54	120.00	5,825
12	**Total consumption (Finished Steel) (1+5+9)**		**785.51**	**94,288**

As can be observed from the following figure 6.3, major players (SAIL, RINL, TSL Group, AM/NS, JSW Steel and JSPL) account for 50.4 TWh, or 53.45% of the total electricity consumption in the sector. As can be observed from the Figure 6.3 below, small-scale steel industries account for the majority of electricity consumption in manufacturing crude steel from iron. On the other hand, six major players in the industry takes accountability of the majority of iron production.

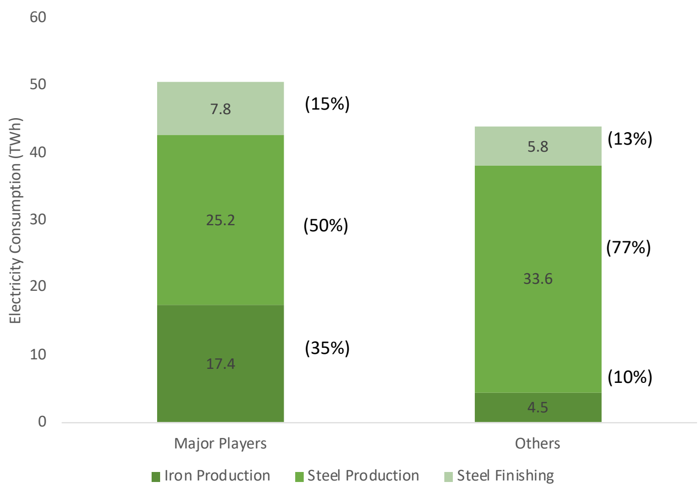


Figure 6.3: Electricity Requirements in different Steel Manufacturing Processes in 2021-22

6.4.2. RE Penetration in the Steel Sector

The steel industries generate off-gas from various processes like – coke dry quenching, blast furnace gas, and coke oven gas, which has heat content and is fired in the boiler to generate power. The waste heat is recovered from the directly reduced iron-process to generate power. Apart from that, the steel industries have captive power plants, primarily meant for self-consumption. As per the CEA General Review, over 58 TWh of electricity was generated from captive power plants of capacities greater than 500 kW in the iron and steel sector in 2021-22. Only 0.23 TWh (0.39%) was produced from solar, wind and hydropower plants.

Table 6.3: Fuel-wise Captive Capacity and Generation in Iron and Steel Sector

Sr. No.	Fuel	Installed captive capacity (MW)	Electricity generated (MU)	Share of generation
1	Coal	14,061	56,405	97.04%
2	Diesel	1,315	160	0.28%
3	Gas	436	1,338	2.30%
4	Solar	65	48	0.08%

Sr. No.	Fuel	Installed captive capacity (MW)	Electricity generated (MU)	Share of generation
5	Wind	144	174	0.30%
6	Hydro	2	4	0.01%
7	Total	16,025	58,128	100.00%

Source: *CEA General Review 2023*[31]

Steel industries meet their electricity requirement from captive generation, including waste heat recovery and off-gas and procure the remaining power from the grid or via open access (third party or captive or power market). The steel industries opting for open access need to fulfill their renewable purchase obligations (RPOs) and, hence, need to procure green/RE power equivalent to a specified percentage of total power consumption. Based on the RPO compliance data obtained for DISCOMs and the RE penetration in captive sources for the iron and steel industry (as per the CEA General Review 2023), the current overall RE penetration in the iron and steel industry is 7.2%. It can be seen inTable 6.4 below that the share of RE power in the case of the ISPs is only 3.1% as compared to 11.3% in the case of small units.

Table 6.4: *RE Penetration and CO_2 emissions in Iron & Steel Sector: FY 2021-22*

Sr. No.	For Finished Steel (2021-22)	Major Players*	Others (SSI)**	Total
1	Total Electricity Requirement (MU)	50,394	43,894	94,288
2	Power Generated from WHR (MU)	11,266	5,315	16,581
3	Net Power requirement (after WHR)	39,128	38,579	77,707
4	CPP Electricity (MU)	33259	15432	48690
5	Share of RE in CPP Electricity (0.39%)	130	60	190
6	Grid Electricity (MU)	5869	23147	29017
7	Share of RE power in Grid Electricity (18.56%)	1089	4296	5385
8	Share of RE power in total electricity consumption	3.1%	11.3%	7.2%
9	CPP CO_2 factor (tCO_2/MWh)	0.96		
10	CO_2 emissions from CPPs (mn tCO_2)	32	15	47
11	Grid CO_2 factor (tCO_2/MWh)	0.66		
12	CO_2 emissions from grid (mn tCO_2)	3.9	15.3	19.2
13	Total CO_2 emissions from CPPs + grid (mn tCO_2)	35.8	30.1	65.9
14	Overall CO_2 factor (tCO_2/MWh)	0.92	0.78	0.85

Note: *Major players includes- SAIL, RINL, TSL Group, AM/NS, JSW Steel and JSPL*

***It is assumed that major players meet 85% of their net electricity requirement from captive sources and remaining from the grid. Other players meet 60% of their net electricity requirement from the grid and the remaining from captive sources.*

The grid CO_2 factor for 2021-22 is projected based on the considered grid RE penetration of 18.56%, the current CO_2 factor for non-RE sources[#] (0.815 tCO_2/MWh) as per the CEA CDM CO_2 baseline released in 2022. Similarly, the CPP CO_2 factor is projected assuming the CO_2 factor for coal plants (0.968 tCO_2/MWh) as per CEA and the assumption that coal forms the non-RE component of CPPs.

[#]Here, non-RE sources include coal, gas, nuclear, and diesel sources of generation.

6.4.3. RPO Compliance

Small Steel industries procure grid power for their operations. DISCOMs and captive/Open Access consumers have a mandate to fulfil the RPO targets as set by the respective SERCs. The Ministry of Power has notified the RPO trajectory till 2030, which increases from 24.6% in FY 2023 to 43.33% by FY 2030[32]. In 2022, the steel-rich states have achieved a RPO compliance of 18.56%. The steel industries procure about 38% of the net electricity requirement from the grid which in a way penetrates the RE in the electricity mix of the sector *(refer Table 6.4)*.

6.5. Challenges Faced by the Steel Players in RE Integration

The steel industries face different challenges in enhancing RE integration. Some of the challenges faced by the steel industry apply to both the large and small industries, and some of the challenges are category-agnostic. i.e., applicable to both categories of industries.

Table 6.5: *Challenges faced by Integrated Steel Plants (ISPs) and Small Steel Industries (SSIs) for RE Integration*

Sr. No.	Challenges	Large Industries/ Integrated Steel Plants (ISPs)	Small Industries/ Small Steel Industries (SSIs)
1	Cost Implication due to RE integration	✓	✓
2	Lack of awareness and technical capacity	NA	✓
3	Regulatory Issues		
	3A. Non-alignment of state regulations with Green Energy Open Access Rules, 2022, viz. i. CSS levied on behind-the-meter projects ii. Inconsistent Banking Policies across states iii. Higher CSS/AS/STU Charges iv. Rule No. 5 (2) of Green Energy Open Access Rules, 2022, where the load of the consumer drawing power should be constant for certain number of time blocks which is difficult to comply with for variable load steel industries operating Electric Arc Furnace (EAF)/ Induction Furnace (IF) *CSS: Cross Subsidy Surcharge* *AS: Additional Surcharge* *STU: State Transmission Charges*	✓	✓
	3B. Delays in Approvals for Open Access	✓	✓
4	Lack of consistency and long-term visibility of policies	✓	✓
5	Lack of resources		

Sr. No.	Challenges	Large Industries/ Integrated Steel Plants (ISPs)	Small Industries/ Small Steel Industries (SSIs)
	5A. Land availability & acquisition	NA	✓
	5B. Finance i. Lack of access to finance to Steel Industry/RE Developers ii. Payment Security Issues for SSIs/ RE Developers	NA	✓
6	High STU drawal Charges in RE-deficient Steel-rich states	✓	✓
7	Technical Constraints		
	7A. Intermittency of RE power	✓	✓
	7B. Transmission constraint	✓	NA
8	High Green Tariff (Cost Plus option)	NA	✓
9	Low volume in Green Power Markets (GDAM/GTAM)	NA	✓

Here are the above challenges discussed elaborately:

1. **Cost Implication due to RE integration:** Captive thermal plants are the major source of electricity for the ISPs or the large steel players. The variable cost of thermal-based captive units is in the range of INR 2.5 - 3/kWh, whereas the landed cost of RE power is in the range of INR 6 - 8/kWh depending upon the charges levied by the state DISCOMs and mode of procurement. Hence, replacing the current thermal captive projects with captive RE will increase the cost and, thus, is not economically viable for the ISPs. As mentioned in Tables 6.17 and 6.18, RE integration can increase the cost of production to as high as around 4%.
2. **Lack of Awareness:** Small steel industries do not have adequate resources and know-how to integrate RE into the production processes. For example, SSIs lack access to various RE suppliers, traders or aggregators. SSIs also have limited knowledge of the nitty-gritty of RE procurement, which acts as a hindrance to RE procurement.
3. **Regulatory Issues**

   k. **Non-Alignment of State Regulations with Green Energy Open Access Rules, 2022:** Many states have not aligned their open access rules with Green Energy Open Access) Rules 2022, such as banking rules and charges (mentioned below). Table 6.6 shows the status of various states on GEOA rules.

Table 6.6: *Status of Green Energy Open Access Rules, 2022*

S.No.	State	Status of GEOA Rules
1	Karnataka	Notified GEOA Rules 2022[33][1]
2	West Bengal	Notified GEOA Rules 2022[34]
3	Haryana	Notified GEOA Rules 2022[3][35]
4	Punjab	Issued draft amendment[4][36]

S.No.	State	Status of GEOA Rules
5	Uttarakhand	Issued draft amendment[5]37
6	Gujarat	Issued draft amendment[6]38
7	Chhattisgarh	Notified GEOA Rules 2022[7]39

i. **Banking Rules not in compliance with GEOA Rules, 2022:** As per the *Captive and Renewable Energy Generating Plants Regulations (CRE) 2019* section 6(1)(c), banking of power is defined as *"the process under which a Generating Plant supplies power to the grid not with the intent of selling it to either a third party or to a Licensee, but with the intention of exercising its eligibility to draw back this power from the grid for its use as per the conditions provided in these Regulations"*[40].

As per the Rule 8 of the *Green Energy Open Access Rules 2022*, banking shall be permitted at least on a monthly basis on the payment of banking charges of 8% as per model regulations by the Forum of Regulators (FOR)[41][42]. However, the policies in some states do not align with this. For example, in the case of Punjab, the banking agreement approved by PSERC provides that the accounting of banking charges be done on 15 minutes-basis (time block-wise) and the settlement be done on monthly basis[43]. The following Table 6.7 shows how the banking policies differ from state to state.

Table 6.7: *Variation in Banking Regulations across states*

Sr. No.	Parameters	Duration of settlement	Time-of-day withdrawal	Banking charges	Compensation for excess electricity	Remarks
1	Odisha	Monthly	No withdrawal during peak hours	Not specified	Payment up to a specific percentage of the total electricity banked	As per the Odisha RE Policy, yet to be operation-alized through regulations
2	Chhattisgarh	Yearly	Peak withdrawal charges would be applicable	2% in kind	Excess energy would be deemed to be purchased by DISCOM	-
3	Jharkhand	Monthly	Withdrawal not permitted during February to June	5% in kind	Excess energy up to 10% of total banked energy would be purchased at 50% of Average pooled power purchase cost	This is as per the Jharkhand State Solar Policy

Sr. No.	Parameters	Duration of settlement	Time-of-day withdrawal	Banking charges	Compensation for excess electricity	Remarks
4	Punjab	Monthly	No withdrawal from June to September and during peak hours in other months	10% in kind	No compensation	As per the latest draft amendment to the open access regulations, yet to be notified
5	Maharashtra	Monthly	As per the ToD slots when the energy was banked (i.e., at peak time, only energy banked at peak time can be withdrawn)	2% in kind	Excess energy up to 10% of actual generation would be deemed to be purchased at Generic RE Tariff Order	
6	Karnataka	Monthly			No compensation; however, RECs will be granted	As per the Green Energy Open Access Regulations, further details would be in a separate regulation. However, currently, annual banking is followed with 2% banking charges for wind and no charges for solar

ii. **Cross Subsidy Surcharge levied on behind-the-meter projects:** Cross Subsidy Surcharge *(CSS definition discussed in Box.1.)* is being levied in some States even for onsite captive plants (behind-the-metre projects), though as per the rules, CSS is only applicable on the power procurement from DISCOMs or via third party open access or power market. From the stakeholder consultations it is known that states like Odisha and Rajasthan levy the CSS for onsite captive plants and Maharashtra imposes CSS in case of onsite captive plants where the load is greater than 499 kVA.

iii. **High and Variable Open Access Charges across States:** Though some states have implemented the rules, tariffs are higher because of high cross-subsidy surcharges, banking charges, etc., which are not in line with the rules[44].

iv. **Misinterpretation of Rule (5) of GEOA Rules, 2022:** Rule (5) of GEOA rules is misinterpreted by some states, which is detrimental to the variable-load steel industries, especially the players operating Electric Arc and Induction furnace-based that have high fluctuating loads. Rule (5) of Green Energy Open Access Rules, 2022[45] is quoted below:

"Provided further that reasonable conditions such as the minimum number of time blocks, which shall not be more than twelve-time blocks, for which the consumer shall not change the quantum of power consumed through open access may be imposed to avoid high variation in demand to be met by the distribution licensee."

While Punjab State Electricity Regulatory Commission (Terms and Conditions for intra-State Open Access) (10th Amendment) Regulations, 2022[46]- Regulation 8(c) reads as: "Provided that the Green Energy open access consumer shall not change the quantum of power consumed through open access for at least twelve consecutive time blocks of 15 minutes time interval during a day. Provided further any variation in the admissible drawal shall be treated as per provisions specified under Regulation 31 of these Regulations."

Punjab State Electricity Regulatory Commission Regulations are not aligned with GEOA Rules, 2022, notified by MoP which causes serious problems for steel units to procure RE power through open access as their load varies hourly.

l. **Delays by DISCOMs in granting Open Access:** State DISCOMs delay the approvals and clearances for open access as C&I consumers are the major contributors to their revenue. Industrial consumers are not informed of the proper reasons for such delays. Industries also have to undergo a tedious process of seeking multiple approvals and clearances for open access.

4. **Lack of consistency and long-term visibility of policies:** Different policies and open access charges, such as cross subsidy, banking charges etc., undergo multiple changes during the lifetime of a captive project. This policy uncertainty affects the viability of the RE project, thus, discouraging industry players from opting for RE projects.

5. **Lack of resources**

a. **Land availability & cumbersome acquisition process:** Steel Industries / RE developers willing to set up RE projects face land availability and its acquisition as a major challenge, especially in the states where barren land is not available easily and the cost of land is high. Lack of formal land allocation policy allocation by states, inconsistent and non-digitised land records, delays in environmental clearances, socio-cultural norms of land ownership and the processes involved in the acquisition and conversion of land, etc., make it difficult for RE developers or industries to acquire the land[47].

b. **Finance**

i. **Lack of access to finance:** Procuring RE via captive/group projects, though a cheaper and cleaner mode of power procurement, is not easy for SSIs. It requires a huge upfront capex of INR 4-5 Crore/MW (depending upon the solar insolation). 1 MW of load requires 2 MW of solar capacity to meet 50% of the power requirement (with a banking facility), translating into a capex of approximately 8-10 crore. The equity contribution (debt-equity ratio of 70:30) required for a 2 MW plant is INR 2.4 to INR 3 crores approximately. For a plant to qualify as captive, the consumer has to make at least 26% equity contribution. Thus, the investment requirement for the same 2 MW plant would be INR 62.4 -78 Lakhs *(26% of 30% = 7.8% of the total capital cost).*

ii. **Payment Security Issues:** Large steel players/ISPs generally procure RE via captive mode as they have adequate financial resources and access to credit at cheaper rates from Banks/FIs. However, SSIs lack such strong financial credentials. Third party Captive power plant developers also find it difficult to raise finance from the banks/FIIs due to risk of default by consumers (who are also the shareholders). Currently, developers are setting up many third-party captive power plants to supply power to C&I consumers. However, such plants are being set up for consumers having very good credibility, e.g., foreign companies, large AAA/AA rated Indian companies etc. Such developers are not willing to set up captive or group captive plants for small consumers/small steel units due to the risk of default in payment of electricity dues and also for the reasons that banks are reluctant to finance such plants as their risk perception is high. The developers ask for Letter of Credit (LC)/ Bank Guarantee (BG) which varies from couple of months to a year (depending upon the developer) to insure themselves against the payment default risk. SSIs find it difficult to arrange BGs/LCs for such huge amounts.

6. **Technical Constraints**

a. **Intermittency of RE Power:** The steel industries' operations require Round-the-clock (RTC) power for the production process, but renewable power is generally intermittent and is available when the sun shines or wind blows. Thus, it needs to be complemented with a supportive banking facility, storage facility or a secondary source of power. The *Capacity Utilisation Factor* (CUF) varies between 19% to 21% for solar plants and between 26% to 31% for wind plants across states[48].

b. **Transmission Infrastructure:** The capacity constraints in the current evacuation infrastructure sometimes led to congestion in the transmission network, curtailing the RE power.

7. **High State Transmission Utility (STU) drawal charges in RE-deficient States:** Most of the steel industries are located in RE-deficient (where solar/wind potential is poor) states like Odisha, Chhattisgarh, Jharkhand, West Bengal, etc. Table 6.8 shows that the steel industry in Odisha wheeling RE from Rajasthan has a high landed cost, both for captive and third-party open access mode, as compared to that of procurement from DISCOM. This is mainly due to the high STU drawal charges in Odisha. Similarly, from Table 6.8 below, it was observed that procuring RE from Rajasthan via open access for any other steel-rich state is costlier compared to Chhattisgarh due to the RE-friendly policies of the state.

Table 6.8: *Charges for Interstate RE Open Access*

			Drawal States			
Sr. No.		**Charges in INR /kWh**	**Odisha**	**Jharkhand**	**Chhattisgarh**	**West Bengal**
1	A	Assumed ex-bus	2.50	2.50	2.50	2.50
2	B1	STU Charges	2.81	1.58	1.31	2.28
3	B2	STU Losses	0.32	0.25	0.28	0.29
4	B3	CTU Losses	0.14	0.14	0.14	0.14
5	B =B1+ B2+B3	Transmission C&L	3.27	1.96	1.72	2.71

Drawal States						
Sr. No.		**Charges in INR /kWh**	**Odisha**	**Jharkhand**	**Chhattisgarh**	**West Bengal**
6	C	Wheeling C&L	1.30	1.08	0.27	0.91
7	A+B+C	Captive RE OA	7.08	5.55	4.49	6.12
8	D	Cross-subsidy surcharge	0.42	1.41	0.45	1.13
9	E	Additional surcharge	0.00	0.00	0.00	0.00
10	A+B+C+D+E	Third-party RE OA	7.49	6.96	4.94	7.25
11	F	DISCOM Tariff	6.26	6.15	7.18	7.52

Source: *CEEW Open Access Calculator*

Assumption: *The project is a 10 MW solar PV system with 20% CUF injected in Rajasthan at 11 kV connectivity without banking and Drawal at 11 kV in the above mentioned states.*

8. **High Green Tariff (Cost Plus option):** Industries can procure RE power from the DISCOMs at a premium over and above the conventional tariff called the Green Tariff. This cost-plus model of the Green Tariff discourages smaller steel uptake to buy green power from DISCOMs.
9. **Low Volume in Green Power Markets (GDAM/GTAM):** The volume of RE traded in Power Exchanges (Green Day Ahead Market and Green Term Ahead Market) is very small. Out of the total energy generated in 2022, only 5% was traded on the power market and only 0.05% was traded on GDAM. Financial institutions are reluctant to finance the merchant RE power project due to uncertainty in the price and uptake of power.

6.6. Projection of Electricity Requirement for Steel Sector in 2031

The projection for the electricity requirement in FY 2030-31 is undertaken based on the steel production targets given in the National Steel Policy (2017). Further, it is assumed that, as a result of energy efficiency initiatives, including the PAT scheme and also consultation with the relevant stakeholders, the specific electricity consumption for each process would reduce by 12% till 2031, i.e. at the rate of 2% per annum. Thus, while the overall specific electricity consumption reduces from 786 kWh/ton (2021-22) to 697 kWh/ton (2030-31), the total electricity requirement for the steel sector is expected to increase at an average rate of 8.7% per annum from 94.3 TWh in 2021-22 to 183.8 TWh by 2030-31.

Table 6.9: *Electricity Requirement for Steel Sector in FY 2030-31*

Sr. No.		Production (MTPA)	Specific electricity consumption (kWh / tonne of product)	Total Electricity Requirement (MU) in 2030
1	Iron Production (2+3+4)	309.42		49,790
2	Sponge Iron - Coal DRI	61.90	88.00	5,447
3	Sponge Iron - Gas DRI	18.10	105.60	1,912

Sr. No.		Production (MTPA)	Specific electricity consumption (kWh / tonne of product)	Total Electricity Requirement (MU) in 2030
4	Hot Metal & Pig Iron	229.42	184.95	42,431
5	Steel Production (6+7+8)	255.00		1,09,692
6	BOF	115.71	153.20	17,727
7	EAF	64.65	584.32	37,776
8	IF	74.64	726.00	54,189
9	Steel Finishing (10+11)	230.00		24,288
10	ISP	131.72	105.60	13,909
11	SSI	98.28	105.60	10,379
12	**Total consumption (Finished Steel) (1+5+9)**		**698.68**	**1,83,770**

Electricity from waste heat recovery currently contributes 16.6 TWh in 2021-22, and is expected to more than double to 38 TWh in 2030-31. CPPs are the single largest source of electricity, contributing to 48.7 TWh in 2021-22. Their current share of CPPs in the net electricity procurement (electricity procurement other than from WHR) is 62.7% and is estimated to increase to 63% by 2030-31. While the quantum of electricity procured from the grid is expected to increase from 29.02 TWh to 53.9 TWh, the share of the grid in net electricity procurement will decrease slightly from 37.3% to 37%. Further, the share of major players in total electricity consumption is estimated to marginally increase from 53% to 55%.

Table 6.10: *Category-wise & Source-wise Electricity Requirement of Steel Sector*

Sr. No.	For Finished Steel	2021-22			2030-31		
		Major Players*	Others (SSI)	Total	Major Players	Others	Total
1	Total Electricity Requirement (MU)	50,394	43,894	94,288	1,01,075	82,695	1,83,769
2	Power Generated from WHR (MU)	11,266	5,315	16,581	26,645	11,506	38,150
3	Net Power requirement (after WHR) (1-2)	39,128	38,579	77,707	74,430	71,189	1,45,619
4	CPP Electricity (MU)	33,259	15,432	48,690	63,266	28,476	91,741
5	Grid Electricity (MU)	5,869	23,147	29,017	11,165	42,713	53,878

**Note Major players includes- SAIL, RINL, TSL Group, AM/NS, JSW Steel and JSPL*

It is assumed that major players meet 85% of their net electricity requirement from captive sources and remaining from the grid. Other players meet 60% of their net electricity requirement from the grid and the remaining from captive sources.

6.7. State-wise RE Requirement in the Captive Electricity Demand in the Steel Sector

In 2030-31, three scenarios of RE penetration in the captive sources were considered - 20%, 30%, and 43.33% (similar to MoP's RPO compliance by 2030) [49]. The requirement, as estimated, has been further allocated to the major steel-producing states based on their share in production of steel as per the JPC (Joint Plant Committee) report. As shown in Table 6.11 below, around 28 TWh of electricity needs to be generated from the RE sources to achieve 30% penetration of RE in captive generation by 2030-31.

Table 6.11: *Electricity Generation from RE in captive required as per different scenarios in 2030-31*

Sr. No.	States	20% RE in captive	30% RE in captive	43.33% in RE in captive
1	Odisha	4070	6105	8818
2	Jharkhand	2994	4490	6486
3	Chhattisgarh	2609	3914	5653
4	Karnataka	2285	3427	4949
5	Maharashtra	1991	2987	4314
6	Gujarat	1609	2414	3486
7	West Bengal	1547	2321	3353
8	Andhra Pradesh	1243	1864	2692
9	**Total**	**18348**	**27522**	**39752**

Further, the RPO targets, as set by the Ministry of Power, have to reach 43.33% by 2030. If this RPO target is met by DISCOMs in India, then even at the current level of RE penetration in the captive sources (i.e., 0.39%), the steel sector will achieve 16.3% of RE penetration (Scenario Business-as-usual (BAU)). Further, at 20%, 30% and 43.33% penetration of RE in the captive sources, as discussed above, the steel manufacturing sector will achieve an overall RE penetration of around 29%, 35% and 43.33% respectively (Scenarios 1-3).

Table 6.12: *Scenario-based Quantum of RE Penetration in Steel Sector (2030-31)*

Sr. No.	2030	Total electricity (MU)	Scenario BAU	Scenario 1 (20% RE in Captive)	Scenario 2 (30% RE in Captive)	Scenario 3 (43.33% RE in Captive)
1	Grid	53,878	23,345 (43.33%)	23,345 (43.33%)	23,345 (43.33%)	23,345 (43.33%)
2	Captive	91,741	357 (00.39%)	18,348 (20.00%)	27,522 (30.00%)	39,752 (43.33%)
3	Net	145,619	23,702 (16.3%)	41,694 (28.6%)	50,868 (34.9%)	63,097(43.33%)

6.8. Reduction in CO_2 Emissions due to RE Penetration

The increase in RE penetration in the steel sector will lead to reduction in CO_2 emissions, thus, reducing the overall CO_2 factor (tCO_2/MWh) from 0.85 in 2021-22 (Table 6.4) to 0.78 in 2030-31 in the BAU scenario, to 0.66 in Scenario 1, to 0.60 in Scenario 2 and 0.52 in case of Scenario 3 as shown in the table 6.13 below. The RE penetration will lead to the reduction in the emission intensity of the steel sector (tCO_2/tcs) from 2.54 in 2023-24 to 2.46 in 2030-31 in the BAU Scenario, to 2.41 in Scenario 1, to 2.38 in Scenario 2 and 2.35 in case of Scenario 3. **With 43% RE penetration** in the steel sector by FY 2030-31 will lead to an **emission reduction of 8% from** 2.54 to 2.35 tCO_2/tcs

Table 6.13: *CO_2 Emissions due to Electricity Consumption in the Steel Sector: 2030-31*

Sr. No.	2030	Scenario BAU	Scenario 1 (20% RE in Captive)	Scenario 2 (30% RE in Captive)	Scenario 3 (43.33% RE in Captive)
1	Grid power	53,878 MU			
2	Grid RE penetration	43.33%			
3	Grid CO_2 factor	0.46 tCO_2/MWh			
4	CO_2 from grid	24.9 mn tCO_2			
5	CPP power	91,741 MU			
6	CPP RE penetration	0.39%	20%	30%	43.33%
7	CPP CO_2 factor	0.96 tCO_2/MWh	0.77 tCO_2/MWh	0.68 tCO_2/MWh	0.55 tCO_2/ MWh
8	CO_2 from CPPs	88.5 mn tCO_2	71.0 mn tCO_2	62.2 mn tCO_2	50.3 mn tCO_2
9	Total CO_2	113.3 mn tCO_2	95.9 mn tCO_2	87.0 mn tCO_2	75.2 mn tCO_2
10	Overall CO_2 factor	0.78 tCO_2/MWh	0.66 tCO_2/MWh	0.60 tCO_2/MWh	0.52 tCO_2/ MWh
11	Emission intensity of the steel sector (tCO_2/ tcs)	2.46	2.41	2.38	2.35

The grid CO_2 factor for 2030-31 is projected based on the considered grid RE penetration of 43.33% and the current CO_2 factor for non-RE sources (0.815 tCO_2/MWh) as per the CEA baseline released in 2022. Similarly, the CPP CO_2 factor is projected assuming the CO_2 factor for coal plants (0.968 tCO_2/MWh) as per CEA and the assumption that coal forms the non-RE component of CPPs.

6.9. Capex Requirement for RE Penetration in the Captive-based Steel Sector

The capex required for achieving the above-discussed RE penetration in the captive sector is shown in the table 6.14 below. The most ambitious scenario - Scenario 3, where Steel Manufacturer meets the RPO targets for captive/open access consumers would require a capex of INR 73,861 crores. The cost has been calculated assuming a 50-50 hybridisation of solar and onshore wind. Depending upon the location of the plants, the banking facilities would be extended to the facilities, and the individual load profiles, wind-solar hybrid plants would be able to substantially meet the requirement without storage. However, if a constant round-the-clock output is sought, the storage system will require additional capex vis-a-vis the capex for RE generation for Scenarios 1-3.

Table 6.14: *Capex Requirement for Scenario-based RE-Penetration in Captive Sector (2030-31)*

Capex Requirement					
Sr. No.	**2030-31**	**Scenario BAU**	**Scenario 1 (20% RE in Captive)**	**Scenario 2 (30% RE in Captive)**	**Scenario 3 (43.33% RE in Captive)**
1	Total captive RE (MU)	358	18,348	27,522	39,752
2	Existing captive RE (MU)	190	190	190	190
3	New captive RE (MU)	168	18,158	27,332	39,562
4	New RE capacity (MW)	62	6,687	10,065	14,568
5	RE generation capex (INR crore)	313	33,901	51,029	73,861

6.10. Modes of RE Uptake in the Steel Sector

The steel industries procure RE via various different modes to meet their RPO targets as shown in the figure 6.4 below.

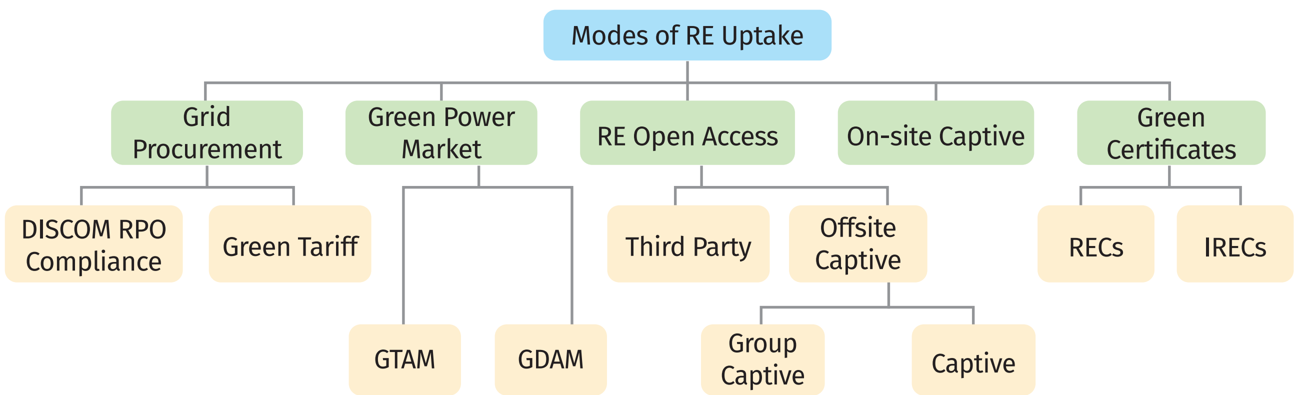


Figure 6.4: *Modes of RE Uptake by Steel Industries*

6.10.1. Grid Procurement

Steel industries procure grid power for their operations. DISCOMs have a mandate to fulfil the RPO targets set by the respective SERCs. The Ministry of Power has notified the RPO trajectory until 2030, which increases from 24.6% in FY 2023 to 43.33% by FY 2030[50]. In 2022, the steel-rich states achieved an RPO compliance of 18.56% (weighted Average). The steel industries procure about 31% of the electricity requirement from the grid, which penetrates the RE in the electricity mix of the sector.

6.10.1.1. Procurement of Green Power from DISCOMs

DISCOMs provide RE to **industries at a** premium over and above the conventional Green tariff. As of 2022, **steel-rich** states have different **premium rates** for green tariff**, which vary** from 25p/kWh (Odisha) to 79p/kWh (Chhattisgarh). Andhra Pradesh has a separate category of green power with a tariff of around INR 12/kWh.

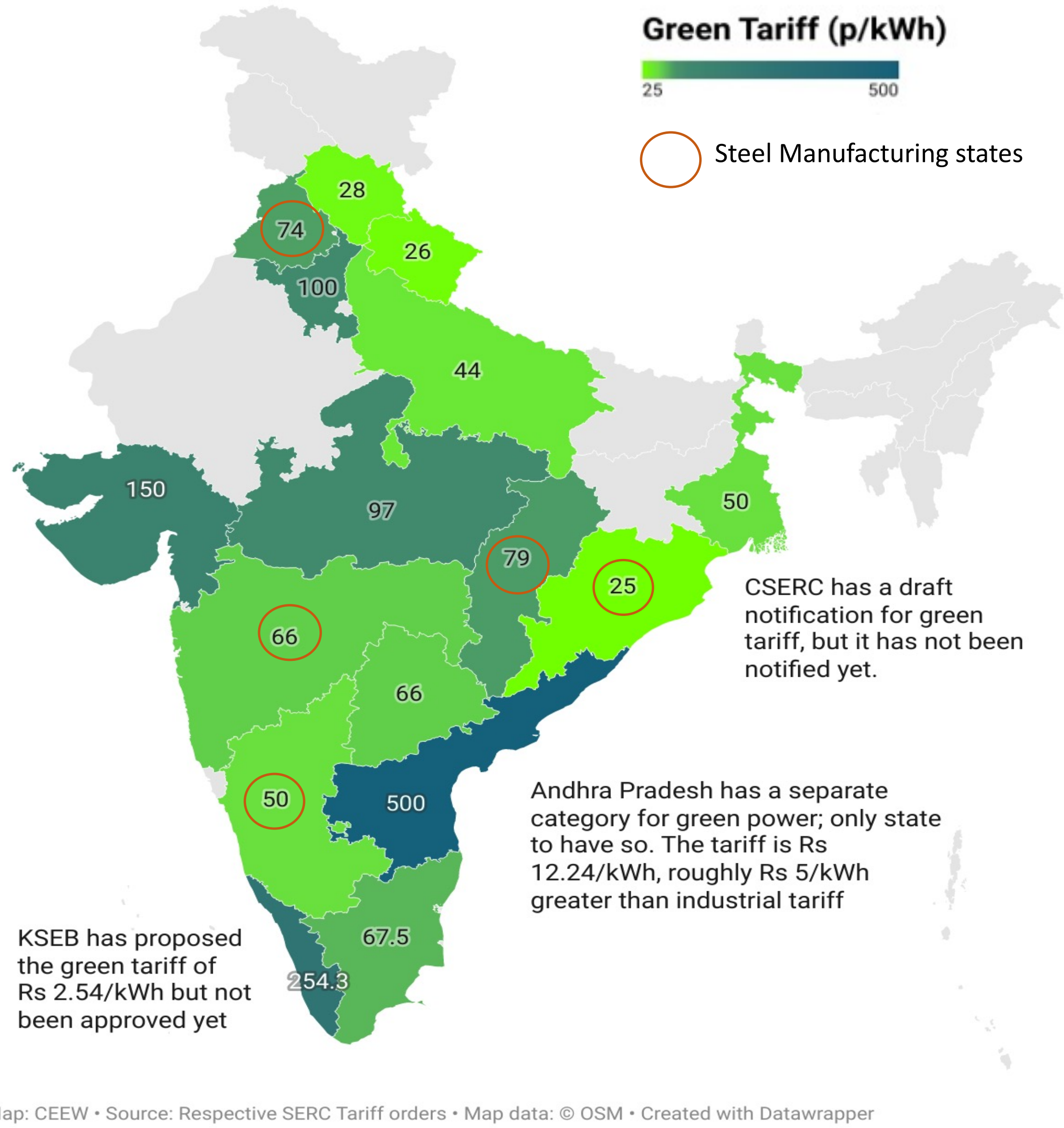


Figure 6.5: *State-wise Green Tariff*

6.10.2. Green Open Access Procurement

The C&I consumers with load greater than 1 MW can procure RE power from third party or offsite captive projects by paying applicable charges to the DISCOMs and transmission utility through Open access mode. However, the recently notified Green Energy Open Access Rules, 2022 have reduced the load requirement limit from 1 MW to 100 kW and have allowed small industrial consumers to procure green energy[51]. Open access gives the choice to the consumers to buy cheaper and reliable power from any generator or supplier instead of completely relying on the state DISCOMs.

Steel Industries can opt for green open access in either third-party mode (OPEX) or Captive/Group Captive mode (CAPEX) based on the availability of resources and their needs.

6.10.2.1. Third Party Open Access

In this mode, a PPA is signed between the consumer and the RE developer. The RE developer owns and maintains the plant, and the consumer pays the tariff to the RE developer as per the signed PPA. In addition to the tariff mentioned in the PPA, the consumer bears the charges as applicable for open access: transmission charges and losses, wheeling charges and losses, SLDC charges, network operation charges, etc. The consumer has to pay the applicable cross subsidy surcharge and additional surcharge as determined by the State Electricity Regulatory Commission (SERC) from time to time *(Elaboration of various open access charges is given in Box 1).*

6.10.2.2. Captive and Group Captive Open Access*

Consumers with access to capital can set up their own Captive RE power plants to meet their electricity requirement. To set up a captive power plant, the consumer need not necessarily make the entire investment alone. As per the Electricity Rules, 2005, consumer has to own at least 26% equity (*(balance 74% may be contributed by a third-party developer who also constructs, operates and maintains the plant)* and consume at least 51% of the annual electricity generated by the captive plant, which translates to only 7.8% of the total capital cost of RE power plant (26% of 30% assuming a debt-equity ratio of 70:30)[52]. The requirement of capex can be further reduced as discussed in section 6.12.1.(5)(d)(iv). Group of smaller consumers can aggregate their demand and collectively contribute 26% equity.

For the Captive/Group Captive plants, the cross subsidy and additional surcharges are not applicable, and, therefore, the cost of power to consumers is the lowest. Tables 6.15 and 6.16 compare the costs.

6.10.3. Green Power Market - GDAM/GTAM

Eligible industrial consumers can procure green power from power exchanges such as IEX, PXIL, and HPX via various modes. However, price volatility, low volumes and curtailment risk are the biggest barriers to the green power market. It also requires expertise for day-to-day market monitoring and trading.

6.10.4. On-site Captive Generation

Steel industries also have the option of installing on-site renewables (DRE) like rooftop or ground-mounted solar. This option offers certain advantages to the industries, like low recurring expenditures, ownership of the plant, eligibility for attractive net metering policies, etc. However, the availability of adequate rooftop area or land adjoining the load is an issue.

6.10.5. Green Certificates

6.10.5.1. Renewable Energy Certificates (RECs)

Renewable Energy Certificate (REC) is an environmental green attribute of power. It is traded over the power exchanges to promote renewable energy and facilitate C&I consumers to meet their RPO target. Each REC represents 1 MWh of energy produced from renewable source/s. RECs are a relatively simple procurement option, which involves - a) no capex, b) no long-term purchase commitment and c) pay as you buy. However, RECs have been prone to frequent regulatory changes. RECs are better suited to meet the short-term targets and are suitable for consumers who are unable to access RE from other procurement routes.

6.10.5.2. International RECs (I-RECs)

I-RECs are globally tradable green certificates, where each certificate is equivalent to 1 MWh of renewable energy produced. I-RECs is an easy way for foreign corporates to offset their carbon footprint[53]. Though I-REC is recognised by major international sustainability standards like GHGP, CDP, RE100, ISO, etc., Indian laws do not allow the use of I-RECs to meet the RPO targets[54]. However, it is expected that in the coming future Indian industries will be willing to purchase I-RECs to attract funding from international investors.

6.11. Landed Cost Comparison and Cost Implications of Energy Transition

6.11.1. Landed Cost Comparison of RE Uptake via various modes

Landed cost calculations are done for interstate and interstate open access for various states considering the various modes of RE procurement with applicable charges. The below table 6.15 gives the break-up of the 'landed cost' of an interstate RE project under the captive and third-party modes and compares it to the tariff of green power sourced from the DISCOM for steel rich states: Odisha, Jharkhand, Chhattisgarh, Karnataka, Maharashtra, Gujarat, West Bengal and Andhra Pradesh.

Table 6.15: *Landed Cost Comparison for Interstate RE Open Access*

Sr.No.	Tariffs in INR /kWh	OR	JH	CG	KA	MH	GJ	WB	AP
1	Assumed ex-bus	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
2	Transmission C&L	3.27	1.96	1.72	3.02	2.57	2.69	2.71	3.06
3	Wheeling C&L	1.30	1.08	0.27	0.47	1.03	0.78	0.91	1.34
4	Captive RE OA	7.08	5.55	4.49	5.99	6.10	5.97	6.12	6.90
5	Cross-subsidy surcharge	0.42	1.41	0.45	1.95	1.70	1.50	1.13	1.76
6	Additional surcharge	0.00	0.00	0.00	0.00	1.32	0.31	0.00	0.00
7	Third-party RE OA	7.49	6.96	4.94	7.94	9.12	7.78	7.25	8.66
8	DISCOM tariff	6.26	6.15	7.18	7.67	7.97	5.36	7.52	6.69
9	Green tariff (REC cost for JH)	0.25	*0.65	0.79	0.50	0.66	1.50	0.50	0.75
10	DISCOM + Green tariff	6.51	6.80	7.97	8.17	8.63	6.86	8.02	7.44

Assumption - *The project is a 10 MW solar PV system with 20% CUF injected in Rajasthan at 11 kV connectivity without banking.*

It can be observed that, except for **Odisha**, the landed cost of interstate captive RE open access is lower than the cost of green power as sourced from the DISCOM.

Consumers can also source power from open access projects set up in the same state. In this case, only transmission and wheeling charges and losses for the concerned state are levied upon the consumer. However, the ex-bus cost of generation may be little higher if the State does not receive adequate insolation. However, in f intrastate projects, banking of power is also allowed at nominal charges, i.e., during surplus RE power generation, surplus power can be banked with the DISCOM which can be withdrawn later when RE power is not available. With the banking facility, 45-50% of total power requirement can be met from RE without any storage compared to 20-25% in the absence of a banking facility. As per GEOA Rules, 2022, up to 30% of the total power consumption can be banked.

The table 6.16 below breaks-up of the 'landed cost' of an intrastate RE project under the captive and third-party modes and compares it to the tariff of green power sourced from the DISCOM for the steel rich states: Odisha, Jharkhand, Chhattisgarh, Karnataka, Maharashtra, Gujarat, West Bengal and Andhra Pradesh.

Table 6.16: *Landed Cost Comparison for Intrastate RE Open Access*

Sr.No.	Tariffs in INR /kWh	OR	JH	CG	KA	MH	GJ	WB	AP
1	Assumed ex-bus	2.75	2.59	2.63	2.59	2.50	2.51	2.77	2.71
2	Transmission C&L	1.53	0.31	0.08	0.08	0.93	0.97	1.01	1.33
3	Wheeling C&L	1.17	0.95	0.17	0.08	0.89	0.59	0.85	1.19
4	Captive RE OA	5.45	3.85	2.88	2.76	4.33	4.07	4.63	5.23
5	CS surcharge	0.42	1.41	0.45	1.95	1.70	1.50	1.13	1.76
6	Additional surcharge	0.00	0.00	0.00	0.00	1.32	0.31	0.00	0.00
7	Third-party RE OA	5.87	5.26	3.33	4.71	7.35	5.88	5.76	6.99
8	Charges for banking 30% of the energy	2.46	0.15	0.02	0.06	0.03	0.79	2.03	0.08
9	DISCOM + Green tariff	6.51	6.80	7.97	8.17	8.63	6.86	8.02	7.44

Assumption - *The project is a 10 MW solar PV system with 20% CUF injected in the same state at 11 kV connectivity with 25% banking.*

Rajasthan discourages the interstate RE open access

RRECL imposes a levy varying from ₹2-₹5 lakhs/MW/year on those solar developers who sell the power produced to utilities other than state-based DISCOMs depending on the year of commissioning as a contribution to Rajasthan Renewable Energy Development Fund (RREDF).

The two tables above show that the cost of RE power is lowest in the case of intrastate Captive or Group Captive power plants due to lower transmission and wheeling charges, no cross subsidy, additional surcharge and other concessions extended by States to promote RE in their States.

The graph below shows the cost of electricity for a 1 MTPA plant (i.e., considering specific net electricity consumption of 651 kWh/ton as discussed in the earlier section).

Depending on the mode and the state, these costs vary from INR 184 crores/year to INR 562 crores/year. Except Odisha, intrastate third-party open access is cheaper than the grid tariff even after considering banking for all states.

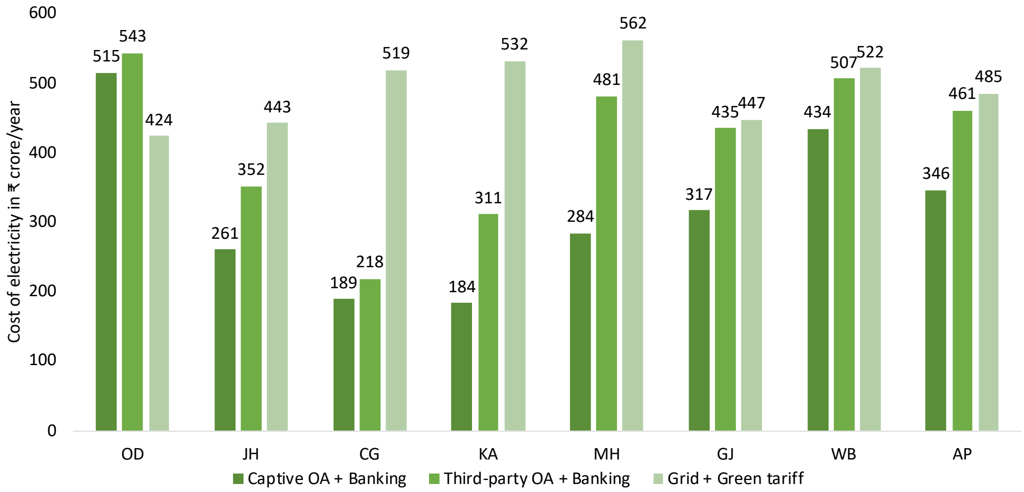


***Figure 6.6.** Annual Cost of Electricity for 1 MTPA Integrated Steel Plant across states (in INR crores)*

Chhattisgarh: A model for RE Open Access

From the graph above, it can be observed that Chhattisgarh has the lowest charges on green energy open access. This incentivises industries to adopt green energy in their electricity consumption portfolio. Chhattisgarh has the lowest state transmission and wheeling charges, as evidenced by the comparison of landed costs for inter-state and intra-state green open access projects, due to special provisions being extended to RE projects.

-Chhattisgarh has a 100% waiver on wheeling charges, a 100% waiver on transmission charges, and a 50% waiver on CSS in case of third party solar/wind/hybrid. Other states can emulate these policies to incentivise greater adoption of green power through open access.

6.11.2. Cost Implications due to Energy Transition

While the additional capex required for transitioning to RE has been already discussed in section 6.9, it is also essential to understand what the impact of the transition would be vis-a-vis the cost of steel. The small steel producers depend on a mix of the grid and their captive plants, whereas the integrated steel plants source the majority of the required electricity from their captive plants. Thus, the cost differential between non-RE and RE power would differ depending on the type of industry. Further, as discussed above, the cost of both grid power and RE open access would differ across states.

To estimate the impact of RE transition in the cost of steel production, it is assumed that the large integrated steel plants would transition from the mix of 85% thermal captive and 15% grid to RE captive open access, whereas, the smaller players would transition from a mix of 60% grid and 40% thermal captive to either third party Group Captive or third-party Open Access RE plants. The incremental cost per ton of steel is calculated assuming the net electricity consumption (electricity requirement after the WHR/off gas generation) of 651 kWh/ton. The cost implication is defined as the ratio of incremental cost per ton of steel to the cost of steel (assumed at INR 78,000/ton).

6.11.2.1. Cost implication of Choosing Fresh Green Power over Fresh Grey Power

The following tables give us the cost implication of installing a new captive RE plant instead of a new thermal captive power plant, both for large and small steel players.

Table 6.17: *Cost implication of choosing Green Power over Fresh Grey Power for Integrated Steel Plants (ISPs)*

Sr. No.	Tariffs in INR /kWh	OR	JH	CG	KA	MH	GJ	WB	AP
1	Total cost of thermal captive (INR /kWh)	6.00							
2	Cost of grid power (INR /kWh)	6.26	6.15	7.18	7.67	7.97	5.36	7.52	6.69
3	Weighted average cost of non-RE power (85% captive and 15% grid) (INR /kWh)	6.04	6.02	6.18	6.25	6.30	5.90	6.23	6.10
4	RE captive OA including banking (INR /kWh)	7.91	4.00	2.90	2.82	4.36	4.86	6.66	5.31
5	Incremental cost per unit (INR /kWh) (4-3)	1.87	-2.02	-3.28	-3.43	-1.94	-1.04	0.43	-0.79
6	Incremental cost per ton of steel (INR /ton)	1219	-1318	-2135	-2235	-1261	-680	281	-517
7	Cost implication	1.56%	-1.69%	-2.74%	-2.87%	-1.62%	-0.87%	0.36%	-0.66%

Assumption: *Landed cost of coal = INR 4000/ton and power plant is located adjacent to the Steel plant*

Table 6.18: *Cost implication of choosing Green Power over Fresh Grey Power for Small Steel Industries*

Sr. No.	Tariffs in INR /kWh	OR	JH	CG	KA	MH	GJ	WB	AP
1	Variable cost of thermal captive (INR /kWh)*	6.00							
2	Cost of grid power (INR /kWh)	6.26	6.15	7.18	7.67	7.97	5.36	7.52	6.69
3	Weighted average cost of non-RE power (60% grid and 40% captive) (INR /kWh)	6.16	6.09	6.71	7.00	7.18	5.62	6.91	6.41
4	RE third-party OA including banking (INR /kWh)	8.33	5.41	3.35	4.77	7.38	6.67	7.79	7.07

Sr. No.	Tariffs in INR /kWh	OR	JH	CG	KA	MH	GJ	WB	AP
5	Incremental cost per unit (INR /kWh)	2.17	-0.68	-3.36	-2.23	0.20	1.05	0.88	0.66
6	Incremental cost per ton of steel (INR /ton)	1416	-443	-2188	-1454	129	687	572	427
7	Cost implication	1.82%	-0.57%	-2.80%	-1.86%	0.17%	0.88%	0.73%	0.55%

Assumption: *Landed cost of coal = INR 4000/ton and power plant is located adjacent to the Steel plant*

It can be observed that, for both large and small steel plants, choosing fresh green power over fresh grey power is costliest in Odisha, the largest steel-producing state in India. The cost implication of choosing fresh green power over fresh grey power is lower for the larger steel plants as captive RE is cheaper than the RE procured from third-party. The implication for the small steel plants is negative in Chhattisgarh, Karnataka, and Jharkhand, indicating that additional RE power would be cheaper in these states than the fresh/additional thermal power.

6.11.2.2. Cost implication of Transitioning to Fresh Green Power over Existing Grey Power

The following tables give us the cost implication of phasing out an existing operational thermal captive power plant and installing a new captive RE plant, for large and small steel players.

It was observed that the cost implication in this case is higher than in the earlier case (choosing fresh captive RE over fresh thermal captive) as the incremental cost per unit is significantly affected by the variable cost of thermal captive, which is only INR 2.5/kWh in this case as compared to INR 6/kWh in the earlier case (where fresh RE captive is being installed instead of fresh thermal captive) due to the negligible fixed costs associated with the existing thermal captive power plants. The required policy support to facilitate this transition has been discussed in the *Recommendations* section *(refer 6.12.2 (2))* as it is crucial to phase out the inefficient thermal captive plants.

Table 6.19: *Cost implication of transitioning from existing grey power to green power for Large Steel Plants*

Sr. No.	Tariffs in INR /kWh	OR	JH	CG	KA	MH	GJ	WB	AP
1	Variable cost of thermal captive (INR /kWh)*	2.50*							
2	Cost of grid power (INR /kWh)	6.26	6.15	7.18	7.67	7.97	5.36	7.52	6.69
3	Weighted average cost of non-RE power (85% captive and 15% grid) (INR /kWh)	3.06	3.05	3.20	3.28	3.32	2.93	3.25	3.13
4	RE captive OA including banking (INR /kWh)	7.91	4.00	2.90	2.82	4.36	4.86	6.66	5.31

Sr. No.	Tariffs in INR /kWh	OR	JH	CG	KA	MH	GJ	WB	AP
5	Incremental cost per unit (INR /kWh)	4.85	0.95	-0.30	-0.46	1.04	1.93	3.41	2.18
6	Incremental cost per ton of steel (INR /ton)	3157	621	-197	-297	677	1258	2219	1421
7	Cost implication	4.05%	0.80%	-0.25%	-0.38%	0.87%	1.61%	2.85%	1.82%

** Fixed cost is a sunk cost and therefore, not taken into consideration*

*** Assumption: Landed cost of coal = INR 4000/ton and power plant is located adjacent to the Steel plant*

Table 6.20: *Cost implication of transitioning from existing grey power to green power for Small Steel Plants*

Sr. No.	Tariffs in INR /kWh	OR	JH	CG	KA	MH	GJ	WB	AP
1	Variable cost of thermal captive (INR /kWh)*	2.50*							
2	Cost of grid power (INR /kWh)	6.26	6.15	7.18	7.67	7.97	5.36	7.52	6.69
3	Weighted average cost of non-RE power (60% grid and 40% captive) (INR /kWh)	4.76	4.69	5.31	5.60	5.78	4.22	5.51	5.01
4	RE third-party OA including banking (INR /kWh)	8.33	5.41	3.35	4.77	7.38	6.67	7.79	7.07
5	Incremental cost per unit (INR /kWh)	3.57	0.72	-1.96	-0.83	1.60	2.45	2.28	2.06
6	Incremental cost per ton of steel (INR /ton)	2328	469	-1276	-542	1041	1599	1484	1339
7	Cost implication	2.98%	0.60%	-1.64%	-0.69%	1.33%	2.05%	1.90%	1.72%

** Fixed cost is a sunk cost and therefore, not taken into consideration*

*** Assumption: Landed cost of coal = INR 4000/ton and power plant is located adjacent to the Steel plant*

The above tables show that it would be costlier for both ISPs and SSIs to transition from existing thermal captive to fresh green captive as compared to the earlier case (where ISPs/SSIs would go for fresh RE captive instead of fresh grey captive) as the fixed costs are negligible when the ISP/SSI is consuming power from an existing captive plant thus, reducing the variable cost of captive power to INR 2.5/kWh from INR 6/kWh in the earlier case (Table 6.17/ 6.18). The cost implication of the transition is highest in the state of Odisha, the largest steel-producing state in India, in case of both ISPs and SSIs and the cost implication of the transition is lowest in Chhattisgarh and Karnataka for both ISPs and SSIs.

6.12. Recommendations

This section discusses the recommendations for increasing the renewable energy penetration in the steel sector.

Here is the elaboration of the most suitable modes of RE procurement for steel players. The recommendations are based on these considerations.

Most Suitable Options for Steel Players for RE Procurement

1. **Captive Mode:** The most suitable mode is captive as it has various advantages like better quality and reliable electricity supply, low cost of power as compared to other modes, and cogeneration benefits of industrial processes.

    a. Large Plants/Integrated Steel Plants:

    i. Self-owned Captive RE plants (100% Equity by the industries)

    ii. Third-party owned Captive RE Plants (minimum 26% Equity by the industry and rest by the developer)

    b. Small Steel Plants

    i. Rooftop Solar (Onsite captive)

    Advantage: No open access charges applied hence reduced cost of power

    ii. Third Party owned Captive RE Plants (26% Equity by the SSP and rest by the third-party)

    Advantage: Lesser capital requirement, i.e., only 7.8% (70:30 Debt: Equity) or 5.2% (80:20 Debt: Equity) of the total project cost investment required

    iii. Third Party owned Group Captive RE Plants (26% Equity by a group of SSPs and rest by the third-party)

    Advantage: The 7.8% or 5.2% of the entire project cost (mentioned above) is contributed by the group the consumers entering into the captive mode, which further reduces the capital requirement of individual consumers

2. **Third Party Open Access Mode:** Procurement of RE via third party open access, i.e., from RE developers wherever regulatory regime is favourable, i.e., cross subsidy charges and additional surcharge are lower. The advantages of procuring via this mode are lower cost of electricity as compared to procuring via grid (Green Tariff) and no requirement of Capital unlike in captive mode.

3. **Power Market:** The C&I consumers can also procure RE via GDAM/GTAM. Procuring RE via the power market has the advantages that no capital cost is required, and consumers can benefit whenever the market-determined RE cost is relatively lowest.

6.12.1. Recommendations for Integrated Steel Plants (ISPs) and Small Steel Industries (SSIs)

1. **Development of RE cell to prepare an action plan to achieve 45% RE penetration in the steel sector by FY 2030-31**: Use of renewable energy in the steel processes is one of the low-hanging fruits to reduce the emissions from the steel sector, which does not require any process modifications. The Ministry of Power (MoP) has notified a target of 43.33% of RPO by 2030. With 43% RE penetration in the steel sector by 2030-31 will lead to an emission reduction of 8% from 2.5 to 2.31 tCO_2/tcs. MoS shall form a RE cell (with the experts in the RE sector) to prepare a detailed action plan to achieve 43% of RE penetration in the steel sector by 2030-31. As suggested in the governance framework, this cell shall become a part of National Green Steel Research and Technology Centre (NGSRTC).
2. **Single Window Support System for SSIs:** It is apparent from Table 6.15 that the cost of procurement RE power from (i) Intra-State Captive/Group Captive plants is much lower than the grid tariffs, followed by (ii) Inter State Captive/Group Captive RE projects and then (iii) third party open access projects. The discussions with the stakeholders, showed that the steel units other than large ISPs lack awareness, access to information and knowledge about various possible options/policies to procure RE power. Therefore, Ministry of Steel (MoS) shall undertake Information and Education activities through workshops and Conferences to create awareness and build their capacity to facilitate RE integration, Further, a Facilitation cell shall be set up by the MoS or any other associated organisation to provide handholding and support needed by small industries for RE integration by creating a web portal or mobile app *(similar to ASH by Ministry of Power (MoP))* to provide data of potential and willing consumers to help potential RE power suppliers/developers to connect with the consumers.

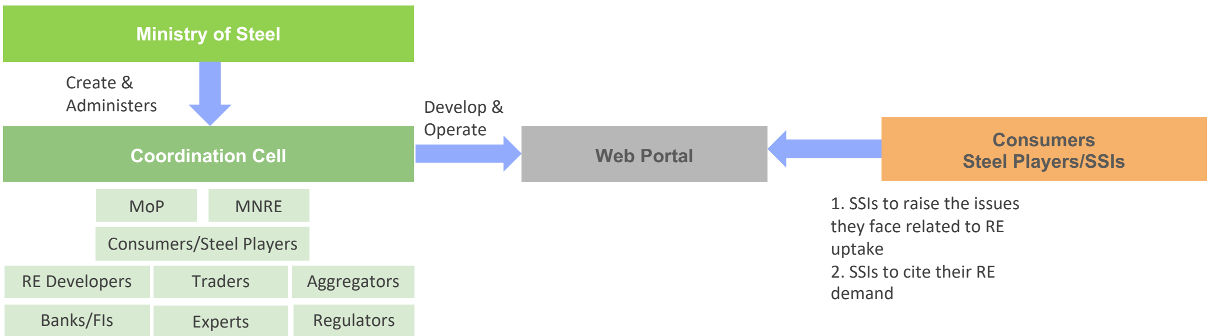


Figure 6.7: *Institutional Arrangement of the Single Window Support System for SSIs*

Functions of the Coordination Cell

a. Help SSIs coordinate with PTC, EESL, SECI to procure RE Power

b. Help SSIs access funding from Multilateral Development Banks (MDBs) and Government-owned NBFCs like PFC, REC, IREDA and other banks/FIs for RE projects

c. Help in drafting the model power purchase agreements for SSIs

d. Hold workshops, conferences, webinars, etc., to train the consumers/SSIs related to technical, regulatory and administrative know-how for RE procurement via various modes

e. Provide knowledge and advisory support to SSIs to help them understand recent developments in the RE space and avail the benefits (Green markets, ToD tariff, Carbon credits, ESG) of the same

f. Aggregation of RE demand for smaller units and providing an interface between the consumers and prospective suppliers of RE power, e.g., MNRE designated procurement agencies, Power Trading Corporation and third party Captive Developers/Open Access developers

g. Follow up with States for expeditious approval for open access

h. Take up with States/SERCs for removal of anomaly/inconsistency, if any, in Open Access Rules with reference to the *Green Energy Open Access Rules, 2022*

3. **Align State Regulations with Green Energy Open Access Rules, 2022:** All the steel-rich states shall be encouraged to align their respective state regulations on open access with the Green Energy Open Access Rules, 2022. MoS and MoP shall nudge SERCs to follow the GEOA Rules 2022.

   a. **Removing the Cross Subsidy Charges for Onsite Captive Projects:** Efforts shall be directed to remove any levy of Cross Subsidy Surcharge on the behind-the-meter projects as it does not follow the regulations.

   b. **Banking Policy:** Efforts shall be made to ensure that banking policies in all the states are in line with the banking charges and settlement duration as specified in the *Green Energy Open Access Rules, 2022.*

   c. **Reduce open access charges as per the rules:** Efforts shall be directed towards aligning the open access charges like cross subsidy surcharge, additional surcharge, etc., with the GEOA rules, 2022.

   d. **Clarification note from MoP on Rule (5) provision 2 of GEOA rules, 2022:** In coordination with MoP, reforms shall be made regarding Rule 5 (2), which states that the upper ceiling limit is 12 time blocks and the SERCs are free to provide lesser duration for which constant load is required to be maintained by the steel units.

4. **Specific modification in Rule 5 of GEOA rules, 2022 for SSIs:** Efforts shall be made to amend Rule No. 5 specifying the constant load requirement for 12 time blocks so that it is not applicable to small steel industries with load less than 25 MW located in steel-rich states. SERCs of steel-rich States may be requested to do away with this rule for small steel industries considering the peculiar nature of load while using IFs and EAFs. MoS shall take this up with MoP.
5. **Long-Term Stability of Policy Framework:** States/MoP shall coordinate to maintain continuity in the relevant policies for at least 10 years. This will give confidence to the consumers/RE developers/ Banks to take informed decisions and facilitate the RE integration in the steel industry.
6. **Financial Support:** As discussed in the section 6.5(5)(b), the investment requirement to set up RE plants is substantial and the smaller units and third-party captive/open access developers, who wish to set up RE plants for smaller steel units, often find it difficult to raise the finance from Banks. To address this issue, following steps shall be taken:

   a. **Risk Coverage for Loan Repayment:** For the smaller steel units that want to set up their own Captive RE Plants (Rooftop Solar/Behind-the-Meter Solar/Open access Captive plant), the government shall consider implementing a scheme similar to a *Partial Risk Sharing Facility* to guarantee the repayment of loans taken by smaller steel units for setting up their own captive RE plants. The detailed mechanism and the amount of corpus required can be worked out after consultation with all the stakeholders.

   b. **Aggregation of demand by SECI:** SECI or an equivalent entity backed by GoI could aggregate the demand of RE power from smaller steel units/SSIs and float tenders for the procurement of power from RE developers. The strong counterparty in the form of SECI would enable procurement of RE power at competitive rates. SECI, in turn, would enter into Power Sale Agreements (PSAs) with SSI units with a mark-up over its procurement price to have a margin. MoS may need to create a ***'Payment Security Reserve Fund'*** which shall be made available to SECI to take care of the potential defaults by smaller steel producers who would purchase power under this arrangement. MoS shall coordinate with SECI to create a framework for its execution.

c. **Payment Security Reserve Fund:** For Third-party Captive or Group captive plants as discussed above, a small *Payment Security Surcharge* of INR 0.05/unit shall be collected from captive consumers which would be parked in an escrow account. This escrow account shall be tapped to make payment to the developer in case of default by a consumer. MoS shall provide an initial corpus of INR 5 lakhs/MW to set up such a *'Payment Security Reserve Fund'*. The support INR 5 lakhs/MW shall be sufficient to guarantee six months of payables assuming a default rate of 10%. Subsequently, this fund shall grow once the Payment Security Surcharge starts flowing into it. Annual accumulation into the Payment Security Reserve fund would be around INR 1 lakh/MW/Year. In case of default by a consumer for more than six months, their equity capital can be forfeited and a new consumer would be inducted. The total financial requirement for the same has been discussed in section 6.13.

   The Payment Security Mechanism discussed above would improve the bankability of RE projects for supplying power to smaller steel units. They would be able to access the loans from Banks/FIs at easier terms and conditions. It would also obviate the requirement that consumers provide a Bank Guarantee/BG or Letter of Credit/LC to group captive/third-party RE developers, thus reducing their financial burden.

d. **Finance:** For the contribution of funds by smaller steel units in Captive/Group Captive Projects following options shall be explored:

   i. **Exploring the Line of Credit & Concessional loans from MDBs:** The financial support (concessional loans) from the multilateral development banks (MDBs) like ADB, KfW, World Bank, etc., should be explored. MDBs can fund the RE integration in the industries in the sector, especially the smaller steel units. Coordination Cell *(as discussed in section 6.12.1(1))* shall take up this task.

   ii. **GST Reimbursement for Captive RE Projects:** State governments may reimburse the GST on expenses related to RE equipment during the installation of captive RE plants to promote RE uptake in the State. This is a common practice to attract industries and promote sustainable industrial development. MoS shall take this up with the Ministry of Finance.

   iii. **Credit from Coal Cess which is collected by Govt. @ INR 400/ton**: The total collection from Coal Cess is INR 32,000 crores approximately. This fund was set up for the development of RE projects. However, subsequently, it was subsumed in the GST equalisation fund for a period of five years. Now that the five-year period is over, an appeal shall be made by MoS to the Ministry of Finance to allow this fund to be used for the development of RE Power, thus, helping in achieving the Net Zero target by 2070.

   iv. **Restructuring CPP Financing Model:** Instead of the current 70:30 Debt to Equity financing model for captive projects that is followed by most of the banks, a financing model of 80:20

Debt to Equity shall be explored. This would reduce the requirement of the capital by the steel players aiming to put up their captive RE plants by almost 2.6% of the project cost (i.e. from 26% of 30% equity = 7.8% and 26% of 20% equity = 5.2%). This would be highly beneficial for the small steel players who are willing to install captive RE plants but are unable to do so owing to their financial constraints. During the discussion with PFC and REC, it was informed that they are already extending loans to RE Power Projects with a Debt:Equity ratio of 80:20. Other financing agencies can also be encouraged to take this up.

7. **Support Land Acquisition for RE Projects:** In coordination with the MoS, state governments shall help the steel industries/RE developers in land identification and acquisition at concessional rates to install captive RE plants. For example, Uttar Pradesh provides land at a concessional rate to private players and free of cost for central government projects[55,56]. Some states like Rajasthan, Madhya Pradesh, Maharashtra, and Gujarat have formulated suitable policies for government land allocation iregarding renewable projects[57]. Other states shall come up with similar policies.
8. **Reduce STU drawal charges for RE-deficient states:** RE-poor states should be nudged to reduce their STU drawal charges for interstate open access to enhance the RE penetration. Chhattisgarh has a provision of 100% waiver on STU drawal charges (transmission charges) for green open access. Uttar Pradesh also provides 100% waiver for solar open access. Such reduction in STU drawal charges by RE-deficient states would make interstate green open access viable for steel industries. MoS shall coordinate with MoP and SERCs for the same.
9. **Promote Green Power Market:** Following steps can aid in increasing the depth of the Green Power market in India:
   a. **Floor Price Introduction**: Introducing a floor price of INR 2.5/kWh in GDAM/GTAM would be helpful as it would instill confidence in the financial institutions to lend to the merchant RE projects, which would help increase the merchant RE capacity. The Ministry of Steel shall coordinate with related ministries on this aspect.

   b. **Introduction of Regulatory Framework for Virtual Power Purchase Agreement (VPPA):** VPPA is the bilateral agreement between the RE power producer and the C&I consumer where no direct physical delivery of power is involved between the producer and consumer. The producer sells the power in the exchanges at prevailing prices and the consumer gets the RECs as per the contract price/strike price[58]. Bringing a comprehensive regulatory framework for VPPA would help increase the volume of RE traded on GDAM/GTAM.

   The Supreme Court Order dated 7th October, 2021 clarified that CERC will regulate all the physical delivery based forward contracts whereas the financial derivatives will be regulated by SEBI, seeking better regulatory and administrative clarity would increase the uptake of RE power in the VPPA model. For example, the procedure and nodal agency for issuance of derivatives, working of contract of differences (CFD), interaction of RE developers with power market, issuance of RECs, etc. The Ministry of Steel may coordinate with respective ministries to introduce this framework.

6.12.2. Recommendations for Integrated Steel Plants (ISPs)

As Table 6.3 shows, the penetration of RE power from ISPs is only 0.39% as against the current RPO of 22.6% and 43.33% in 2030. Therefore, it is imperative to facilitate ISPs to set up Captive RE capacities to meet their RPO obligation. In this regard, following steps shall be taken.

1. **Fresh Grey Captive Installation to be avoided:** Industries shall be informed on challenges regarding addition of coal-based captive capacities for captive requirements. Not adding captive thermal power will result in savings to ISPs once the State Regulations are aligned with GEOA. At present, the approximate cost of power from fresh coal plants is INR 6/unit (including transmission charges/ losses, etc.) while, at present, the landed cost of captive RE Power in steel-rich States is less than INR 6/unit except for Odisha and West Bengal. Therefore, there is no economic rationale for ISPs to set up new coal-based captive plants. But the addition of fresh RE captive capacity would require huge Capex. The Coordination Cell of MoS *(as discussed in section 6.12.1(1))* can extend its scope to facilitate arrangement of funds from bilateral and multilateral organisations like World Bank, IFC, ADB, JICA & KfW even for the large steel players.
2. **Retirement of old and inefficient coal-based plants:** Some ISPs have coal-based captive plants as old as 45-50 years. Such plants emit more carbon and other pollutant gases such as SOx, NOx and fly ash. . Besides pollution, they consume more coal and water. The heat rate of new ultra supercritical plants is 2100 kCal/kWh while that of some of the old captive plants could be as high as 2800 to 3000 kCal/kWh. Therefore, the ISPs operating old and inefficient captive thermal power plants with heat rates greater than 2600 Kcal/kWh shall be encouraged to scrap these plants and be incentivised to substitute them with RE plants. But phasing out of operational thermal captive plants will have huge cost implications on the per ton cost of steel. In some states like Odisha, the cost implication is as high as 4.05% for ISPs and 2.98% for SSIs *(refer Section 6.11.2.2 - Table 6.19/6.20)*. Therefore, some steps can be taken to support industries in terms of investment for retiring old and inefficient plants are mentioned below.

   Investment Requirement

   Such phasing out of inefficient and polluting captive thermal plants will need substantial investment. Assuming 20% of electricity generated from old coal-based captive capacity is retired and substituted by RE capacity, an investment of INR 12,419 crores will be required (Refer Table 6.21) which is substantial.

   To incur such a huge investment, some incentives shall be provided to offset the Capex. Some of them are listed below:

   a. 1000 MW of old coal-based thermal plants requires 5 million tonnes of coal per year. The *Coal Cess* collected by the government for 5 million tonnes of coal works out to INR 200 crores/year, i.e., INR 20 lakhs/MW/Year. This amount can be reimbursed to ISPs retiring their old coal based captive plants for a period of 12 years (as per CERC norms, the debt servicing period of a thermal power plant is 12 years) from the date of commissioning.

   b. Based on MoS certification, Accelerated Depreciation @ 80% for fresh RE capacities installed to substitute old coal-based plants can be proposed.

   c. Interest subvention shall be provided to the steel industries opting to phase out old captive coal power plants.

   d. We shall explore facilitating investments through Green Bonds, ESG compliance, and monetisation of Carbon Credits, among other things..

The following Table 6.21 shows the capital cost required for installing new RE plants if 20% of the current captive plants operated by ISPs are scrapped.

***Table 6.21:** Capital Cost required to install RE captive capacity by scrapping inefficient thermal captive for ISPs*

Sr. No.	Description	Value	Assumption/Reference
1	Electricity produced by captive plants of ISPs in 2021-2022	33,259 MU	Refer Table 6.10
2	Units of Electricity to be replaced by captive RE plants	6652 MU	Assuming 20% units need to be scrapped
3	RE Captive Capacity replaced by scrapping thermal captive plants for ISPs	2449 MW	Average of solar and wind power CUF and Capex requirement considered Average CUF = 31%
4	Fund required to replace the inefficient thermal plants with RE plant	INR 12,419 crores	Average capex requirement = INR 5.07 crore/MW

3. **Waste Heat Recovery (WHR) power to be excluded for RPO Compliance:** As per the current policy provisions, steel manufacturing plants cannot claim the WHR energy to offset their renewable purchase obligations. WHR Power (Waste Heat/Flue Gases) produced by a steel player during its production shall be excluded while calculating the RPO obligation for the concerned steel player and only net power consumption (after WHR power consumption) be considered for estimating the RPO compliance requirement. For example, if a steel player's annual electricity requirement (from captive power) is 100,000 kWh and 20% of the electricity is generated by WHR, then RPO would be applicable on 80,000 units instead of 100,000 units.

CHAPTER 7

MATERIAL EFFICIENCY

7.1. Introduction

Efficient utilisation of materials is a key strategy towards achieving a circular economy. It refers to the practice of optimising the use of materials, energy, and resources throughout their life cycle to achieve maximum value while minimising waste and environmental impacts. This approach encompasses the principles of the 3Rs – Reduce, Reuse, and Recycle. It involves reducing material consumption, promoting the reuse of materials or products, recycling materials at the end of their life, and designing products for durability and resource efficiency.

In the steel industry, the production process demands significant quantities of raw materials (iron, coke, limestone alloying elements, etc.), energy and water, resulting in resource-intensive operations. Additionally, various forms of waste, such as slag, dust, and emissions, are generated throughout different stages of the supply chain. Therefore, integrating material efficiency into the sector addresses the imperative to optimise resource use, minimise waste, and reduce environmental impacts. This aligns with sustainable industrial practices and responsible resource management, contributing to broader sustainable development goals. According to the International Energy Agency (IEA), about 40% of cumulative emissions can be reduced by adopting material efficiency strategies[1]. In the context of India's rapidly growing steel industry, which is poised to play an increasingly prominent role on the global stage, enhancing material efficiency is not merely an operational requirement but a strategic need that aligns with both economic and environmental objectives.

Material efficiency in the Indian iron and steel sector has been identified across various stages with a focus on three key areas as strategic pathways:

a. **Beneficiation:** Beneficiation is the process of improving the quality of raw iron ore through mechanical and chemical processes to remove impurities and increase its iron (Fe) content. By removing impurities such as silica, alumina, and phosphorus, beneficiation enhances the efficiency of subsequent processing steps, reducing energy consumption, lowering emissions, and decreasing the volume of waste generation.

b. **Pelletisation:** Pelletisation is a process that converts fine-grained iron ore concentrates into small, spherical pellets that are suitable for use in blast furnaces or direct reduction processes. Pelletisation improves the handling and transportation efficiency of the iron ore concentrates, reduces dust emissions, and enhances the efficiency of iron-making processes by providing a uniform feedstock with controlled porosity and reactivity.

c. **Scrap utilisation:** Scrap utilisation involves recycling steel scrap from various sources back into the steel-making process, reducing reliance on primary raw materials, conserving energy, and lowering emissions. This practice mitigates environmental impact by diverting waste from landfills and reducing the need for virgin resource extraction.

7.2. Beneficiation

The process of beneficiation involves the transformation of raw materials to enhance their quality and value, making them suitable for specific applications. In the iron and steel sector context, beneficiation primarily focuses on improving the quality of iron ore through various techniques such as crushing, screening, washing, magnetic separation, and floatation. These processes aim to increase the iron content and reduce impurities, thereby optimising the efficiency of steel production.

In a conventional steel-making process, the presence of impurities reduces the efficiency of conversion, leading to higher energy consumption and emissions. For example, every 1% increase in alumina in the blast furnace (BF) feed leads to a 2.25% increase in coke rate and a 3% drop in BF productivity.[2] The presence of gangue minerals such as alumina and silica adversely impacts iron and steel making as they deteriorate the product quality, leading to increased slag generation, increased production costs and elevated energy consumption. With a 1% increase in Fe content, the BF productivity improves by 2%, and the consumption of coke is reduced by 1%[3]. Beneficiation addresses these challenges by increasing the ore's metal content and reducing gangue content, thereby enhancing resource utilisation and minimising emissions.

7.2.1 Beneficiation: Global Scenario

Beneficiation plays a critical role in increasing material efficiency in the iron and steel industry, which is present in around 50 nations worldwide. The largest iron ore producers are Brazil, Australia, China, India, the United States of America, and Russia, with Australia and Brazil leading global iron ore exports, each accounting for approximately one-third of the total. Globally, the estimated iron ore reserves exceed 800 billion tonnes of raw ore, containing over 230 billion tonnes of metallic iron[4,5].

However, it is important to note that the average quality of iron ore has been on the decline for years. This decline is attributed to the selective depletion of higher-grade reserves, specifically the grade with 67% or higher Fe content, coupled with the expansion of supply to meet the rapidly growing demand, particularly from developing countries. Historically, the average iron content in the ore was above 62%, with impurities around 5%. However, by 2016, this average iron content had decreased to 61%, accompanied by an increase in impurities to 6.5%[6], highlighting the challenges and opportunities in the evolving landscape of global iron ore quality. In response to this challenge, the beneficiation of fines and process tailings presents a promising avenue for optimising resource utilisation and overcoming the limitations posed by dwindling high-grade lump reserves.

Iron ore beneficiation technologies vary globally, with different regions adopting specific methods based on factors such as ore characteristics, environmental regulations, energy availability, and economic considerations. Several countries are recognised for expertise in iron ore beneficiation, driven by technological advancements, infrastructure development, and the availability of high-quality ore deposits. Amongst these countries are Australia, Brazil, China and South Africa. The Chinese beneficiation plants employ a variety of techniques, including wet processing, dry processing, and magnetic separation, to upgrade low-grade ores. Brazil leverages advanced processing techniques, including floatation, magnetic separation, and gravity concentration, to produce high-quality iron ore concentrates. In South Africa, beneficiation plants use methods such as dense media separation, jigging, and spirals to produce high-grade iron-ore concentrates.

7.2.2 Beneficiation: Indian Scenario

Hematite is the most important iron ore mined because of its high-grade quality and lumpy nature for steel production. The total resources of iron ore (hematite) in the country as of 2020 are estimated at 24,058 MT[7]. Almost the entire present-day production of iron and its products comes from hematite reserves. Ministry of Steel mainly classifies iron ore below 58% content as low-grade.[8]

However, based on IBMs National Mineral Book Grade, the grade classification adopted in the inventory as of 01.04.2020 is based mainly on four chemical constituents namely Fe, SiO2, Al2O3, and phosphorous. Accordingly, the classification is as follows –

a. High Grade Fe : >65% (lump & fines) SiO2 : 2% (max) Al2O3 : 2% (max) P : 0.1% (max)

b. Medium Grade Fe : 62 to 65% (lump & fines) SiO2 : 3% (max) Al2O3 : 3% (max.) P : 0.1% (max)

c. Low Grade Fe : < 62% SiO2 : 4.5 (max) Al2O3 : 4% (max) P : 0.1% (max)

Figure 7.2 highlights the significant role of medium-grade ore, showing its dominance in sheer quantity compared to the rest. This distribution emphasizes the centrality of medium-grade ore in the steel-making landscape in India and underscores the imperative for beneficiation to meet the stringent requirements of modern steel production.

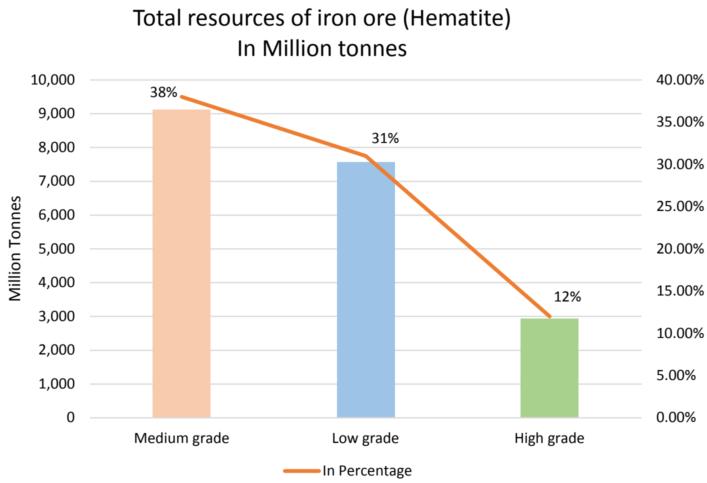


Figure 7.1: *Total resource of Iron ore (Hematite)*[9]

** Only the high, low, and medium grade lumps and fines of iron ore have been considered, excluding the beneficiable, unclassified not-known fines, blue dust unclassified grade categories of Iron ore, thus resulting in less than 100% total.*

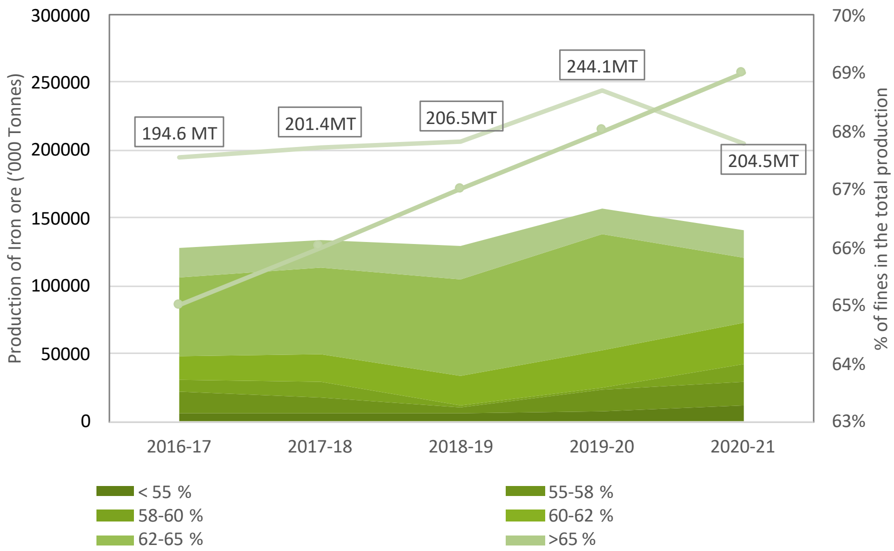


Figure 7.2: *Grade-wise inventory of Iron ore, with percent of fines in total production*[10]

The Fe (t) cut-offs for hematite and siliceous-hematite ores are 45% and 35%, respectively. Ores with Fe content exceeding these thresholds, such as siliceous ore with over 35% Fe and other hematite ore with more than 45% Fe, require beneficiation for utilisation in steel production. Domestic iron ore production is mainly in the form of lumps and fines, with a ratio of 3:7. Indian iron ores are generally quite soft and friable in nature and generate substantial fines while mining, physical processing and handling. Studies have revealed that mining and physical processing of iron ore produces large amounts of slimes and fines, typically 35% and 25-10% of run of mines[11], which, if not beneficiated, leads to potential resource loss and environmental damage.[12] Between 2016 and 2021 there has been an increase in the quantity of fines generated by 9%.

For the year 2022-23, total iron ore exports accounted for 21.17 MT [13]. Fines accounted for a large portion of these exports. The fines are exported due to the economic and energy-intensive agglomeration process required for steel production, as well as the lack of access to a strong export market. Underutilisation in domestic consumption is a key factor driving the substantial export of iron ore fines.

Although India is blessed with large reserves of Iron ore containing an average grade of around 58% Fe, however, exponential growth in their utilisation for meeting steel-making demand is putting pressure on their future availability. This poses operational efficiency challenges to traditional steel manufacturing mainly due to the presence of high levels of impurities like silica and alumina. The necessity for beneficiation stems from the limitation that simple size-based separation processes alone cannot yield products with high iron (Fe) content. Impurities like silica and alumina get liberated with finer fractions.

The practice adopted majorly in steel making is the utilisation of medium to high-grade ores (+62% Fe). It is achieved by resorting to selective mining keeping the cut-off up to as high as 58-60% Fe. To maintain high-grade ore, often low-grade lumps and lateritic material are rejected. Generally, classifier fines (-10+0.15 mm) are not processed any further and are used for sinter-making. Further, the present industrial practice causes a considerable loss of iron values in process/mine rejects, and their stacking has adverse effects on the environment and causes ecological imbalance.

India has a capacity of 136.23 MTPA[14] for beneficiation (including washing). However, the beneficiation facilities in the country are inadequately utilised due to techno-economic constraints. The state-wise iron ore fines beneficiation, including washing capacities, are presented in figure 7.3 below.

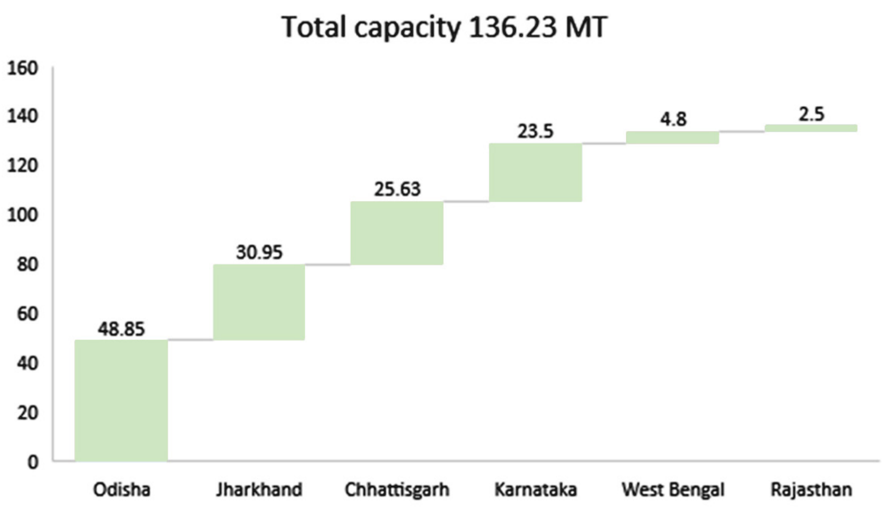


Figure 7.3: Iron ore fines beneficiation state-wise plant capacity in India [15]

India's iron ore fines beneficiation (including washing) capacity is likely to increase to 143 MT by 2025 and then further to 170 MT by 2030 from the current installed capacity of around 136.23 MT, according to data published by SteelMint. However, major players have committed to increase capacity to 192 Mt by 2030. The capacity may take longer than 2030 to materialise and will depend on the quantity of iron requirement, ore produced and its quality. Among the states, Odisha, with the largest iron ore beneficiation capacity, accounts for nearly 35% of the country's total capacity, followed by Jharkhand at 23% and Chhattisgarh at 19%.[16]

To achieve the National Steel Policy (NSP) target of 300MT crude steel capacity by 2030, there is a need to enhance existing resources through beneficiation and agglomeration. This strategy is crucial for optimising resources and meeting the ambitious steel capacity goals outlined in the NSP, 2017.

7.2.3 Beneficiation: Challenges

The importance of utilising low and lean-grade iron ore resources has grown significantly, but there are certain difficulties in processing and utilisation of low and lean-grade iron ore as listed below:

1. Beneficiation of low-grade ores is a capital-intensive process compared to simple crushing and screening operations as performed on high and medium-grade ores.
2. The Indian beneficiation industry is dependent on wet beneficiation technologies for iron ore. Water is a critical resource for the beneficiation process, but some of the iron ore-rich regions in India face water scarcity. This water scarcity can limit the amount of ore that can be beneficiated, and the quality of the pellets produced from concentrate generated by dry beneficiation technology is still at a nascent stage in India.
3. Often, the beneficiation plants are not within the mining lease area. Having them in mining locations is advantageous because of the minimum transportation cost. Further transportation of beneficiated iron ore of very fine size is difficult due to its moisture content and environmental issues (causing air pollution during storage/transportation). This calls for placing a beneficiation plant near the agglomeration facility to avoid logistical and environmental issues.
4. The beneficiation process requires substantial energy, and power shortages in remote mining locations can hinder the production of beneficiated iron ore pellets. This adds to the higher beneficiation cost.
5. Disposal of tailings is a major obstacle. The Indian Beneficiation industry does not have space for disposing of the tailing generated during the beneficiation process. Wet tailing storage in the tailing dam has a risk of dam failure. The dry tailing disposal method, through a pressure filter, requires substantial capital and operating expenditure. Risks associated with tailing dams are- land allotment of tailings dams and environmental clearance. The capital cost at 2021 prices is in the range of INR 185 to INR 200 per tonne, while the operational cost is estimated between INR 750 to INR 850 per tonne per annum with regard to beneficiated fines.

7.2.4 Beneficiation: Action Plan

Efforts to promote and enhance beneficiation in the iron and steel sector necessitate a strategic approach. The recommendations are as follows:

1. **Resource assessment:** It is important that the resources within a deposit are properly assessed grade-wise. Resources may be assessed preferably as above 62% Fe, 62 to 55% Fe, and below 55% up to 45% Fe. If required, resources below 45% may also be assessed for silicious and magnetite ores. Such resource assessments will help arrive at potential capacity additions in selected locations, including possible incentives that can be offered, if any, as per the point identified below. This will help target resources that can be beneficiated and decide upon locations where beneficiation plants can be set up.
2. **Optimised Beneficiation circuits**: MoS may facilitate the development of optimised beneficiation circuits to treat different Fe bands and mineralogical composition of iron ores (i.e., 45-50 % Fe, 50-55

% Fe, >55% Fe, and ore above 60% Fe for DRI/EAF route) and lean grade resources [(Banded Hematite Quartzite (BHQ) /Banded Hematite Jasper (BHJ) / Banded Hematite-Gossan Quartzite (BGQ)] using conventional or reduction roasting processes.

3. **Facilitation for setting up beneficiation projects**: MoS may coordinate with various Ministries and State governments to facilitate land allotment to establish beneficiation plants and tailing disposal. Further, the Ministry of Steel can work with Ministry of Environment, Forest and Climate Change (MoEFCC) to facilitate the issuance of environmental clearances for setting up beneficiation plants.
4. **Waiving off Royalty**: MoS may take up the matter of waiving off or imposing a nominal royalty on low-grade iron ore to incentivize their utilisation. There is also a need to charge the royalty, statutory levies bid and premium on the grade and quantity of input of fines for beneficiation instead of beneficiated product. This warrants proper consultation with the State Governments of ore mining states and other stakeholders to achieve the desired policy change. This is important because there is already a significant material loss happening due to conversion to the final output which warrants fiscal incentives for beneficiation over and above revisions of royalty since it involves an additional capital investment than usual mining and mineral processing.
5. **Tax Exemptions**: The government may encourage beneficiation through tax exemptions on capital invested in the creation of a beneficiation facility.
6. **Effective tailings management:** Efforts to be taken up to maximise metal recovery from mining tailings through strategic planning, advanced technology utilisation, and implementation of innovative extraction processes like bioleaching and hydrometallurgy.
7. **Rationalize base price of iron ore fines:** To enhance the economic viability of beneficiation, there is a need to periodically review and rationalize the base prices of iron ore fines, ensuring adaptability to changing economic conditions.
8. **Research &Development:** The beneficiation technology is based on the mineralogical characterisation of iron ore. There is a need to establish the beneficiated process for different mineralogical compositions of ores through either conventional/reduction roasting/dry or a combination in lab and pilot scale through R&D study. R&D grants from the government for developing improved or new technology for efficient beneficiation of low and lean grades of iron ore, dry beneficiation of iron ore, and utilisation of tailings through value addition should be encouraged. There is a need for public-funded research institutions like CSIR labs, National Institutes of Technology (NITs), and Indian Institute of Technology (IITs) to take up more scientific studies in collaboration with industries that can provide meaningful solutions for commercialisation.

7.3. Pelletisation

Pellets[17], an agglomerated form of iron ore fines, are a crucial raw material while serving as an alternative to sinter and lump ore across various iron-making units. Being rich in iron content and distinct from sinter, pellets offer numerous advantages. They facilitate the efficient utilisation of beneficiated low-grade iron ore fines. Their increased iron-making usage leads to decreased carbon emissions, higher blast furnace productivity, and reduced energy consumption. Moreover, pellets enhance furnace permeability, ensuring smooth gas flow and ferrous burden descent, thereby optimising energy efficiency and coke consumption. Environmental advantages also include reduced dust generation compared to other agglomeration methods like sintering. Their high and consistent mechanical strength, along with increased abrasive resistance, elevates sponge iron production by 20-25% with the same fuel input.[18]

7.3.1 Pelletisation: Global Scenario

Globally, the total installed production capacity of pellets is estimated at 830 MT[19]. Demand for iron ore pellets is expected to grow significantly owing to the rising adoption in steel manufacturing plants. Sales are projected to increase at a CAGR of 4.3% between 2021 and 2031. The global pellet production capacities and pellet utilisation pattern are given in figures 7.4 and 7.5 below.

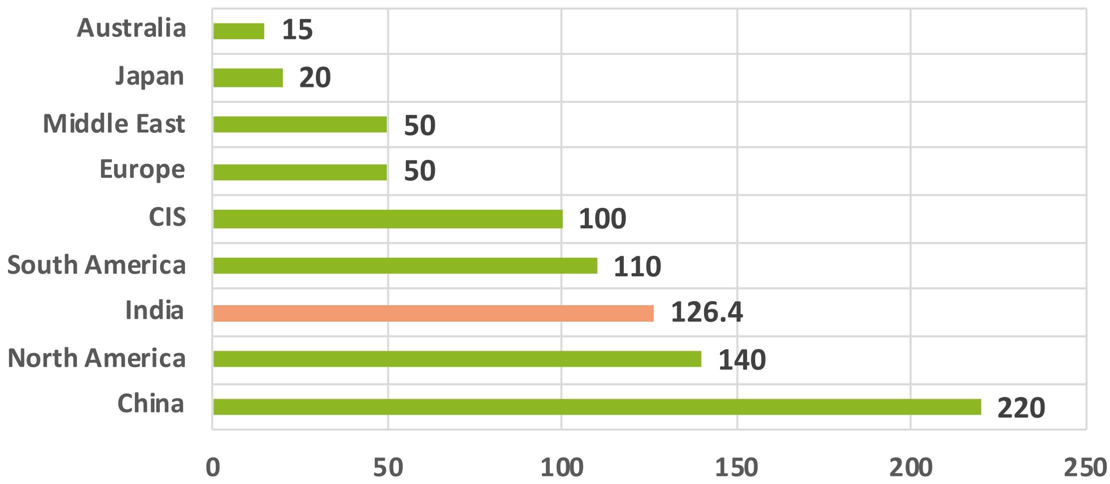


Figure 7.4: Global pelletisation capacity in 2021 (in MTPA)[20]

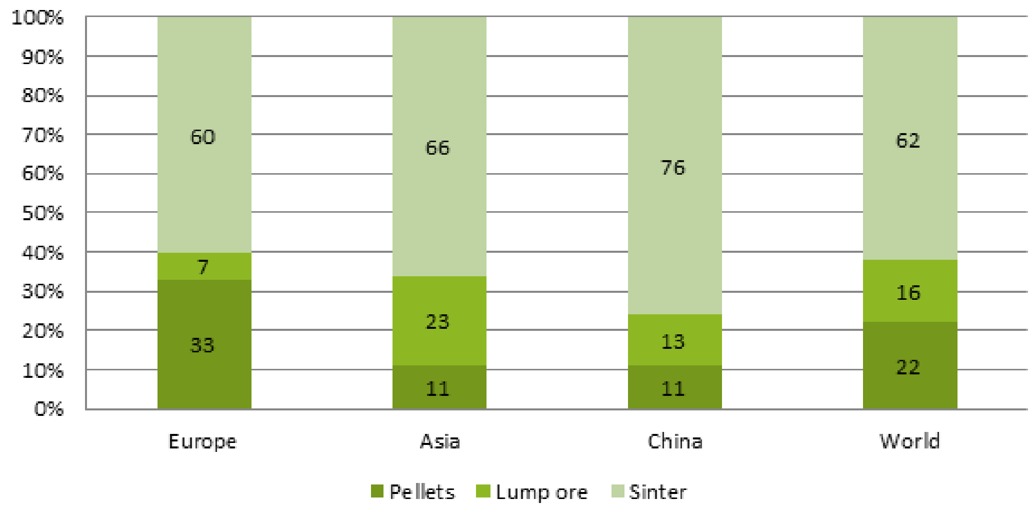


Figure 7.5: Pellets Utilisation Pattern-Global[21]

Since pelletising is more energy efficient than any other form of agglomeration, a recent European Commission report recommends increasing the ratio of pellets in the ferrous burden to at least 50% on average in blast furnaces.[22]

7.3.2 Pelletisation: Indian Scenario

Given the tremendous advantages of pellet usage, the Indian pellet industry has emerged as an independent economic activity. All India status (2020-21) of pellet plant capacity in MT, production, capacity utilisation and export are provided in figure 7.8 below.

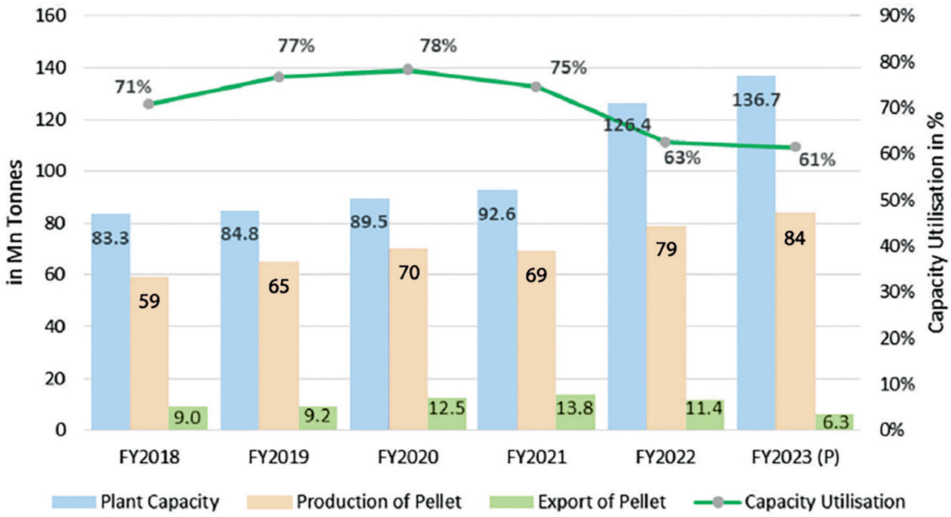


***Figure 7.6:** Status of Indian pellet industry*[23]

Out of the total production capacity of 136.7 MTPA, India's pellet production stood at 84 MT, i.e., 61% of the total capacity. India exported 6.32 MT of pellets, and the balance of 77.68 MT was used domestically in DRI making, blast furnaces and COREX process.

7.3.3 Pelletisation: Challenges

Despite unprecedented benefits linked to the use of pellets in the country, there exist certain gaps and constraints associated with increasing the usage of pellets produced from iron ore fines and beneficiated concentrate, as listed below:

1. **Presence of high impurities in iron ore:** Indian iron ore reserves often have high impurity levels like alumina and silica, necessitating beneficiation processes for their removal. The pellets can still be produced but with compromised quality in terms of physical, chemical and metallurgical characteristics, which means higher conversion costs. Unless India has substantial capacity utilisation in beneficiation, pellet manufacturing cannot be scaled up.

2. **Infrastructure constraints:** The transportation and storage of iron ore concentrate and pellets can be challenging, especially in regions with limited infrastructure. This increases logistics costs and impacts the competitiveness of iron ore-based beneficiation and pellet production in India

3. **Volatility of Pellet Market:** Pellet manufacturers that do not have their mines (owned/linked) buy iron ore from the open market. Large variations in the iron ore prices affect pellet prices. Also, the plants are located away from mines, and the transportation cost is very high, leading to the higher prices of the pellet, which results in lower uptake of pellets in steel-making

7.3.4 Pelletisation: Action Plan

Efforts to promote and enhance pelletisation in the iron ore and steel sector necessitate a strategic approach. The recommendations are as follows:

1. **Maximising Pellet Utilisation:** MoS may encourage industries to maximise pellet utilisation in both DRI units as well as in Blast Furnaces, through incentive mechanisms. MoS may design a policy framework and develop an action plan that supports beneficiation and pelletisation. This may focus

on utilising beneficiated concentrate from lean-grade ore, investing in beneficiation plants, forming alliances with mining firms to guarantee a consistent supply of lean-grade ore, putting cutting-edge technologies into place for effective beneficiation procedures, setting mandatory limits on the use of pellets for the plants.

2. **Logistics and Infrastructure:** To streamline pellet delivery and minimise logistics expenses, new pellet plants should be planned to be strategically placed near steel mills or ports. Conducting feasibility studies to pinpoint ideal locations, infrastructure development around chosen sites to ensure smooth operations, and collaboration with local governments to secure approvals and support may be undertaken.
3. **Slurry Pipeline:** MoS may facilitate the installation of slurry pipelines for cost-effective, more reliable, energy-efficient, environment friendly and less carbon-intensive transportation of iron ore concentrate from the mines to the pelletisation plants. This will also reduce the problem of congested transportation networks in mining areas.
4. **Research and Development (R&D):** MoS may foster innovation by developing economically viable briquettes from iron ore fines and steel plant wastes while evaluating their usage against those pellets. Efforts to encourage R&D in this area should include allocating funding for R&D projects focused on pelletisation and briquette making, partnering with academic and research institutions to explore new technologies, collaborating with countries using more advanced technologies, etc.

7.4. Scrap utilisation

Scrap, or recycled steel, is increasingly vital in steel production. In plants that use electric arc furnaces, up to 100% of the raw materials can be from recycled sources, while blast furnaces typically use up to 30%.[24] Compared to producing steel from iron ore, producing it from recycled steel saves significant amounts of energy because all the steps to convert ore to iron, such as the BF process, are bypassed. As a result, producing steel from recycled material generates significantly less CO_2 emissions than producing it from iron ore.

Steel scrap offers numerous benefits in the steel-making process, including reduced carbon emissions, resource consumption, and enhanced quality control. Utilising scrap contributes significantly to environmental preservation. Moreover, scrap integration ensures better quality control by mitigating residual copper content, radioactive presence, and container closure risks, thereby bolstering overall industry emissions suppression.

The efficiency of scrap usage is underscored by its ability to be melted, recycled, and utilized as fresh steel, diminishing the necessity for new iron-making capacity addition. The merits extend beyond environmental conservation, with shredded scrap notably reducing melting times and offering cost-effective consistency across furnace operations. The comprehensive benefits of scrap utilisation, as quantified by the United States Environmental Protection Agency (EPA), include substantial energy savings of 75%, a 90% reduction in virgin material usage, an 86% decrease in air pollution, and significant reductions in water consumption, water pollution, mining wastes, and consumer waste[25]. Overall, steel scrap not only reduces the need for virgin steel production but also conserves natural resources and fosters a more sustainable industrial landscape.

7.4.1 Scrap: Global Scenario

Recycling steel scrap from end-of-life products is an established practice as it makes economic sense for steel producers to adopt the less energy-intensive recycling process as compared to reducing iron ore. Today, about 31% of the world's steel is produced from recycled steel scrap. By sector, global steel recovery rates are estimated to be at least 85% for construction, 90% for automotive (reaching close to 100% in the US), 90% for machinery, and 50% for electrical and domestic appliances. [26]

In countries that have been industrialized for a long time, a significant portion of the new steel comes from recycled steel. This is because of the ample supply of steel built up over centuries of industrialisation from pre-existing construction and infrastructure. However, in developing regions, they mostly have to make new steel from scratch as they grow their supply and do not possess any significant amounts of steel to recycle[27].

In the global steel-making scenario, around 650 MT of scrap is consumed yearly for steel production (compared with a total crude steel production volume of around 1869 MT per year). This avoids the emission of approximately 975 MT of CO_2 annually and significantly reduces the use of other natural resources, such as iron ore, coal and limestone, which would have been consumed for the reduction of iron ore.[28]

Looking ahead, the availability of scrap, and consequently the potential for increasing recycled steel production, is anticipated to expand. This expansion correlates with historical trends in steel production, with steel products introduced to the market years or even decades ago reaching the end of their lifecycle. As such, scrap generation from 2030 onward is expected to mimic the sharp production growth seen from 1990 onwards, propelled by surging demand in countries like China and India. The lifespan of steel products varies widely, from a few weeks for packaging to up to 100 years for buildings. On average, steel products last about 40 years. However, despite this longevity, the demand for steel is rapidly increasing, surpassing the scrap supply. Currently, all collected scrap is recycled, posing limitations on augmenting scrap availability. Any potential increase will mainly stem from the expected rise in post-consumer scrap availability.

7.4.2 Scrap: Indian Scenario

Out of the total 144 million tonnes of crude steel production in India for FY2023-24, about 21 % of it is produced through the ferrous scrap route. Further, out of this total scrap used, 25% (nearly 9 MT) is imported.

Presently the internal scrap generation (in steel production/processing units) rate is gradually decreasing due to the adoption of continuous casting and improved technologies in mills. Therefore, the industry has to depend upon other sources for scrap. However, the scrap generation rate will be increasing due to the gradual increase in steel production and steel usage. India's Steel Scrap Recycling Policy 2019 estimates a requirement of 70-80 MTPA to produce 250 MTPA by 2030. This would be challenging as it is estimated to require at least 700 scrap processing centres of 1 lakh ton/annum capacity and 2800 – 3000 collection and dismantling centres with adequate logistic facilities. For such a high quantity of scrap production, collection dismantling centres and logistic facilities must be gradually increased with suitable policy support.

End-of-life Vehicles (ELV) have been identified as a good source of ferrous scrap for steel production, primarily in the secondary steel sector. In this direction, Ministry of Road Transport & Highways (MoRTH) notified ELV policy in September 2021 to set up Registered Vehicle Scrapping Facility (RVSF) for scrapping ELVs in a scientific and environmentally sound manner.

7.4.3 Scrap Utilisation in India: Challenges

Despite unprecedented benefits linked to the use of scrap in the country, there exist certain gaps and constraints associated with increasing the utilisation of scrap in steel manufacturing processes, as listed below:

1. **Manpower Intensive Recycling Process:** The recycling process in India heavily relies on manual dismantling and segregation of scrap components, unlike in developed countries, which provide better control over composition but demand a higher labour input.[29]

2. **Informal Nature of Value Chain:** India's current scrap recycling ecosystem operates informally, lacking a formal structure. This results in issues like fragmentation, non-compliance with regulations, low-quality output, and limited transparency within the value chain.

3. **Quality of Scrap**: Steel recycling faces challenges not only in sourcing enough scrap but also in ensuring its quality, with contaminants like copper and tin compromising recycled steel's usability.

4. **Lack of Data Availability:** The lack of credible data on scrap utilisation in steel-making is a significant challenge due to the informal nature of the scrap sector. This absence of data impedes informed decision-making regarding resource allocation and process optimisation.

5. **Trade barriers:** India's ambition to increase steel production capacity faces hurdles due to restrictions on scrap steel exports from other regions, such as the EU, exacerbating the shortage of scrap supply and hindering efforts to meet production targets.

6. **Insufficient Infrastructure for Recycling Initiatives**: Initiatives aimed at boosting the domestic recycling industry, such as the scrapping of older vehicles, have been hindered by low capacity utilisation and the limited availability of old vehicles for recycling. These obstacles hamper efforts to increase scrap supply and promote sustainable recycling practices.

7. **Barriers against Implementation of ELV (End of Life) Policy:** State level adoption of Scrappage Policy - 25 states and 2 Union Territories have notified implementation of Scrappage policy in their states, but major states like Tamil Nadu and Telangana are not yet on-boarded. Even the states that have adopted the policy, have not adopted it in full spirit across the parameters of disincentives, incentives, liability waivers & industrial incentives, as suggested. Only 11 States have adopted the policy in full spirit.

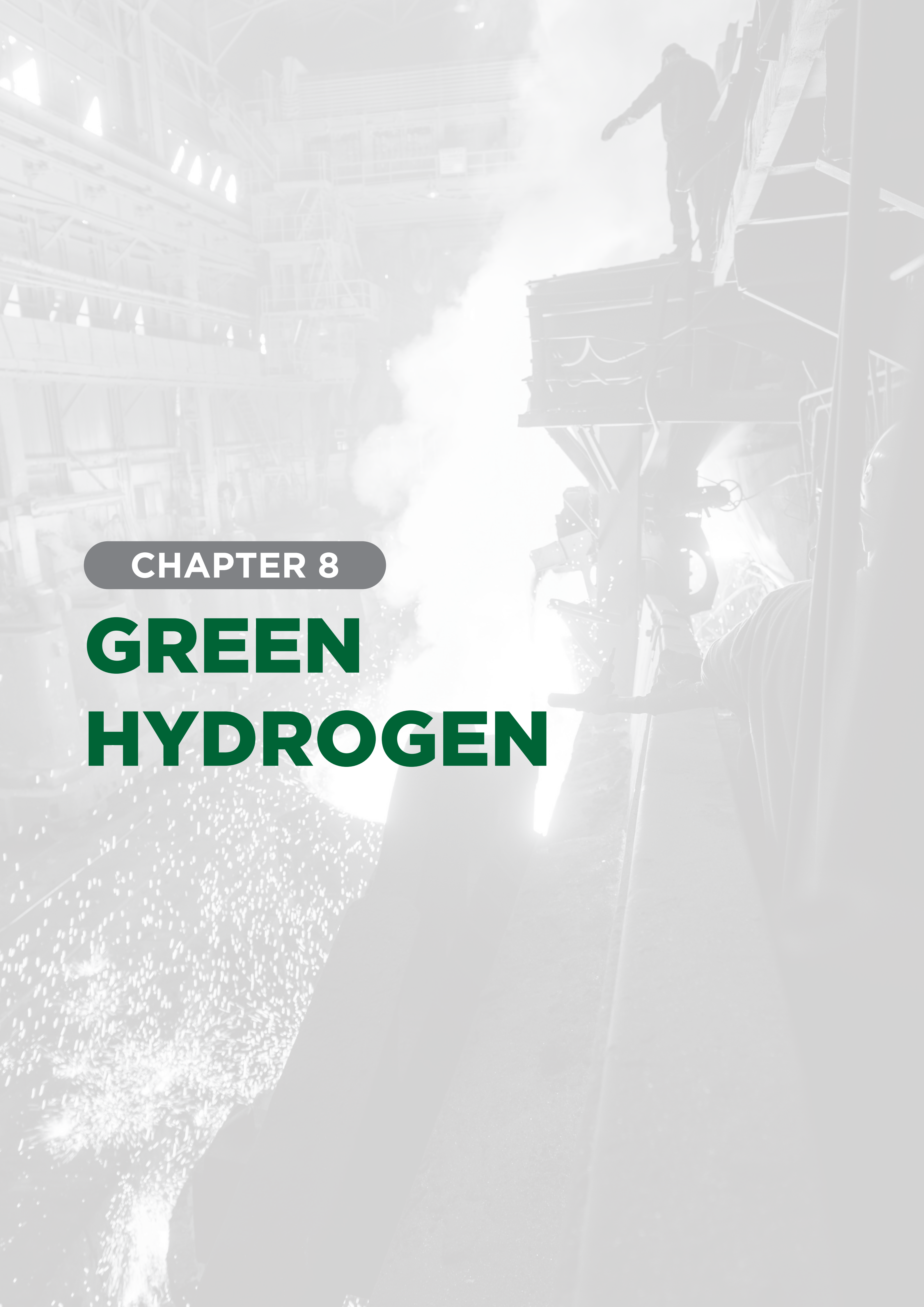
   Further, the ELV policy of MoRTH does not make it mandatory for unfit vehicles to be scrapped. This results in underutilization of the dismantling capacity of the plant. Logistics are yet to be developed for smooth movement of ferrous scrap from RVSF to Shredder and from Shredder to Steel Cluster. Additionally, there is a lack of awareness amongst the public, RTOs and many Government Departments about the process of scrapping vehicles, citizen incentives, waiver of liabilities etc.

   Addressing these challenges is crucial for the steel industry's transition to a more sustainable and circular model, which is vital for global environmental preservation. Resolving these challenges demands better waste management practices, improved sorting, and disassembly, requiring policy support for incentivisation. Thus, several interventions are provided to address these challenges in the next section.

7.4.4 Scrap: Action Plan

Steel recycling plays a pivotal role in a circular economy strategy by not only decreasing the demand for iron ore extraction but also aiding in emissions reduction. Elevating the utilisation of scrap in the steel industry necessitates a comprehensive intervention strategy. Therefore, given below are several interventions that can be explored to enhance scrap utilisation in the Indian iron and steel sector.

1. **Establishment of Circular Economy Parks and Recycling Zones:** The establishment of circular economy parks and recycling zones requires policy support aimed at facilitating their creation, thereby incentivising recyclers to develop processing facilities, with government tax incentives crucial in encouraging their setup and fostering the growth of robust recycling infrastructure.
2. **Greater awareness of vehicle scrappage policies:** An effort is needed to create enhanced awareness of vehicle scrappage policies and the potential benefits of the scrappage policy and schemes. The Ministry of Steel may work closely with the Ministry of Road Transport and Highways of India along with the state governments to support this initiative and ensure that vehicle scrappage facilities are set up across various locations, thereby encouraging the establishment of scrap collection centres.
3. **Safety Measures and Testing:** Prioritising safety measures involves mandating the installation of radiation detection equipment in all steel mills, foundries, and recycling units to ensure the safe handling of scrap, while contaminants such as copper and tin should be carefully managed to maintain the quality of scrap for various applications.
4. **Industry Status and Integration:** Granting industry status to the recycling sector and developing an e-marketplace for unorganized sector players to integrate with the organized sector will streamline operations and ensure transparency, thus fostering growth and efficiency within the recycling industry.
5. **Government Procurement Policies:** Government procurement policies should prioritize products made from recycled material, thus encouraging the utilisation of recycled materials across various sectors. This plan proposes government leadership through procurement, industry-wide policies, and targeted market support to strengthen the recycled materials market.
6. **Standardisation and Regulation:** Standardising recycling operations and establishing a National Material Recycling Authority are crucial steps for effective regulation and quality control. Reducing GST rates from 18% to 5% can help curb fraudulent practices and incentivize the formalisation of the unorganized sector.
7. **Extended Producer Responsibility (EPR) and Integration of Informal Sector:** Implementing Extended Producer Responsibility (EPR) in the automobile and white goods sectors will hold producers accountable for their products' end-of-life management while integrating informal scrap collection systems, such as Kabadiwala, into the formal sector will enhance efficiency and reach, ensuring a more effective recycling ecosystem.



CHAPTER 8

GREEN HYDROGEN

8.1. Introduction

A significant portion of the emissions from the steel sector are attributed to the ironmaking process. In traditional BF and DRI production pathways, carbon is used as a reducing agent to remove oxygen from the iron ore, leading to emissions of CO_2. Typically, this carbon is obtained from coke in the BF and feed coal (thermal) in the rotary kilns. Coal is also used as a fuel to meet the energy requirements of the ironmaking process. The combustion of coal, either as pulverised coal in BF or fuel coal in rotary kilns, also leads to CO_2 emissions.

Green hydrogen can potentially replace the use of coal both as a reducing agent and an energy source. Hydrogen is a strong reducing agent and can be used to obtain iron from iron ore. The most important incentive for using hydrogen as a reducing agent is that, unlike using carbon obtained from coal, its use as a reductant produces H2O and not CO_2. Consequently, if hydrogen is obtained from clean energy sources like wind and solar, there are no CO_2 emissions from the ironmaking process. Green hydrogen can also be used as an energy source to offset the use of pulverised coal in blast furnaces. This mitigates emissions from pulverised coal combustion in the blast furnace. Thus, green hydrogen can replace carbon as a reducing agent and fossil fuels as an energy source for producing iron.

Green hydrogen is vital for the long-term, deep decarbonisation of the steel sector. The National Green Hydrogen Mission, launched on 4th January 2023, envisions creating the ecosystem for its uptake in the steel industry. However, 100% green hydrogen-based steel production faces significant barriers due to technology challenges and high upfront costs. Therefore, until this becomes commercially viable, green hydrogen can be used to incrementally decarbonise steel production through blast and shaft furnaces by partial replacement of fossil fuel. This chapter discusses the role of green hydrogen in decarbonising the Indian steel industry through its uptake in blast furnaces and shaft furnaces.

8.2. Global and Indian scenario for using green hydrogen in the steel sector

There are 4 potential uses of Green Hydrogen in the Steel Sector, being experimented globally –

Hydrogen injection in blast furnace: Injection of hydrogen in the BF through tuyeres to reduce the coal/coke consumption. There are limitations on the amount of hydrogen that can be injected into the blast furnaces; hence, the potential to decarbonise steel production is limited.

Hydrogen injection in shaft furnace: Injection of Hydrogen in vertical shaft-based DRI making where it can partially substitute the natural gas/other reducing gas. The proportion can be incrementally raised to maximise the use of hydrogen.

100% hydrogen-based DRI: Using 100% hydrogen in DRI production coupled with renewable energy offers a pathway for fossil-free steelmaking. However, steel produced through such a pathway is significantly more expensive than conventionally produced steel due to the high cost of green hydrogen.

Hydrogen use in horizon technologies: Hydrogen can be used in new technologies like hydrogen plasma reduction, hydrogen-based fine ore reduction and hydrogen use in gas-solid suspension in a flash furnace. However, these technologies are at a lower TRL level and will take a few years to operate commercially.

Figure 8.1 provides a snapshot of global and Indian scenarios for green hydrogen use across three technologies.

Technologies for green hydrogen

	Green hydrogen use in blast furnace	Hydrogen blending in natural gas-based shaft furnaces	100% Hydrogen-based DRI production in shaft furnaces	Hydrogen use in horizon technology
TRL	5	6	5	4
Global scenario	• ThyssenKrupp conducted several tests since 2019 in Germany on one of the 28 tuyeres of the blast furnace for 24-hours • Nippon Steel is conducting experiments using heated hydrogen in a test furnace (12 m^3) for blast furnace hydrogen injection; estimated 22% emissions reduction	• Tenova tested 90% replacement of natural gas in DRI on small scale plant (9 kt/yr) in Mexico during 1990s • Multiple initiatives exists globally like SALCOS, Hamburg H_2 project etc	• HYBRIT demonstrated the technical feasibility on pilot scale • Other initiatives include project by H_2 Green Steel, tKH2Steel, GravitHy, and one project by ArcelorMittal	• POSCO and Primetal developed the FINEX process that use H_2 with low-cost coal. • Voestalpine demonstrated the HYFOR process for using H_2 for reducing iron ore fines and SuSteel process using hydrogen plasma technology. • University of Utah developed the FIT process to produce metallic iron using hydrogen, natural gas, coal gas, or their combination in gas-solid suspension
Indian scenario	• Tata Steel successfully injected ~6 kg/thm of hydrogen for four days resulting in 10% coke rate reduction and 7-10% CO_2 emissions reduction per ton of crude steel (tcs)	• JSW Energy is putting up 25MW green hydrogen facility to produce 3,600 tonnes H_2 per year at Vijayanagar, Karnataka to be commissioned by March 2025 for use in the DRI at the steel production facility of JSW Steel Vijayanagar.		• IMMT has demonstrated hydrogen plasma smelting reduction of Fe_2O_3 on a laboratory scale

Figure 8.1: Summary of global and Indian scenarios for green hydrogen use across four technologies

8.2.1. Global Scenario

The use of green hydrogen in the steel sector is yet to find commercial applications across all the potential routes, as discussed above. Globally, steel players are working on technologies at TRL 4 or 6. The details of the projects across different locations globally are given in Table 8.1

Table 8.1: *Status of projects utilising various green hydrogen-based technologies in steel production across the world*

Sr. No.	Project Developer	Technology Name/details	Current Status
Hydrogen injection in blast furnaces			
1	Thyssenkrupp Site: Duisburg Country: Germany	• Thyssenkrup has successfully conducted tests on hydrogen injection in one of the 28 tuyeres of a blast furnace	• Thyssenkrup plans to extend this test to all 28 tuyeres for maximising the uptake of green hydrogen in blast furnaces
2	Nippon steel Site: Kimitsu Country: Japan	• Nippon Steel has tested hydrogen injection in a test blast furnace (12 m3) at the East Nippon Works, Kimitsu Area. • The test has demonstrated reducing emissions from blast furnace steelmaking by 22%	• Nippon Steel plans to conduct more tests and aims to reduce the CO_2 intensity of steel production from the blast furnace route by 30%
Green hydrogen injection in shaft furnaces			
1	Salzgitter AG Site: Salzgitter Country: Germany	• SALCOS (Salzgitter Low CO_2 Steelmaking) • Demonstration project of 2.0 MTPA DRI to be set-up at Salzgitter. • Use of NG and H2 as reducing agents in the DRI Unit. • H2 will be produced by high-temperature electrolysis based on Solid Oxide Electrolysis Cells (SOEC). It will produce 200 Nm^3/h of hydrogen, consuming only 720 kW AC power and steam from waste heat. • Fossil-free electricity will be generated locally by wind turbines erected at Salzgitter. • DRI to be used as feedstock in EAF.	• Tenova, Danieli and DSD Steel Group to build this direct reduction plant (DRP). • DRP and electrolyser are expected to be ready by 2026.
2	Arcelor Mittal Site: Hamburg Country: Germany	• Hamburg H2 project • Capacity of plant 0.1 MTPA • Aim to replace existing NG-based DRI with 100% H2-based DRI. • Initially, grey H2 from by-product gases will be used in the DRI unit.	• The plant is expected to be operational by 2025.

Sr. No.	Project Developer	Technology Name/details	Current Status
		100% green hydrogen-based technology in steel production	
1	SSAB, LKAB and Vattenfall Country: Sweden	● HYBRIT ● Demonstration project of 1.3 MTPA DRI to be set-up at Gällivare ● Hydrogen will be produced locally by water electrolysis, and fossil-free electricity will be generated remotely at the Vattenfall facility ● DRI generated to be used as feedstock in EAF at Oxelösund	● Pilot scale underground lined rock cavern (LRC) H2 storage facility of 100 m3 capacity under testing at Lulea ● The demonstration facility at Gällivare is expected to be ready by 2026
2	Thyssenkrupp Steel Europe Site: Duisburg Country: Germany	● tKH2Steel (Thyssenkrupp H2Steel) ● Demonstration project of 2.5 MTPA DRI ● Hydrogen will be taken from the H2 grid through the pipeline. The planned hydrogen pipeline between Dorsten and the Duisburg district of Hamborn (DoHa project) will provide a secure connection to a supra-regional hydrogen network ● DRI will be used as feedstock to green-powered EAFs	● Thyssenkrupp Steel awarded the engineering, supply and construction contracts to SMS group ● Completion is expected by the end of 2026
3	ArcelorMittal Sites: Bremen and Eisenhüt-tenstadt Country: Germany	● H2-based DRI plant at one each at Bremen and Eisenhüttenstadt plant – total capacity 3.5 MTPA ● H2 from the North German Clean Hydrogen Coastline network ● Green sponge iron (DRI) to be processed into steel in an electric arc furnace	● Facilitates are expected to be ready by 2030
4	H2 Green Steel Boden, Sweden	● SMS Group and Midrex ● Midrex Technologies, Inc. (Midrex) and Paul Wurth, an SMS Group company, announce a signed agreement with H2 Green Steel to supply the world's first commercial 100% hydrogen direct reduced iron (DRI) plant. The 2.5 million tons per year MIDREX H2™ Plant will be in Boden, northern Sweden	● The project is expected to be in operation by 2025 ● Ramp up to 5 MT by 2030 planned

Sr. No.	Project Developer	Technology Name/details	Current Status
5	GravitHy Country: France	• 2 MTPA Green DRI using Green Hydrogen/low Carbon Hydrogen. • The DRI will be used either on-site as a feedstock for green steel or traded globally in the form of Hot-Briquetted Iron (HBI) • Project Consortium Members are: • EIT InnoEnergy, the innovation engine for sustainable energy supported by the European Institute of Innovation & Technology, a body of the European Union (EU), • Engie New Ventures, • Plug, • FORVIA, • GROUPE IDEC through GROUPE IDEC INVEST INNOVATION and Primetals Technologies	• The project plans to mobilise EUR 2.2 billion worth of investment at commissioning, with construction commencing in 2024. The company aims for the plant to be fully operational by 2027, subject to any required regulatory approvals
6	Hydnum Steel, Location: Puertollano, Spain	• The plant will initially produce 1.5 million tons of hot rolled coils; the annual capacity is projected to be at 2.6 million tons of hot and cold rolled coils by 2030 • The plant will have a DRI production unit and a complete cold rolling complex in phases 2 and 3. The DRI plant will be powered by green hydrogen generated using local renewable energy • Project Consortium Members are: • Russula, • ABEI Energy, • Siemens, and • Primetals Technologies as the engineering and technology provider.	• Project was signed in June 2023
Horizon green hydrogen-based technology in steel production			
1	POSCO Site: Pohang works Country: Korea	• FINEX process jointly developed by POSCO & Primetals, wherein fine ore and low-cost coal are used, and the ratio of H2 will be gradually increased in two currently operational furnaces with 3.5 MTPA capacity	• Key technological elements are already in the demonstration phase

Sr. No.	Project Developer	Technology Name/details	Current Status
2	Voestalpine Site: Donawitz Country: Austria	• HYFOR (Hydrogen-based Fine-Ore Reduction)1 • Developed by Primetals Technologies, this process uses ultra-fine ore with a size distribution of <150 microns and an H2-rich gas or even 100 % H2 as the reducing gas	• In 2021, it was commissioned and successfully operated • Each test run processed about 800 kg of iron ore
3	Voestalpine Site: Donawitz Country: Austria	• SuSteel (Sustainable Steelmaking)2 • Research will be undertaken into the carbon-neutral production of crude steel from iron ore in a single process step using a novel hydrogen plasma technology • In future, the facility will operate a type of electric arc furnace to produce steel directly, avoiding the crude steel stage by using hydrogen plasma to reduce ores	• A testing facility is currently being established
4	University of Utah Site: Utah Country: US	• FIT (Flash Ironmaking Technology)3 • Fine iron ore concentrates are directly reduced to metallic iron using hydrogen, natural gas, coal gas, or their combination in gas-solid suspension • 90-99% reduction can be completed in 2-7 seconds when fed through a flash furnace at 1200-1500 °C. The temperature in the furnace is kept below the melting point of the iron ore concentrate to avoid sticking and fusion of the particles	• Under development with a mini pilot reactor with a solid feed rate of 1-7 kg/h, commissioned proving its technical feasibility
5	HYFOR Pilot Plant Location: Voestalpine, Donawitz Country: Austria	• Direct use of any iron ore pellet feed concentrates (< 0.15 mm; hematite or magnetite) by utilising hydrogen as reducing gas (optionally generated from natural gas) • Scale 800 kg iron ore; 100% H2-based fluidised bed. No pelletising is required, which enables low operation costs. High oxide yield due to dry dedusting and recycling of oxide dust. CO_2 free ironmaking by use of hydrogen based on renewable energies. High reduction rate at low temperatures and pressures due to high particle surface	• • First plant tests successfully conducted in 2021 • An industrial-scale prototype plant is being developed

8.2.2. Indian Scenario

The pursuit of a net-zero trajectory for the Indian steel industry requires a substantial reduction in emissions from 2.54 t CO_2/tcs (average) to zero by 2070, which can be aided by deep decarbonisation initiatives such as the use of green hydrogen. However, it is noteworthy that much of the pioneering research and development efforts aimed at achieving breakthrough technologies for CO2 reduction are underway outside India, championed by renowned research institutions and technology providers. Against this background, it becomes essential to assess the adaptability and applicability of using green hydrogen within the unique context of India as India presents a distinctive set of factors, encompassing raw materials, energy sources, alternative fuels, workforce expertise, value chain intricacies, research and development capabilities, and logistical considerations.

Green hydrogen is also vital for the Indian steel industry from a strategic perspective, given that the sector is significantly import-dependent for its coking coal. Therefore, any reduction in the coke rate due to the use of green hydrogen will reduce India's import dependency and save on foreign exchange

Taking a concrete step in this direction, the Ministry of Steel is formulating pilot projects under budgetary support of INR 455 crore provided by NGHM. All the 3 approaches, as described earlier, are being adopted for the pilot projects.

Among the steel producers, TATA has taken initial steps of experimentation in the Blast Furnace, as outlined in the table. JSW is proposing future production and use of Green Hydrogen in steel making. JSL has already started the use of Green Hydrogen in downstream processes. A summary of these projects is provided in Table 8.3.

Table 8.2: *Status of projects utilising various green hydrogen-based technologies in steel production in India*

Sr. No.	Project Developer	Technology Name/details	Current Status
1	TATA Steel Location: Jamshedpur, Jharkhand	Tata Steel successfully injected ~6 kg/thm of hydrogen for 4 days, resulting in a 10% coke rate reduction and 7-10% CO2 emissions reduction per ton of crude steel (tcs)	Pilot phase
2	JSW Steel Location: Vijayanagar, Karnataka	JSW Energy is putting up a 25MW green hydrogen facility to produce 3,600 tonnes of H2 per year at Vijayanagar, Karnataka, to be commissioned by March 2025 for use in the DRI at the steel production facility of JSW Steel Vijayanagar	Under construction
3	Jindal Stainless Limited Location: Hisar, Haryana	Jindal Stainless Limited has commissioned India's first long-term off-take green hydrogen plant with a production capacity of 78 tonnes per year of green hydrogen. Hydrogen is being used for annealing (downstream process). It is the world's first off-grid Green Hydrogen plant for the stainless steel industry and the world's first Green Hydrogen plant with rooftop and floating solar. This project is also a state-of-the-art green hydrogen facility with a target to reduce carbon emissions considerably by around 2,700 Metric Tonnes per annum and 54,000 tons of CO_2 emissions over the next two decades	Operational

Sr. No.	Project Developer	Technology Name/details	Current Status
4	IMMT Location: Bhubanesh-war, Odisha	CSIR-IMMT, Bhubaneswar, has developed a Hydrogen Plasma Smelting Reduction process on the laboratory scale to produce steel that completely eliminates CO_2 gas emission. It uses hydrogen gas as the source of heat energy to smelt iron ore instead of coke or coal, which is used conventionally. The optimised laboratory scale parameters (hydrogen flow rate, argon flow rate, hydrogen volume, reduction time, feed rate and quantity) were replicated successfully in bench scale (10 kg) with the product obtained of 99.54% pure iron with negligible sulphur and phosphorous content	Laboratory trials

8.3. Challenges

The uptake of green hydrogen in the steel sector faces multiple challenges due to its nascent stage of development in the country and globally. These challenges are elaborated below:

1. **Lack of a fully developed ecosystem:** The green hydrogen ecosystem across the value chain that includes production, transport and storage is still evolving in India and the infrastructure is yet to be built. The Ministry of New and Renewable Energy has released the National Green Hydrogen Mission to develop the ecosystem and scale up the green hydrogen economy. However, it will take a few more years for the green hydrogen ecosystem to be fully developed to ensure its uptake by the steel sector.
2. **Geographic hurdle in the availability of green hydrogen:** The availability of green hydrogen will be a challenge for the steel sector as a significant share of steel production capacity is deployed in the eastern states. In contrast, RE production capabilities lie primarily on the western side of the country. While RE used to produce green hydrogen, or green hydrogen itself, can be transported across state borders, this involves additional costs for producers. Significant capital investment will also be needed to transport green hydrogen from low-cost-producing areas to the steel plants. This will take a few years to materialise into actual projects.
3. **High cost of green hydrogen:** The current cost of green hydrogen is around 4-6 $/kg, which is significantly higher than the energy cost of incumbent fuels used in the steel industry today. Consequently, green hydrogen is amongst the most expensive measures for decarbonising the current technology mix of steel production. Unless the cost of green hydrogen is reduced to an acceptable level and it achieves parity with other production processes, the industry will likely focus on other decarbonisation measures like energy efficiency and renewable energy to meet its climate goals.
4. **Limited role in decarbonising the current production pathways:** Green hydrogen will play a limited role in mitigating emissions from the current technology mix for steel production in India. Green hydrogen can partially offset the coal or coke used in blast furnaces, but fossil fuels will still meet a significant portion of the total energy requirement. Globally, green hydrogen is expected to play a critical role in transitioning the DRI sector. Shaft furnaces are amenable to a varying blend of green hydrogen in the medium term and can eventually transition away from natural gas in the long term as green hydrogen achieves cost parity. However, the Indian DRI sector is primarily coal-based and gas-based shaft furnaces, where green hydrogen blending is possible, contributing to only 18% of

the total sponge iron production capacity. Currently, green hydrogen cannot be injected into the rotary kilns. Consequently, in India, green hydrogen uptake will be limited to blast furnaces and shaft furnaces, which have limited potential in the current scenario.

5. **Limited role in greenfield/brownfield projects:** Natural gas is a bridge fuel to green hydrogen owing to its substitutability by hydrogen. However, the steel players do not have access to natural gas at competitive prices. Consequently, the proposed capacity expansion plan by ISPs in India till 2030-31 focuses primarily on the blast furnace route, whereas the smaller players plan expansion through rotary kilns. Therefore, similar to the existing production mix, green hydrogen will continue to have a marginal impact in mitigating emissions from the greenfield/brownfield projects in India.
6. **Technological maturity:** The technologies pertaining to green hydrogen-based steelmaking and the green hydrogen value chain itself are yet to reach maturity in terms of technology readiness across the world. Most existing projects are being carried out on a pilot basis.
7. **Lack of experience in handling hydrogen by the steel industry:** The Indian steel industry uses carbon-based fuels like coal and natural gas to produce steel. There is a lack of experience in utilising only hydrogen for steel production given its endothermic nature of reduction. Further, hydrogen production and storage within the steel plant would be challenging as the industry is not fully equipped to handle hydrogen.
8. **Capital requirement:** Existing and greenfield steelmaking capacities require significant capital investment in order to modify and build facilities that are amenable to new-age fuels like green hydrogen.

8.4. Green Hydrogen Use in the Steel Industry: Cost Implications and Emissions Reductions

8.4.1. Assumptions

Commercial production and use of green hydrogen is still an uncharted territory. Given the uncertainty about the future use of green hydrogen in steel production, it is necessary to make certain broad assumptions going forward with this chapter. The assumptions are listed below:

1. **Green hydrogen costs and projections**

The trajectory of the cost of green hydrogen up to 2030-31 is obtained from the preliminary estimates of the NGHM of the Ministry of New and Renewable Energy (MNRE). Based on the industry inputs, the starting point is assumed to be USD 5 per kg for the year 2024-25. As shown in Figure 8.2, the projections are based on three scenarios - conservative, base and ambitious. In the base scenario, the cost of green hydrogen is expected to reduce to USD 1.5 per kg by 2030-31; in the conservative scenario, it will reduce to USD 2 per kg and USD 1 per kg in the ambitious scenario. The cost for the intermediate years is then obtained by linear interpolation for each of the three scenarios.

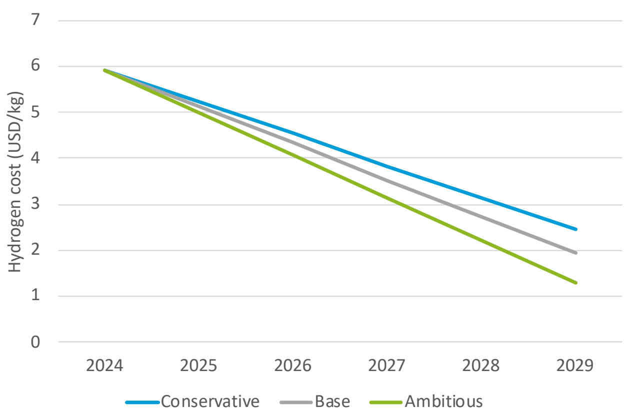


Figure 8.2: *Cost of hydrogen is expected to reduce from USD 5 to 1 per kg in the ambitious scenario*

2. Steel production volumes

The steel production from BF-BOF, DRI-EAF and DRI-IF routes for the years 2022-23 to 2030-31 is depicted in Figure 8.3, estimated using the National Steel Policy, 20174. The National Steel Policy mentions that the BF-BOF route will contribute to 60-65% of the steel production (out of 255 million tonnes per annum (MTPA) by 2030-31). The remaining share will mostly come from the DRI route. It is assumed that these shares will stay the same as they exist today. Also, it is assumed that the figures for steel production solely from steel scrap are subsumed in the figures for steel production via the DRI-IF route. Also, it is considered that the potential for injecting hydrogen exists only in the blast furnace and the shaft furnace and not in coal-based rotary kilns.

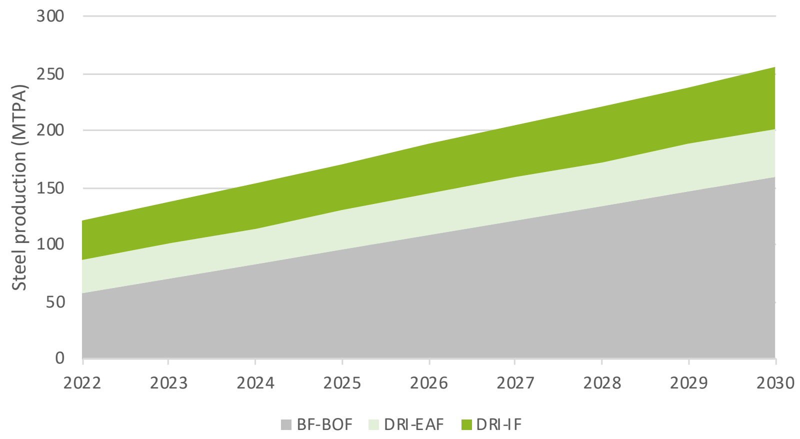


Figure 8.3: *Projections of steel production through various routes from 2022-23 to 2030-31*

3. Transmission of RE power for green hydrogen production

Green hydrogen can be supplied to the steel plants either through hydrogen pipelines or the plants can opt for in-house production by wheeling power from RE-rich states. The construction of hydrogen pipelines will need significant capital investment and until the cost of green hydrogen reaches parity with those of incumbent fuels, it is unlikely that India will have a hydrogen pipeline grid. Therefore, while hydrogen pipelines are a long-term option, this chapter considers the RE can be sourced from either co-located RE plants or via open-access mechanisms for producing green hydrogen at the site of the steel plant. It is assumed that steel plants have abundant land for installing electrolysers, and the location of the steel plant will not be determined by the fact that it uses green hydrogen as fuel.

4. The ceiling of hydrogen application across various technologies

The injection of hydrogen in blast furnaces and shaft furnaces is limited by the appropriate thermo-chemical balance that needs to be maintained. Green hydrogen injection in blast furnaces can either replace coal or PCI. However, based on industry inputs, green hydrogen is assumed to replace coke consumption. Further, as per the industry inputs, the hydrogen injection threshold is taken as 15kg/tcs, which replaces 50 kg/tcs of coke. A consequence of hydrogen injection in the blast furnace is increased oxygen consumption. It is assumed that oxygen consumption increases by 15-20 normal m3/tcs, and this additional demand is generated entirely from RE and costs an additional USD 0.16 per normal m3. It may be mentioned that the additional oxygen can also come from the process of green hydrogen production. That said, the cost of additional oxygen for the DRI route contributes insignificantly to the calculations of the viability of green hydrogen use. As per industry inputs, the maximum possible hydrogen injection for a shaft furnace is higher at 67 kg/tcs of hydrogen, which replaces 261 standard cubic metre (scm) of natural gas per tcs produced.

5. **Capex requirement for modifying existing technologies for green hydrogen uptake**

As per industry inputs, in a blast furnace, the modification cost is INR 135 crore for a 500 m3 unit (1100 tonnes/days X 365 days = 0.4 Million tonnes). Similarly, the modification cost in a shaft furnace is taken as INR 870 crore for a 100 tonnes per hour (TPH) (100 X 24 X 365 = 0.88 Million tonnes) unit.

6. **Price of coking coal and natural gas**

The feasibility of hydrogen use in steelmaking is closely linked to the cost of the fuel/reductant it is replacing, which is coking coal for the blast furnace and natural gas in DRI production. For the purpose of this chapter, coke replacement in the blast furnace and natural gas replacement in the shaft furnace have been considered. Based on industry inputs, the cost of coking coal, for assessing the breakeven cost of green hydrogen, has been taken as USD 220/tonne. Further, the breakeven cost is also indicated for a range of coking coal costs of USD 180/tonne to USD 260/tonne. The projected prices of coking coal obtained from the literature also support this assumption. Similarly, the range of cost for natural gas has been taken as USD 8-18/MMBtu. The breakeven price of green hydrogen for shaft furnaces is obtained for an NG cost of USD 8-18 /MMBtu. However, industries get natural gas at USD 14-16/MMBtu today. One MMBtu equals 1055 MJ, and the exchange rate has been taken as 83 Rupees to a dollar.

7. **Hydrogen injection in the shaft and tuyeres of the blast furnace**

Green hydrogen can be injected in the blast furnace either through tuyeres or the shaft. Ideally, as green hydrogen is an expensive fuel, efforts should focus on maximising its potential to replace coke. Hydrogen injection through the shaft is expected to potentially replace significantly higher coke than injection through tuyeres. However, hydrogen injection in the shaft of a blast furnace has not been demonstrated anywhere in the world. As discussed in section 8.2, hydrogen injection through tuyeres has been demonstrated in a few plants globally. A pilot demonstration also exists in India. Therefore, while hydrogen injection in the shaft might be a better option than tuyere injection, in the absence of any experience related to shaft injection, this report assumes that tuyere injection might be a starting point for hydrogen uptake in the blast furnace. Hydrogen injection in the shaft can be considered as a potential choice in the future with a better understanding of its effect in reducing coke consumption, the capital requirement for modifying the blast furnace and accounting for other ancillary expenses.

8.4.2. Use of green hydrogen in blast furnace route

Hydrogen injection in BFs entails replacing the conventional carbon-based fuels/reductants, i.e. coke or coal, with hydrogen gas during the iron-making process. Some of the considerations for this purpose are discussed in the following sections.

8.4.2.1. Technological modifications

For successful integration of hydrogen injection, several key technological adjustments must be made to the existing blast furnace infrastructure.

1. **Designing hydrogen injection system:** A dedicated hydrogen injection system must be meticulously designed to deliver the required flow rate through multiple tuyeres. Hydrogen causes endothermic reactions in the furnace; thus, the uniform temperature distribution across the cross-section of the blast furnace has to be maintained. This can be achieved by controlled injection through all or an evenly distributed subset of tuyeres.
2. **Heating requirements:** Hydrogen injection in the blast furnace can be done either via the tuyeres or from the upper section of the blast furnace. However, if hydrogen is to be injected from the upper

section, it has to be heated to a specific temperature, which requires a heating system. This is quite challenging.

3. **Logistics:** Before undertaking the complex process of hydrogen injection into a blast furnace, a thorough examination of safety protocols, cost implications, and transportation and storage requirements for hydrogen and consequent provisioning for the same is necessary. A pressure modulation system is essential for the decompression and compression of hydrogen at various stages.
4. **Integration challenges:** Seamless integration of the hydrogen pipeline with the tuyere line will require additional engineering adjustments in the pipeline, lance, flowmeter, and related components. As stated earlier, these aspects have not been covered in the report; it has simply been assumed that green hydrogen will be available for use in steel plants at the cost projected by MNRE. However, the cost of modifying the blast furnace and integrating green hydrogen into the production process has been considered in the analysis for obtaining breakeven cost.
5. **Practical application and limitations:** Theoretically, the reduction in coke consumption can reach up to 60 kg/tcs with an increased hydrogen injection rate from 10 kg/tcs to 35 kg/tcs. However, practical limitations in BF restrict the range to approximately 13 – 16 kg hydrogen/tcs, equivalent to replacing 3 – 4 kg of coke per kg of hydrogen. Any further increase to match the theoretical rates requires additional costly structural modifications in the blast furnaces.

In summary, hydrogen injection in blast furnaces presents a transformative opportunity for the steel industry to reduce emissions, but it also necessitates careful technological adjustments, adherence to safety protocols, and a thorough understanding of the practical limitations.

8.4.2.2. Emissions reduction

Figure 8.4 shows the emissions reduction potential from hydrogen injection in blast furnaces. Injecting around 15 kg of green hydrogen/tcs in the blast furnace results in emissions savings of 190 kgCO_2/tcs due to reduced coke consumption. For the blast furnace, this is calculated against base case emissions of 2.46 tonne of CO_2 (tCO_2) per tonne of crude steel (tcs) with a charge mix of 91% hot metal and 9% scrap (since a certain share of scrap is used in steel production), and with an iron-to-steel conversion ratio of 1.1. The emissions savings achieved through the use of green hydrogen to the extent of 15 kg/tcs in the blast furnace is 7.7%. Figure 8.5 also depicts the range of emissions reduction for a hydrogen injection range of 13-17 kg/tcs.

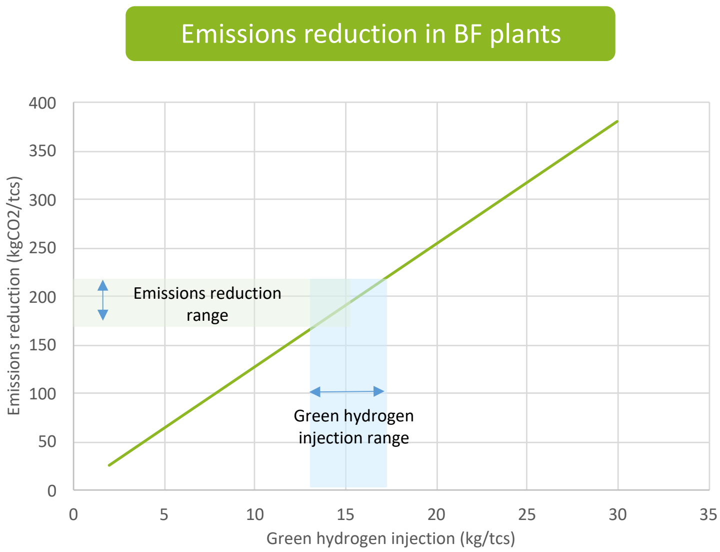


Figure 8.4: Emissions reduction with hydrogen injection in blast furnaces

8.4.2.3. Breakeven cost

The uptake of hydrogen in blast furnaces depends on its ability to replace coking coal and, therefore, its cost. Figure 8.5 shows the breakeven cost of green hydrogen for a range of coking coal prices. The injection of green hydrogen in the blast furnace also increases oxygen demand. It is assumed that the power required to produce additional oxygen in the PSA unit is obtained from renewable energy. The cost burden due to additional oxygen injection is also factored in when evaluating the breakeven cost of green hydrogen. To be preferred over coking coal, the cost of green hydrogen must be reduced to as low as USD 0.48/kg at a coking coal cost of USD 180/tonne. Similarly, for an upper limit of coking coal price of USD 260 per tonne, the breakeven cost of hydrogen is USD 0.88/kg. This implies that, essentially, the cost of hydrogen needs to be reduced further below that in the most ambitious scenario of MNRE to enable its use in the blast furnace process by the year 2030-31, as shown in Figure 8.4. It must also be noted that the breakeven cost of green hydrogen will likely have to be even lower, as the assumption that the cost of hydrogen will follow the trajectory as estimated by MNRE does not consider the cost of storage etc.

It should be noted that projecting the price of coking coal is challenging since it depends on external and geopolitical factors. Figure 8.4 shows the breakeven cost of green hydrogen for a coking coal cost range of USD 180 to 260/tonne. However, in estimating the steel price increase, in the base case, an average coking coal price of USD 220/tonne is considered till 2030-31. The increase in steel price for the coking coal cost of USD 180/tonne and USD 260/tonne has also been evaluated. The estimations for the breakeven cost of green hydrogen and the steel price increase also consider the cost of modifying the blast furnace, which is based on industry inputs.

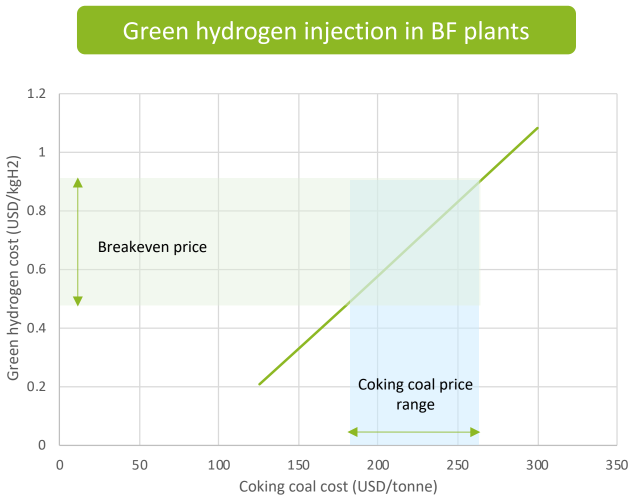


Figure 8.5: *Emissions reduction with hydrogen injection in blast furnaces*

8.4.2.4. Cost escalation of steel

In the conservative, base and ambitious scenarios for the cost of green hydrogen, the increase in the cost of steel reduces from a peak of INR 5134/tonne (10.2%) in 2024-25 to INR 1335/tonne (3%), INR 780/tonne (1.5%) and INR 59/tonne (0.12%), respectively, in 2030-31, for a coking coal price of USD 260/tonne. If the coking coal price is taken as USD 180/tonne, the increase in the cost of steel reduces from a peak of INR 5633/tonne (11.3%) in 2024-25 to INR 1834/tonne (3.7%) in the conservative, INR 1278/tonne (2.6%) in the base scenario and INR 558/tonne (1.1%) in the ambitious case scenario by 2030-31. At an average coking coal price of USD 220/tonne, the increase in steel cost reduces from about INR 5384/tonne (10.3%) to INR 1585/tonne (2.7%), INR 1029 (1.6%) and INR 308/tonne (0.1%) in the conservative, base, and ambitious scenario, respectively. The percentage increase in steel cost due to hydrogen injection in the blast furnace for coking coal price of USD 220/tonne is graphically depicted in Figure 8.6. As shown in the Figure, considering a steel cost of INR 50,000/tonne5, it is expected that green hydrogen blending in blast furnaces will increase the production cost by approximately 11% in 2024-25, which will gradually taper off in the future with a decrease in green hydrogen cost relative to the cost of coke. In addition, Table 8.3 lists the incremental decrease in cost escalation up to 2030-31 for the three scenarios, conservative base and ambitious for a coking coal cost of USD 180/tonne and USD 260/tonne.

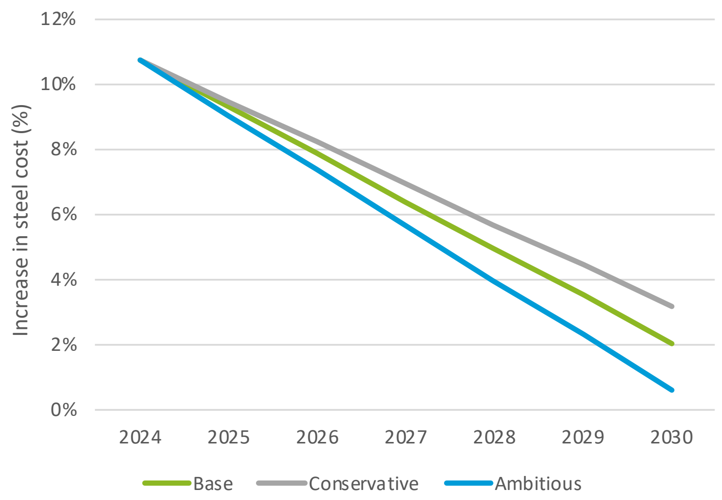


Figure 8.6: *Cost escalation of steel owing to use of Green Hydrogen in BF (for a coking coal cost of USD 220/tonne)*

Table 8.3: *Cost escalation of steel (for a coking coal cost of USD 180/tonne and USD 260/tonne)*

Year	Coking coal cost - USD 180/tonne			Coking coal cost - USD 260/tonne		
	Conservative	Base	Ambitious	Conservative	Base	Ambitious
2024-25	11.3%	11.3%	11.3%	10.3%	10.3%	10.3%
2025-26	10.0%	9.8%	9.6%	9.0%	8.8%	8.6%
2026-27	8.7%	8.4%	7.9%	7.7%	7.4%	6.9%
2027-28	7.5%	6.9%	6.2%	6.5%	5.9%	5.2%
2028-29	6.2%	5.5%	4.5%	5.2%	4.5%	3.5%
2029-30	4.9%	4.0%	2.8%	3.9%	3.0%	1.8%
2030-31	3.7%	2.6%	1.1%	2.7%	1.6%	0.1%

8.4.3. Shaft furnace - Electric arc furnace route

Green hydrogen can replace 65-70% of natural gas consumption in gas-based DRI, contingent on the technology employed. Nevertheless, this transition should be approached incrementally and tailored to individual plant circumstances. For steel production facilities not yet equipped with DRI units, installing a shaft furnace fuelled by either natural gas, synthesis gas, or coke oven gas (COG) provides a versatile starting point. It should be noted that iron ore reduction using hydrogen is an endothermic reaction. Therefore, there is a need to ensure adequate availability of energy to handle the endothermicity associated with hydrogen. The resulting product—cold direct reduced iron (CDRI), hot direct reduced iron (HDRI), or HBI—can be readily incorporated into the downstream processes after the DRI unit with minimal modifications. Subsequently, as the availability of hydrogen gas at competitive prices increases, incremental replacement of pre-existing fuel may start. The extent of the required structural changes for this purpose will be contingent on the evolving technology landscape.

8.4.3.1. Technological modifications

1. **Logistics:** Before undertaking the complex process of hydrogen injection into a shaft furnace, a thorough examination of safety protocols, cost implications, and transportation and storage requirements for hydrogen and consequent provisioning for the same is necessary. A pressure modulation system is essential for the decompression and compression of hydrogen at various stages.
2. **Designing hydrogen injection system:** A dedicated hydrogen injection system must be meticulously designed to deliver the required flow rate through the furnace. Hydrogen causes endothermic reactions in the furnace; thus, the uniform temperature distribution across the cross-section has to be maintained. This can be achieved by controlled injection through all or an evenly distributed subset of regions in the furnace.
3. **Integration challenges:** Seamless integration of the hydrogen pipeline with the shaft furnace will require additional engineering adjustments in the pipeline, lance, flowmeter, and related components. These aspects have not been covered in the report, as stated earlier, and it has simply been assumed that green hydrogen will be available for use in steel plants at the cost projected by MNRE. However, the cost of modifying the shaft furnace for injecting green hydrogen has been considered in the assessment for evaluating the breakeven cost.

8.4.3.2. Emission reduction

Figure 8.7 shows the breakeven cost of green hydrogen for replacing natural gas in shaft furnaces. As per industry inputs, injecting 41.5 kg/tcs of green hydrogen in the shaft furnace (or complete replacement of natural gas) leads to an emission reduction of 349 $kgCO_2$/tcs compared to the gas-based DRI-EAF process. The base case emissions level is taken as 1.5 tCO_2/tcs, where 40% (0.55-0.65 tCO_2/tcs) emissions are due to DRI production, and the rest is from the EAF. This estimation is for a charge mix of 85% DRI, 15% scrap, and an iron-to-steel conversion ratio of 1.11.

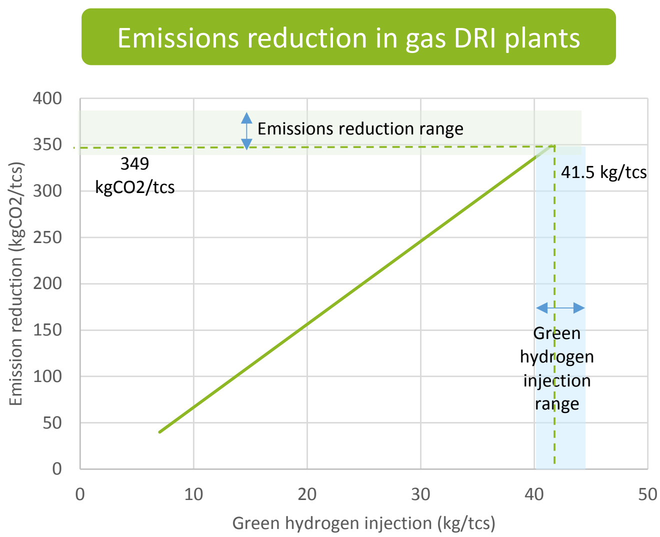


Figure 8.7: Emissions reduction by injecting green hydrogen in gas-based shaft furnaces

8.4.3.3. Breakeven cost

Hydrogen has the potential to replace 65-70% of natural gas consumption in a shaft furnace, depending on the technology adopted. Figure 8.8 shows the breakeven cost of green hydrogen for a range of natural gas prices and the reduction in emissions intensity for a range of green hydrogen injection levels. The breakeven price of hydrogen ranges from USD 0.75-2.02/kg for a natural gas price of 8 - 18 USD per MMBtu.

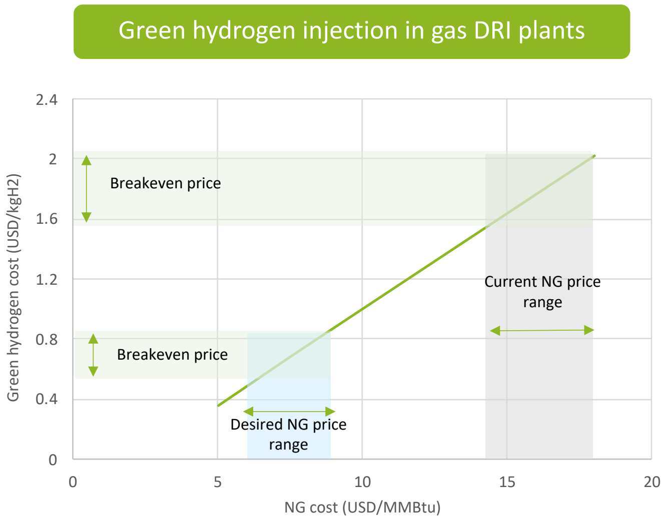


Figure 8.8: Breakeven cost of green hydrogen for replacing natural gas in shaft furnaces

8.4.3.4. Cost escalation

The graph in Figure 8.9 represents the percentage increase in steel cost for a scenario where 65% of the 198 kg (261 scm) per tcs of natural gas at USD 12/MMBtu is replaced with 41.5 kg/tcs of green hydrogen. The acceptable range for the natural gas price in the steel industry is USD 6-9/MMBtu. The natural gas price of USD 9.5/MMBtu is slightly higher than the industry-acceptable price but it is also the lowest natural gas price at which green hydrogen injection becomes commercially viable in an ambitious scenario by 2030-31. The graph also represents the increase in production cost for the base case scenario of green hydrogen cost, which will reduce from a peak of 27% in 2024-25 to 2% by 2030-31.

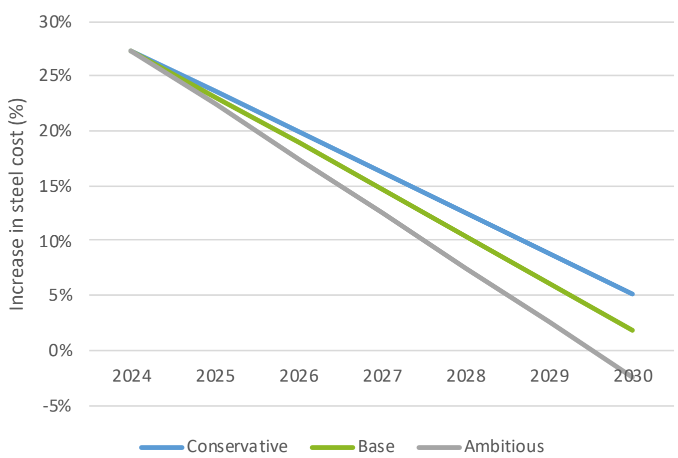


Figure 8.9: Cost escalation of steel production for the base case scenario

It is seen that the cost increase is expected to reduce from a peak of ~INR 13668/tonne (27%) in 2024-25 to about INR 2536/tonne (5%) in a conservative scenario and to INR 908/tonne (2%) of steel in the base scenario by 2030-31. However, in an ambitious scenario, the cost increase reduces to INR -1204/tonne (-2%) for a gas price of USD 12/MMBtu. A negative sign implies that using green hydrogen reduces the cost of producing steel through the gas-DRI+EAF route. In addition, for a natural gas price of USD 8 to 9.4/MMBtu, green hydrogen injection becomes unviable even in the ambitious scenario since using natural gas is a cheaper alternative. The percentage cost escalation of steel for a natural gas price of USD 8 and 18/MMBtu is summarised in Table 8.4.

Table 8.4: *Cost escalation of steel (for a natural gas cost of USD 8/MMBtu and USD 18/MMBtu)*

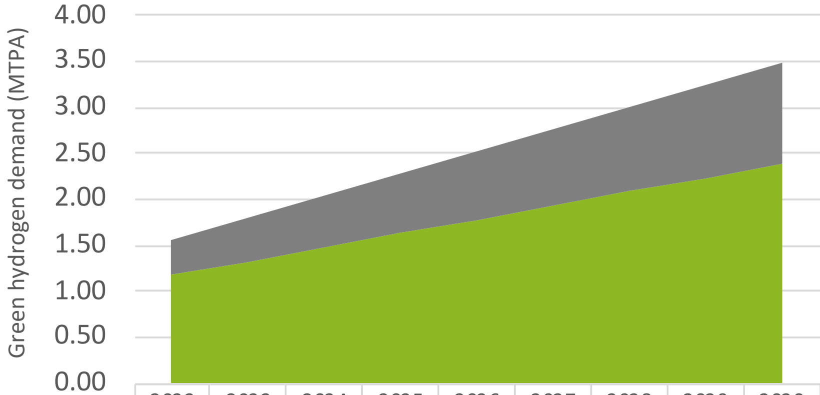
Year	Natural gas cost - USD 8/MMBtu			Natural gas cost - USD 18/MMBtu		
	Conservative	Base	Ambitious	Conservative	Base	Ambitious
2024-25	31.1%	31.1%	31.1%	21.7%	21.7%	21.7%
2025-26	27.4%	26.8%	26.1%	18.0%	17.5%	16.8%
2026-27	23.6%	22.6%	21.2%	14.3%	13.2%	11.8%
2027-28	19.9%	18.3%	16.2%	10.6%	9.0%	6.9%
2028-29	16.2%	14.1%	11.2%	6.9%	4.7%	1.9%
2029-30	12.5%	9.8%	6.3%	3.2%	0.5%	-3.0%
2030-31	8.8%	5.5%	1.3%	-0.5%	-3.8%	-8.0%

8.4.4. Hydrogen-based DRI production

Green hydrogen can be used to produce fossil-free DRI. If the electricity demand in the EAF unit is met by RE, then the process can produce fossil-free near-zero steel. However, fossil-free DRI and steel production is at a pilot scale today; only one plant (HYBRIT) exists globally. Nonetheless, as indicated in Table 8.1, there are multiple initiatives globally for scaling up fossil-free steel production. The existing shaft furnaces in India cannot transition to 100% hydrogen-based DRI production. Therefore, new investments will be needed for setting up hydrogen-based DRI production capabilities in India. Nevertheless, the average emissions intensity of steel in India is 2.54 tCO_2/tcs. Therefore, producing one tonne of fossil-free steel can mitigate 2.54 tCO_2 emissions.

8.4.5. Green hydrogen uptake potential in the steel industry

Figure 8.10 shows the theoretical uptake potential of green hydrogen in the steel industry. It is seen that the steel industry can consume approximately 1.80 MTPA of green hydrogen in 2023-24. This can potentially increase to 3.5 MTPA by 2030-31. The green hydrogen uptake potential is higher in blast furnaces, given that significant capacity exists for producing steel through this route. 100% hydrogen-based DRI is not indicated in Figure 8.10, as only pilots are being considered for this route till 2030-31.



	2022	2023	2024	2025	2026	2027	2028	2029	2030
Shaft furnace (MTPA)	0.38	0.47	0.56	0.65	0.74	0.83	0.92	1.01	1.10
Blast furnace (MTPA)	1.17	1.33	1.48	1.63	1.78	1.93	2.09	2.24	2.39

Figure 8.10: *Green hydrogen uptake potential in the steel industry*

The high cost of green hydrogen is likely to impede its utilisation across the steel sector. Based on the price projections and the breakeven prices discussed earlier, it is expected that by 2030-31, it will be possible to use green hydrogen to substitute natural gas in DRI production only under a very optimistic scenario. Considering that the industry will use green hydrogen only when breakeven prices are achieved and that there are no other policy interventions to support the industries meet their escalated production cost, uptake of green hydrogen will happen only if its cost reduces to below USD 1 per kg. As per ambitious projections of MNRE, this can only be achieved beyond the year 2029-30. It is expected that green hydrogen use in the gas-based DRI-EAF process will create a demand for 1.1 MTPA of green hydrogen by 2030-31 at a natural gas price range of USD 12/MMBtu, resulting in emissions savings of 9.2 million tonnes of CO_2 ($MtCO_2$) per annum, as shown in Figure 8.11. These calculations are based on the capacity addition targets set in the National Steel Policy for gas-based DRI production (as shown in Figure 8.3 and specific green hydrogen consumption values. If natural gas is available at USD 8-9.4/MMBtu, green hydrogen demand will reduce to zero since the industry would prefer natural gas over green hydrogen. It should be noted that the calculations for green hydrogen uptake in the steel industry have been done for all three scenarios - conservation, base and ambitious. However, green hydrogen uptake is possible only if its cost is reduced as per the ambitious scenario considered by MNRE. It should be noted that it takes significant time to develop the infrastructure, including the deployment of RE, electrolyser and storage capacity for the uptake of green hydrogen in steel units. The lead time for setting up the infrastructure has not been considered in the analysis, as the green hydrogen ecosystem is still evolving in India.

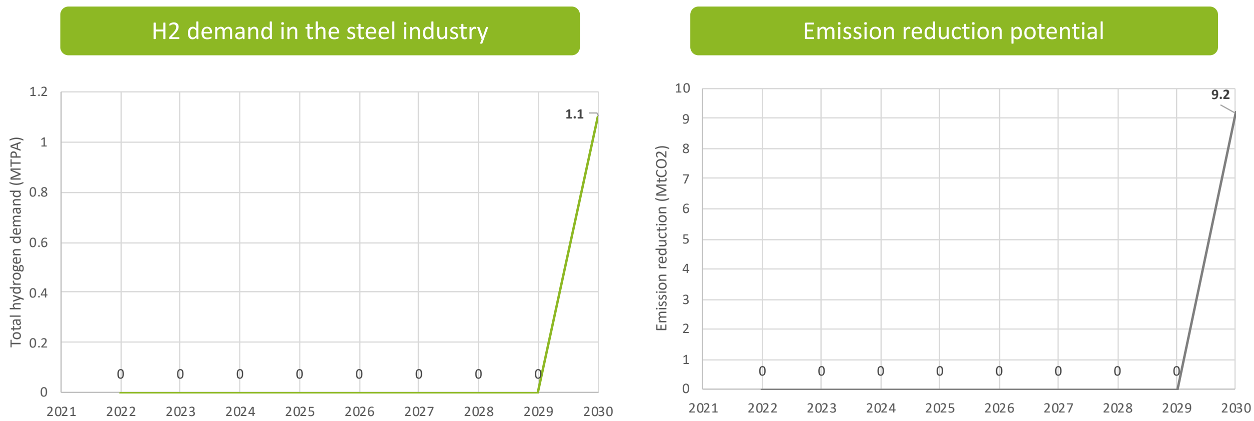


Figure 8.11: *Green Hydrogen demand in steelmaking*

8.4.6. Potential demand of green hydrogen in Indian steel industries

In theory, the steel industry has the potential to uptake 1.8 MTPA of green hydrogen in 2023-24 and 3.5 MTPA in 2030-31. In 2030-31, 2.39 MTPA green hydrogen can be consumed in blast furnaces, and the remaining 1.10 MTPA can be consumed in shaft furnaces. In the case of blast furnaces, green hydrogen has a breakeven cost of USD 0.48-0.88/kg, while it is higher for shaft furnaces at USD 0.75-2.02/kg. The cumulative hydrogen demand of 3.5 MTPA would require nearly 70 GW of RE capacity and 28 GW of electrolyser capacity. This is summarised in Table 8.4.

Table 8.5: *Theoretical hydrogen uptake potential and the infrastructure requirement for green hydrogen consumption in the steel sector*

Sr. no.	Route	H2 injection possible in 2023 -24 (MTPA)	H2 injection possible in 2030 -31 (MTPA)	Breakeven cost (USD/kg)*	Emission reduction potential (kgCO_2/tcs) and (% reduction)	Increase in the cost of steel (%)+
1	Blast furnace	1.33	2.39	0.48-0.88	190 (7.7%)	2-11%
2	Shaft furnace	0.47	1.10	0.75-2.02	349 (~25 %)	2-27%
	Total	**1.8**	**3.5**			

**At coking coal cost of USD 180 – 260/tonne and natural gas cost of USD 8-18/MMBtu.*

+ Values indicated for 2030-31 and 2023-24 scenarios at base coking coal price of USD 220/tonne and natural gas cost of USD 12/ MMBtu for the base scenario of decrease in hydrogen cost.

Figure 8.12 shows the locations of steel plants that can use green hydrogen. The blast furnace route accounts for 77 MTPA of the total 120 MTPA steel production, while the gas-DRI production accounts for only around 9 MTPA. Steel production plants with a capacity of 5-10 MTPA each are mostly located in the eastern and western parts of the country due to access to raw materials and logistical requirements. Even though the location of the new steel plants in the year 2030-31 cannot be predicted, they will likely be located close to areas with sufficient iron ore reserves.

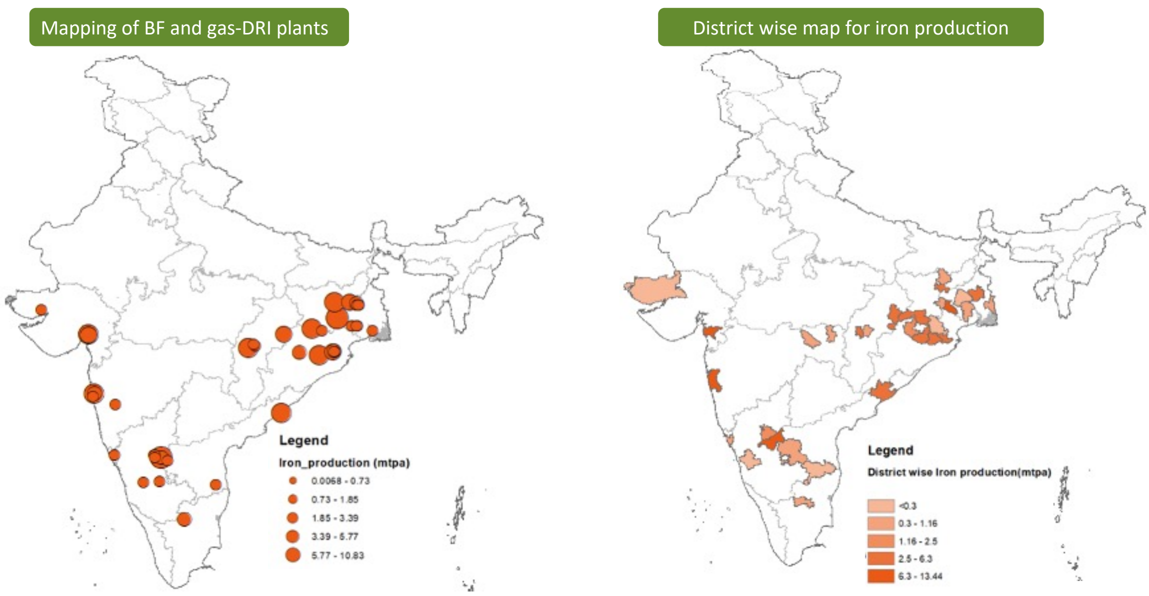


Figure 8.12: *Steel production and capacity across various clusters and districts in India*

Figure 8.13 shows the green hydrogen requirement across various steel clusters in the country and also the district-wise distribution for the year 2023-24. The plots are based on the assumption that all gas-based and BF units start using green hydrogen immediately to the maximum technical limit. Additionally, as stated previously, the demand for green hydrogen by the steel industry will only pick up post-2029-30, only in an ambitious scenario.

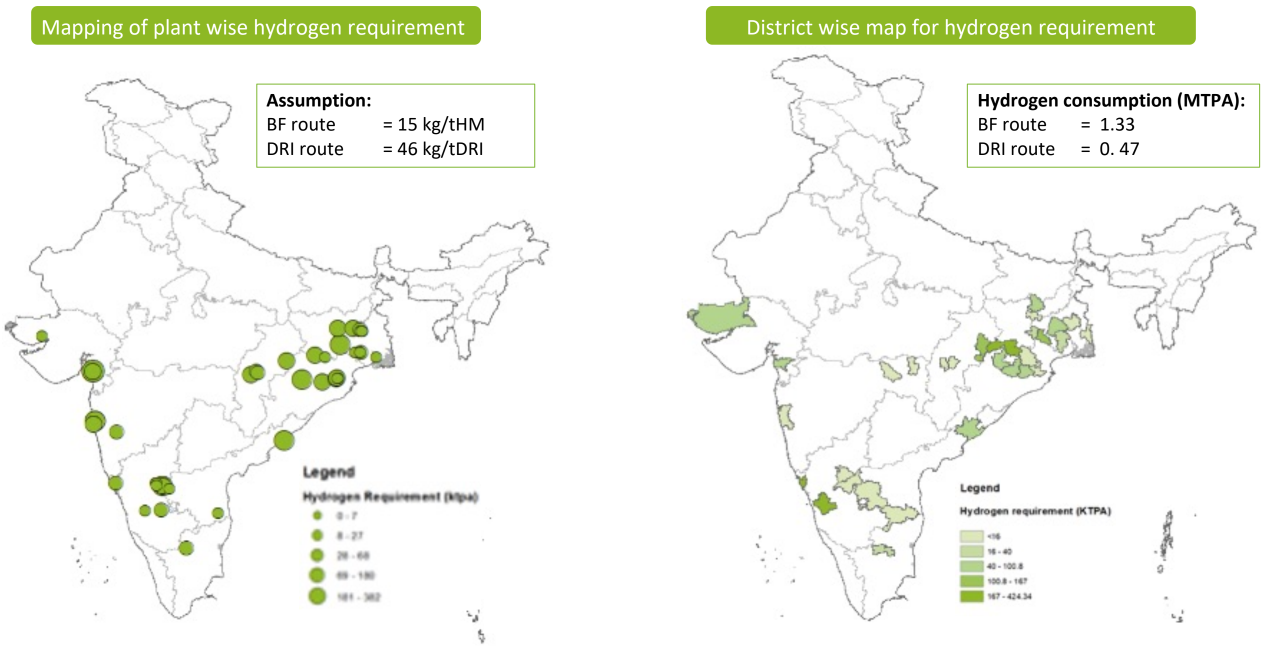


Figure 8.13: *Potential green hydrogen requirement in the country in FY 2023-24*

Except in Karnataka, the steel plants in India are located in states that do not have good RE resources. A few steel plants are located near cities, and it would be difficult to find land resources for setting up green hydrogen hubs and valleys in their vicinity. The refinery and fertiliser units in India also face similar challenges. Therefore, the Ministry of Power has notified an enabling green hydrogen/ammonia policy6 that offers a waiver of interstate transmission charges for 25 years to producers of green hydrogen from RE projects commissioned up to June 30, 2025. This date was further extended till December 31, 20307. It is expected that the steel plants can also benefit from these waivers and initiatives by the central government. It is envisaged that the RE plants for producing green hydrogen will be located in remote locations, and electrolysers will be housed either near or within steel plants for producing green hydrogen.

8.5. Possibilities for International and Multilateral Cooperation on Green Hydrogen

International collaboration

Section 8.2.1 of the report lists international examples of the use of the two major technologies for the use of green hydrogen in the production of steel. These are green hydrogen blending with coal in BFs and hydrogen blending with natural gas in an NG-based Shaft Furnace. These international examples are from Germany and Japan for the blast furnaces and Germany for the hydrogen blending in gas-based DRI units. There are a few initiatives on 100% hydrogen-based DRI production across Sweden, Germany, France and Spain. Further, research on horizon green hydrogen-based technologies is under progress in Korea, Austria and the US. All this points to the possibility of having productive international collaborations in the two areas with entities in Germany and other European countries. However, a caveat in this regard is that the technology being used in countries abroad would have to be adapted to Indian conditions, particularly those pertaining to the quality of iron ore and the infrastructure for supplying green hydrogen.

Multilateral collaboration

Apart from bilateral cooperation, the several multilateral initiatives that have been undertaken in the area of green hydrogen should also be explored. These can possibly benefit India not only in keeping abreast with the latest developments in hydrogen technologies but also in finding avenues for bilateral cooperation. The multilateral initiatives in the area of green hydrogen include those by the International Energy Agency (IEA), World Bank, Mission Innovation, Hydrogen Council, International Hydrogen Fuel Cell Association (IHFCA), International Partnership for Hydrogen Fuel Cells in the Economy (IPHE), International Organisation for Standardisation (ISO) and Clean Energy Ministerial Hydrogen Initiative. Of these, the ones by IEA and the World Bank are of particular relevance.

The IEA tracks the overall progress of the steel sector yearly and presents a commentary on country and regional highlights, the CO_2 emissions intensity of steel, material efficiency strategies, technology development, innovations, supporting infrastructure, policy, international collaboration, and private sector strategies. As per the IEA,8 several international efforts to collaborate on steel decarbonisation have been launched in the past few years.

The World Bank's Green Hydrogen Support Program assists governments in developing countries to identify short- and long-term green hydrogen opportunities. It also addresses the challenges associated with the deployment of green hydrogen projects, such as technology risks, capacity building, regulatory requirements, and economic analyses. The program aims to support the World Bank clients in creating an environment that will enable them to ramp up green hydrogen projects through two main workstreams.

1. **Grants and technical assistance:** Between 2020 and 2023, the program directly supported ten green hydrogen country activities. The program is currently offering technical support to projects in Brazil, Costa Rica, India, Maldives, Morocco, Namibia, Panama, Tunisia, and Ukraine.
2. **Global knowledge:** The program launched the "Hydrogen for Development Partnership" (H4D) at COP 27. The H4D Partnership was created as a global platform to produce knowledge, build capacities, and accelerate investments. As of September 2023, H4D has 35 partners, including international organisations (OECD, GIZ), major business associations (FCHEA, Hydrogen Council), hydrogen clusters (Port of Pecem in Ceará Brazil and Norrbotten hub in Sweden), and public institutions (CORFO, development bank in Chile).

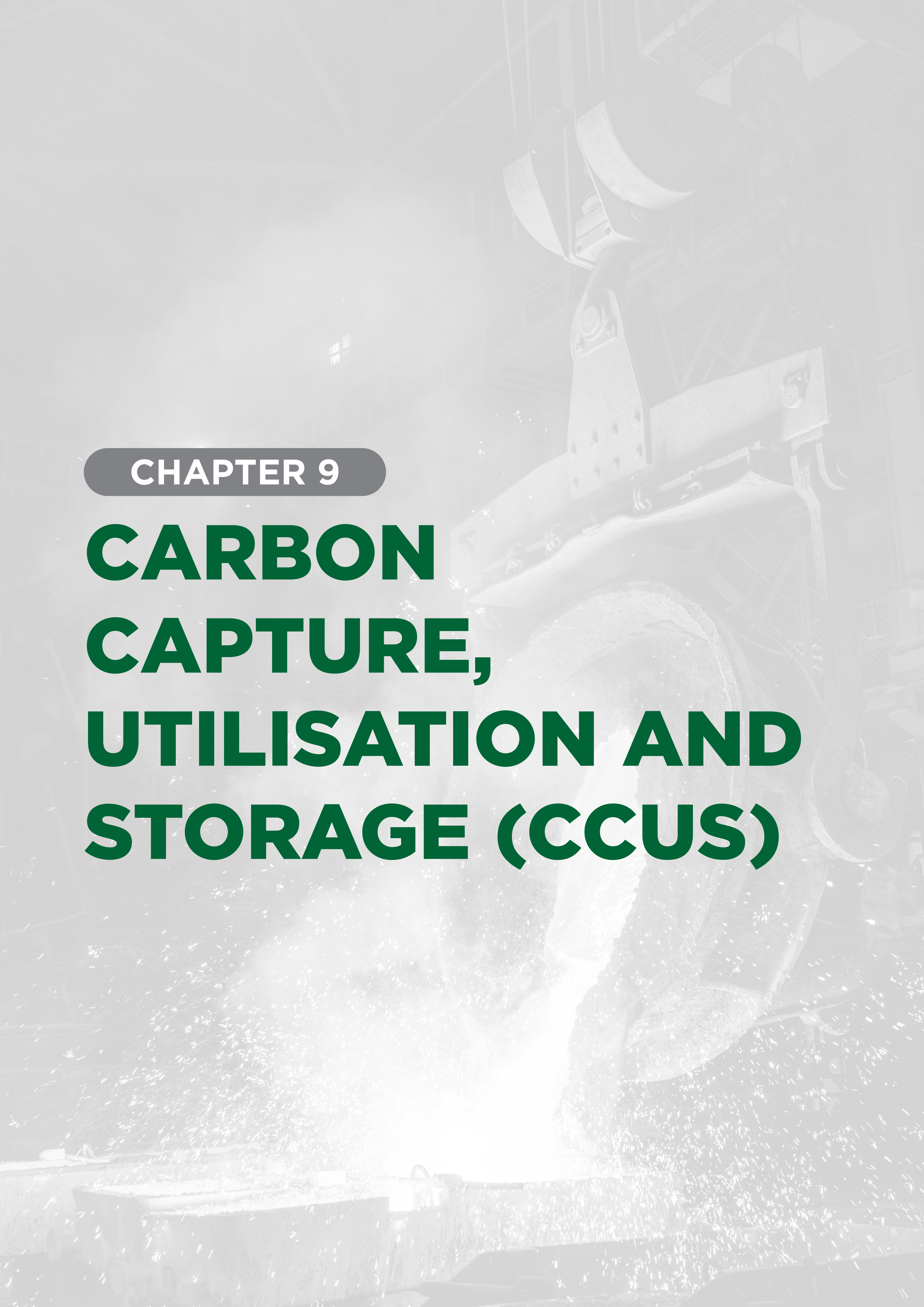
In India, the green hydrogen support program provided a grant to fund the "Green Hydrogen Opportunities and Roadmap for India," linked to the "Supporting Energy Transition of Indian Power Sector" project. Further, the World Bank has been working with the Government of India on a 2-phased USD 3 billion Development Policy Operation. The pillars of this engagement are (i) promoting green hydrogen, (ii) scaling up renewable energy, and (iii) enhancing climate finance for low-carbon energy investment. The Steel Ministry could explore if the green hydrogen support program could be used for grants, technical assistance and knowledge creation for the use of green hydrogen in steel production.

The other multilateral initiatives listed above should also be explored by the Steel Ministry for possible benefits toward the decarbonisation of steel production.

8.6. Action plan

It is evident from the earlier sections that for deep decarbonisation, the Indian steel industry must gradually move from the BF-BOF route to the green hydrogen DRI route. The Ministry of Steel endeavours to facilitate this transition by enabling steel manufacturing entities to switch to green hydrogen through the following action plan:

1. **Support pilot projects across end-use applications:** The Ministry of Steel may support pilot projects across all three end-use applications of green hydrogen - hydrogen uptake in a blast furnace, hydrogen blending in an existing shaft furnace and a 100% hydrogen-based DRI plant.
2. **Incentivise the installation of shaft furnaces:** Natural gas is a bridge fuel to green hydrogen. The Ministry of Steel may make efforts to incentivise the installation of shaft furnaces in India so that they can eventually transition to green hydrogen as its costs are reduced while making efforts to augment the supply of natural gas to the steel sector. Further, the steel industry may be encouraged to install shaft furnaces using off-gases in the plants to produce DRI.
3. **Coordinate with the ministries to extend benefits provided to green hydrogen projects to the steel industry:** The Ministry of Steel may coordinate with the Ministry of Power and Ministry of New and Renewable Energy to extend benefits provided to green hydrogen projects in the refinery and fertiliser sector to the steel industry as well.
4. **Accelerate International and multilateral collaborations to increase green hydrogen use:** The efforts at international and multilateral collaborations may be accelerated to derive maximum benefits from international developments for accelerating the adoption of green hydrogen in the Indian steel industry.
5. **Project to estimate the amount of green hydrogen that can be injected in rotary kilns:** The Ministry of Steel may undertake a project to estimate the amount of green hydrogen that can be injected in rotary kilns and identify the design changes required to maximise its uptake. The Ministry may focus on research and development of clean technologies for steelmaking.
6. **Development of experimental blast furnaces or shaft furnaces for hydrogen use:** Currently, there are no experimental Blast Furnaces or Shaft Furnaces in India for the use of the steel industry as they try to experiment with hydrogen in production processes. The Ministry may fill this crucial gap and support the development of such experimental facilities.
7. **Incentivising the use of green hydrogen for DRI making:** To incentivise the use of green hydrogen for DRI making, the ministry may encourage the development of designing reactors within the country for eventual making within the country. A consortium-based approach may be utilised for design, engineering, pilot and eventual capital equipment manufacture domestically to reduce the cost of setting up such facilities.
8. **Development/incentivisation of benefaction and pelletisation:** Concomitant steps may be taken for the development/incentivisation of benefaction and palletisation for switching to hydrogen-based DRI.



CHAPTER 9

CARBON CAPTURE, UTILISATION AND STORAGE (CCUS)

9.1. Introduction

Carbon capture, utilisation and storage (CCUS) is an umbrella term for all technologies and processes that capture carbon dioxide from an emissions stream or the air, convert it to other usable products and chemicals (utilisation) or sequester it permanently within different geological sinks to avoid its emissions to the atmosphere (storage). The CO_2 must be captured within the plant boundaries for the steel industry. CO_2 capture technologies can be broadly categorised into absorption-based and adsorption-based processes involving multiple solvents and adsorbents. The captured CO_2 can be converted to produce various chemicals and fuels. The most prominent CCU applications include the conversion of CO_2 to fuels like methanol, ethanol, synthetic natural gas (SNG), sustainable aviation fuels (SAF) or chemicals like olefins and carbonates. It can also be recycled to produce syngas used as a reductant for producing iron. The conversion of CO_2 to chemicals and fuels can happen within the plant boundary or outside it. The captured CO_2 can also be transported via pipelines to various storage sinks like basalt, saline aquifers, oil and gas reservoirs, and coal fields.

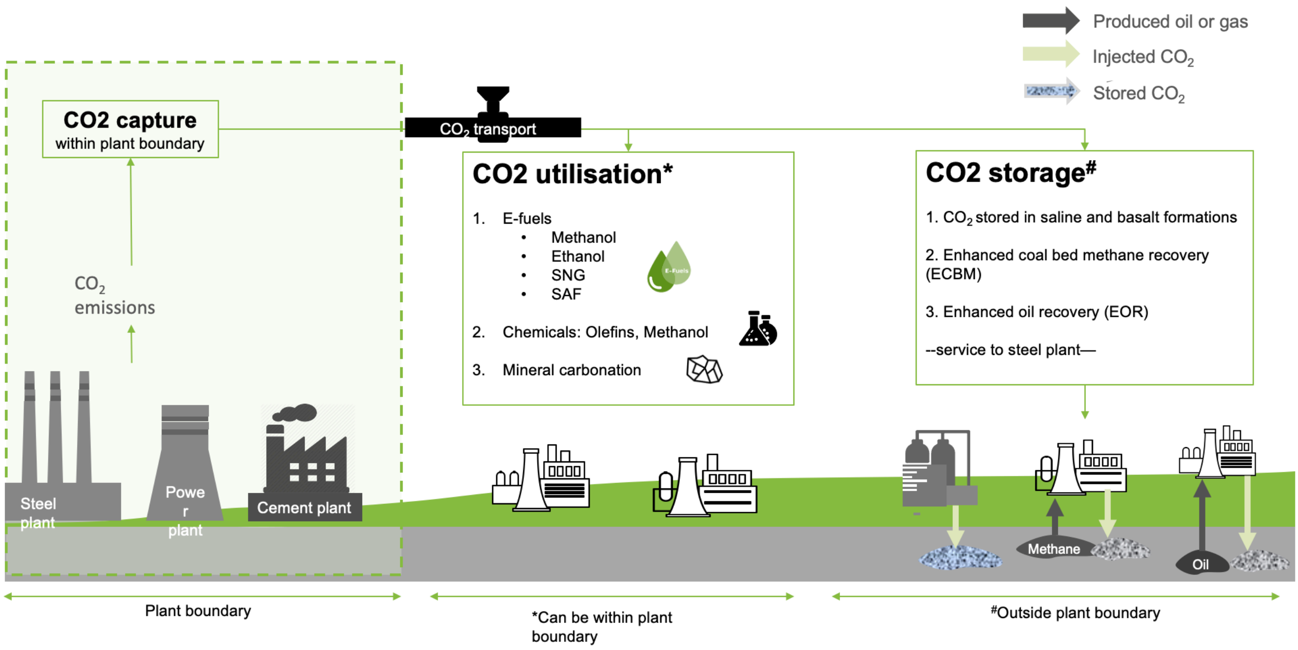


Figure 9.1: *Schematic process flow of CCUS pathways in steel industries*

Coal-based blast furnaces and rotary kilns contribute to approximately 93%[1] of India's total iron production. The weighted average age of Indian blast furnaces is only approximately 15 years[2], whereas the total life of a blast furnace is approximately 40 years. While gas-based shaft furnaces can seamlessly transition to green hydrogen, they have a limited role to play in the transition of blast furnaces. Further, the use of green hydrogen in rotary kilns has not yet been established. Therefore, green hydrogen has a very limited role in decarbonising the existing technology mix for iron production in India. Research indicates that up to 56%[3] of emissions from legacy steel plants in India can only be mitigated through the CCUS pathway. Further, India is expected to have a significant investment in blast furnaces and rotary kilns for capacity expansion till 2030. Given these constraints, CCUS is expected to play a pivotal role in the deep decarbonisation of India's iron and steel sector. The chapter presents the technical, operational and economic considerations for the deployment of CCUS technologies in India.

9.2. Global scenario

Figure 9.2 provides a curated list of CCUS deployments in the steel industry, covering a range of applications and project parameters. Globally, numerous large CCUS projects are also deployed in other industries, such as power, cement, petrochemicals, etc, which are not indicated in Figure 9.2. As per the databases of the World Steel Association[4] and the Leadership Group for Industry Transition[5], most of the CCUS projects in the steel industry are located in Europe. Companies such as ArcelorMittal in Belgium and France, ThyssenKrupp in Germany, Tata Steel in the Netherlands, Vattenfall and SSAB in Sweden have built or are in the process of building projects based on multiple pathways such as methanol, ethanol and polyurethane and syngas production along with CO_2 storage. In the USA, only one plant, the United States Steel, is operational that uses CO_2 to produce carbonates. In Asia, carbon capture and storage projects can be found in Japan, where Nippon Steel is operating an enhanced oil recovery project, and POSCO is planning a carbon capture and storage project in South Korea. Chinese companies also have deployed projects that utilise carbon dioxide. However, very few details are available of these projects. There is also an enhanced oil recovery project by Emirates Steel that is operational in the UAE.

Source: Carbon capture and use and storage factsheet, WSA, LeadIT

Figure 9.2: Overview of CCUS projects in global steel industrial units

9.3. Indian Scenario

In India, various academic and R&D institutes and industries are working to develop and demonstrate different types of CCUS technologies, particularly in CO_2 capture and utilisation. A few key initiatives by the Indian steel companies and other industrial units are depicted in Figure 9.3.

CCUS projects being implemented by the Indian steel industry

- **TATA Steel:** Tata Steel, Jamshedpur has commissioned a five-tonne per day (TPD) CO_2 capture plant from blast furnace gases. It is based on an amine-based absorption technology. In the next phase of the project, the company plans to recycle the captured CO_2 in the steelmaking operations.

- **JSPL:** It has operationalised a 2000 TPD plant that captures concentrated CO_2 from commercial-scale coal gasification at Angul. In addition, the same plant has a 1500 TPD CO_2 capture unit connected with a DRI unit. It uses a Rectisol-Lurgi technology for gasification and MDEA as a solvent through the Midrex process for capture in DRI. These CO_2 capture units at JSPL are a part of the plant requirement. JSPL is also exploring CO_2 utilisation to bio-ethanol, methanol and soda ash.

- **JSW Steel:** It has a 100 TPD CO_2 capture unit connected to a gas DRI plant commissioned at Salav, Maharashtra. It converts captured CO_2 to carbonates and supplies liquified CO_2 to the beverages industry. Table 9.1 lists the status of carbon capture technologies in the steel sector.

Efforts in other Indian Industries

Apart from the steel industry, a few other industrial units are also deploying CCUS projects. As depicted in Figure 9.3, these projects are either in the R&D stage or demonstration/pilot stages. Existing pilot and R&D projects highlight various uses of CO_2 in producing urea, liquid fuels (methanol/DME/aviation fuel), enhanced oil recovery and food beverage industries, etc. These industries have been focusing on utilisation projects through two methods: Power-to-Gas (P2G) and Power-to-Liquid (P2L). P2G uses renewable electricity for water electrolysis to produce hydrogen, which will then be combined with CO_2 to produce synthetic natural gas (SNG). P2L follows a similar path, using renewable energy for electrolysis to create liquid fuels like methanol by combining hydrogen with captured CO_2. Further, a 10 TPD plant for converting CO_2 to ethanol through a bio-fermentation process is under construction and further research is being done at IIP Dehradun to convert it to sustainable aviation fuel (SAF). The IOCL refinery based in Panipat uses gas fermentation technology, based on microbial gas fermentation, to produce ethanol using CO (from captured CO_2) and hydrogen. Regarding the direct use of CO_2, Oil India Ltd is working on CO_2 assisted enhanced oil recovery project in Assam. NTPC has commissioned a 20 TPD CO_2 capture plant in the power sector. This plant is connected to a 500 MW fossil fuel-fired unit at NTPC Vindhyachal. The plant will use green hydrogen along with captured CO_2 to produce methanol.

The industrial sector is also planning a few pilots for CCUS. Dalmia Cement has planned an approximately 1370 TPD CO_2 capture unit in their Tamil Nadu plant. Oil and gas companies and the refinery units are conducting feasibility studies for CCUS deployments. ONGC and IOCL have done a feasibility study for the capture of 0.7 MTPA of CO_2 from HGU at IOCL Koyali refinery and utilising the CO_2 for EOR at ONGC's Gandhar oilfields and for F&B industry usage. ONGC also has an MoU with Shell for cooperation on exploring CO_2 storage study and EOR in key basins in India and with Equinor for developing CCUS hubs and projects. BPCL has done a feasibility study for the gasification of 1.2 MTPA petcoke and conversion to carbon-abated chemicals, hydrogen and power.

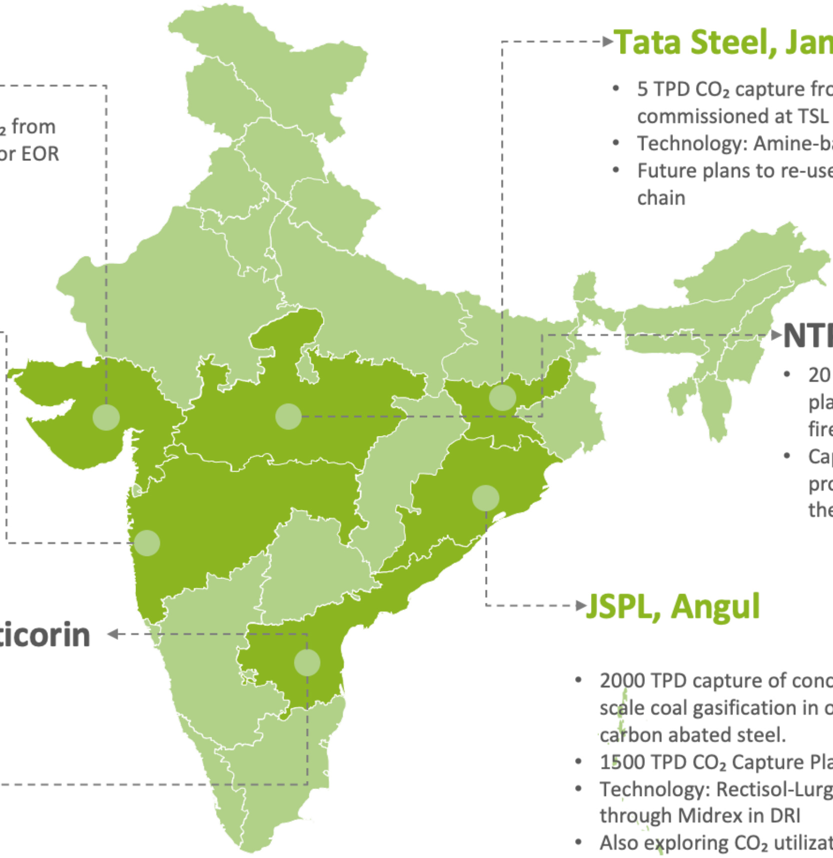


Figure 9.3: *Overview of CCUS projects in the Indian steel industry and other industrial units*

Table 9.1: *Status of CCUS technologies deployed in the steel sector*

Sr. No.	Parameter	TATA STEEL	JSW	JINDAL STEEL & POWER LTD
1	Steelmaking route	BF	Gas DRI	Coal Gasification-DRI-EAF
2	Location of CCUS pilot (R&D)	Jamshedpur	Salav, Tal- Murud, Dist- Raigad Maharashtra	Angul
3	Brief Intro to the CCUS Project	The captured CO_2 is utilised for the treating GCP water in the LD process. Among the fledgling technologies for CO_2 capture, the R&D team at TSL has evaluated that the amine-based adsorption process is the most suitable for CO_2 capture from by-product BF gas. Additionally, the R&D team has identified a commercial usage for the captured CO_2.	The plant was commissioned in the year 2000. CO_2 being utilised by the beverages industry	In the gasification unit, CO_2 needs to be captured and removed to increase the GCV of syngas. Rectisol process (methanol) developed by Lurgi as a part of the gasification process is used for the removal of gas. In DRI, Midrex, a technology supplier, has a tie-up with a CO_2 capture technology supplier that uses MDEA as a solvent, and the same has been used in the DRI plant.
4	CO_2 capture capacity	5 TPD	100 TPD	2,000 TPD at the gasification unit (rectisol) and 1,500 TPD at the DRI unit
5	Year of commissioning	2021	2000	2014
6	Status (Operational/ shutdown/ demonstration)	Operational	Operational	Operational

Sr. No.	Parameter	TATA STEEL	JSW	JINDAL STEEL & POWER LTD
		CO_2 Capture		
1	Technology	Amine-based absorption	Conversion to potassium Carbonate	Rectisol-Lurgi for gasification and MDEA through Midrex for DRI
2	Point of CO_2 capture	Blast Furnace	Gas DRI unit	Gas cleaning in the gasifier and top gases from the DRI reactor
3	CO_2 Capture cost (INR/ tCO_2)	3,500-4,000	-	No cost is calculated separately as both are part of the process. However, MDEA is a steam-based process as Rectisol (methanol) is a cryogenic operation that operates at minus 30 degrees Celsius. Based on in-house power cost and steam cost, the cost of capturing in MDEA is around 2,600-2,800 per ton, whereas, in MDEA, the cost is around 1,000-1,100 per Ton
4	CAPEX (INR)	5-6 crores	-	Not calculated separately as it was part of the process
5	OPEX (INR/tCO_2)	3,500-4,000	-	The cost given above is the operating cost.
	a. Steam requirement (kg steam/t-CO_2)	1,000-1,100	1,740	Approximately 1,700 kg per tonne of CO_2 in the MDEA process. In methanol, the steam requirement is very low.

Sr. No.	Parameter	TATA STEEL	JSW	JINDAL STEEL & POWER LTD
	b. Mass flow rate (kg/h), pressure (bar) and temperature (deg C) of steam requirement	220-240 kg/h, 3 bar, 130-140 deg C	40,000 kg/h, 3.5 bar, 150 Deg C	-
	c. Power requirement (kWh/t-CO_2)	80-90	45	25-28 kWh/T of CO_2 in MDEA
	d. Other auxiliary for plant	Cooling water	-	Being part of the process, not measured separately
6	Technology provider	Carbon Clean	Giammarco Vetrocoke, Italy	Lurgi for Rectisol and Midrex for DRI
7	Approximate indigenisation % (cost-wise)	_	-	Only some piping and vessels were fabricated locally. All critical components are supplied from other countries.
8	Key features of the technology	1. Low solvent loss; 2. Solvent life 5-6 years; 3. No hazardous emission	-	One is cryogenic and operates at high pressure and low temp - whereas the other is high temperature and low pressure

Sr. No.	Parameter	TATA STEEL	JSW	JINDAL STEEL & POWER LTD
		CO_2 utilisation		
1	Technology	-	Used for beverage industry application	-
2	End product type	-	Liquid CO_2	-
3	End product capacity	-	100 TPD	-
CO_2 Stor-age	**NA**	**NA**	**NA**	

The Indian industry has undertaken a few initiatives to indigenise the design and engineering of carbon capture technologies. These initiatives are listed in Table 9.2.

Table 9.2: *R&D projects on carbon capture in India*

Sr. No.	R&D Project	Technology	Organisation (and collaborating institutes)
1	Development of zeolite and 'Pressure Swing Adsorption' process for CO_2 capture	Physical Process	NTPC (collaboration with CSMCRI, NEERI, CSIR-IIP, IITB)
2	Development of amine and process for CO_2 capture	Chemical Process	NTPC (collaboration with IITG, IITB)
3	Demonstration of microalgae-based CO_2 capture	Biological Process	NTPC (collaboration with IOCL)

9.4. Challenges with CCUS

As a technological pathway, CCUS is necessary for the deep decarbonisation of the Indian steel sector. However, it still faces significant challenges that need to be overcome for an efficient deployment of CCUS in the steel sector. This section of the report expounds on the challenges of deploying CCUS in the Indian steel industry. The challenges are identified for CO_2 capture, utilisation and storage.

9.4.1. Carbon capture

- **High cost of capture:** Today, the cost of capture is prohibitively high, ranging from USD 40-70/tonne of CO_2, which is a major barrier to its deployment in the steel sector.
- **Uncertainty on utilisation or storage:** While there are a few pilots on CO_2 capture in the steel industry, there is uncertainty on the utilisation or storage of captured CO_2 as the ecosystem for the same does not exist in India. Therefore, in the absence of guaranteed downstream use of CO_2, it is unlikely that the steel industry will invest in CO_2 capture technologies.
- **Low CO_2 concentration in flue gas from steel plant:** The capital and operating costs of different carbon capture technologies depend on the CO_2 source characteristics, i.e., pressure and CO_2 concentration, which mainly determine the choice of carbon capture technology and, consequently, its cost. It is seen that the capture cost increases exponentially below a CO_2 concentration of 15-20% (%v/v). The CO_2 concentration in the iron and steel units is at the inflection point below which the cost increases significantly. The CO_2 concentration in other industrial units, such as power generation is significantly higher than that of iron and steel plants, and hence, the cost of CO_2 capture is also low. Therefore, the low concentration of CO_2 in the iron and steel units will be a challenge from the cost perspective.
- **High steam and power requirement:** The existing CO_2 capture technologies suitable for the iron and steel sector require significant energy input in the form of steam and electricity. Consequently, operating a capture unit itself is associated with a certain amount of emissions, given the prevalent energy mix in Indian steel plants. Reducing emissions from operating the carbon capture unit will require deploying RE resources, which might further increase the cost of CO_2 capture. This will also need the deployment of significant RE resources and newer technologies to meet heating demand in the CO_2 capture unit.
- **Capture efficiency of current technologies:** The existing CO_2 capture technologies have a capture efficiency of 55-60%, while the peak capture efficiencies range from 80 to 85%[6]. Therefore, the residual emissions must be mitigated through other mechanisms like direct air capture or afforestation. Direct air capture has a significantly higher capture cost, given the low concentration of CO_2 in the atmosphere. Further, afforestation faces significant challenges in a developing country like India, given the competing uses for land.

9.4.2. CO_2 utilisation

- **High cost of abatement:** There is a significant premium associated with products made out of captured carbon dioxide vis-a-vis the products made through conventional production routes, primarily due to the high cost of carbon capture and green hydrogen, which is generally one of the inputs for various CCU pathways. It is seen that the cost of mitigation for green hydrogen-based fuels and chemicals like methanol, sustainable aviation fuels, olefins, and SNG exceeds USD 300-500 per tonne of CO_2. Most CCU applications are expected to become commercially viable only at a green hydrogen price of USD 1 per kg. This economic premium discourages consumers from demanding carbon-abated products.
- **Lack of domestic and international OEMs:** Very few domestic OEMs have developed or are manufacturing technologies related to CO_2 conversion. Although OEMs exist across various CCU applications

internationally, they are fewer in number, and the market for CO_2 conversion technologies is not competitive enough to drive down the costs. Therefore, it is expected that there will be a significant technology and proprietary cost component in an underdeveloped market like CCU. In addition, given the low TRL level of some of these technologies, the gestation period for CCU technologies to attain maturity might still be significantly high.

- **Lack of CCU ecosystem in Indi**a: CCU is essential to decarbonise the steelmaking processes and achieve the goal of AtmaNirbhar Bharat. However, there is no ecosystem that enables the development and deployment of CCU technologies in India today. There are no policies framed around CO_2 conversion technologies in India, and the CCU ecosystem in India is still developing. While the launch of the national green hydrogen mission is expected to increase its demand in refineries and fertilisers, the use of green hydrogen for producing fuels and chemicals might need more time.
- **Lack of experience within the steel sector:** The Indian iron and steel industry produces finished steel as the main product. However, it is envisaged that CO_2 will be captured and utilised within the boundaries of the steel plant to decarbonise the existing production pathways. Therefore, if and when CCU technologies are deployed, the steel sector will produce steel, and various chemicals and fuels in an integrated steel and chemical plant. However, the steel industry is not equipped or experienced to produce chemicals and fuels. Moreover, inexperience and lack of knowledge in CO_2 utilisation technologies and the production of chemicals or fuel can be a barrier for these steel producers in the initial phase.
- **Low demand for carbon-based products:** At present, there are no procurement mandates for any off-taker to purchase and consume carbon-based products in India. Without such a mandate ensuring a guaranteed offtake, producers of carbon-abated products are hesitant to deploy large capacities, thereby impeding the cost reductions that can be achieved with economies of scale.

9.4.3. CO_2 storage

- **Lack of estimation of true sequestration potential in India:** Broad-level estimates show that India has a theoretical CO_2 storage potential of approximately 629 GT of CO_2 . The realistic potential after considering the above-ground challenges is 359 Gt of CO_2[7]. However, there is no estimate of the true CO_2 sequestration potential in India based on actual site characterisation. This is expected to create significant uncertainty for investments in CCS projects in the country.
- **Positive cost of abatement:** Given that sequestered CO_2 has limited economic value and the cost associated with building and operating the infrastructure, CCS will always have a positive cost of CO_2 mitigation. A positive cost implies that the deployment of CCS measures will always increase the cost of steel unless there is some revenue from the stored CO_2 in projects like enhanced oil recovery (EOR). This poses a significant barrier compared to other competing carbon mitigation technologies like renewable energy or green hydrogen, the prices of which are expected to reduce in the future. Therefore, the steel industry considers CCS to be the last decarbonisation measure.
- **No policy for CCS:** To date, there is no policy for CCS in India. Consequently, there are no clear governance structures for CO_2 storage. In addition, given that CCS requires bulk transport of CO_2 in pipelines, right-of-way issues for laying transport pipelines could be a major barrier, as is the case with ongoing natural gas projects.
- **Lack of pilots in India:** There is a lack of CCS demonstration projects across various types of sinks in India. The lead times required for pre-feasibility and site assessment studies are up to 10 years7. This is expected to be a major bottleneck for deploying CCS projects in the steel sector in India.

9.5. CO_2 capture

9.5.1. CO_2 capture technologies

NITI Aayog's report on Carbon Capture, Utilisation and Storage[8] provides the details of all technologies, including the operating parameters, efficiencies and available solution providers. Therefore, this section briefly discusses various types of CO_2 capture systems without delving into further details. CO_2 capture technologies can be categorised into absorption-based processes and adsorption-based processes.

Absorption-based processes

Solvent-based CO_2 capture processes are based on the fundamental principle of selective absorption of CO_2 over the other gaseous constituents. The CO_2 present in the feed/process gas is first selectively absorbed in an absorber using a solvent (physical or chemical); the CO_2 lean gas exits the absorber. Next, the CO_2-rich solvent is sent to a stripper-type configuration where the CO_2 is released from the solvent, and the lean solvent is regenerated for reuse. Thereafter, the CO_2-rich stream is purified, dehydrated, and compressed to raise the pressure to the required level, depending on the end-use or disposition pathway for the captured CO_2. Solvent-based CO_2 capture technologies are further categorised based on whether the CO_2 reacts with the solvent chemically (chemical solvents and chemical absorption) or dissolved physically (physical solvents and physical absorption).

Adsorption-based processes

In the adsorption-based CO_2 capture process, the CO_2 molecules selectively adhere to the surface of the adsorbent material and form a film. The adsorption phenomenon is due to the difference in diffusivities and heat of adsorption values of different constituents of the feed gas. The working principle of adsorption-based CO_2 capture can be described in three primary steps: (a) CO_2 adsorption on the surface of the adsorbent material, (b) Diffusion of other gaseous molecules through the adsorbent material, (c) CO_2 desorption from the adsorbent material by either decreasing or increasing pressure or temperature.

If pressure is changed to desorp CO_2, the process is known as Pressure Swing Adsorption (PSA). Alternatively, if the temperature is changed to desorp CO_2, the process is termed Temperature Swing Adsorption (TSA).

9.5.2. CO_2 Capture Technology Suitability for Indian Steel Sector

The cost of carbon capture strongly depends on the CO_2 concentration in the flue gas. A higher concentration of CO_2 implies a lower capture cost. Given this background, it would be important to identify potential sites within an ISP for locating the carbon capture unit. Table 9.3 indicates the gaseous emission from various emission points data in integrated steel plants viz coke oven furnace, blast furnace, basic oxygen furnace, etc. The data is obtained from major steel plants in India for various locations. It can be seen that blast furnaces have a CO_2 concentration of 17 – 23% and are best suited for installing carbon capture systems. Furthermore, in an ISP, the bulk of the CO_2 emissions can be attributed to the blast furnace. Therefore, it is envisaged that large-scale CO_2 capture systems will be installed at the blast furnace exit. Basic oxygen furnaces have a lower concentration range of 13 – 17%, while a coke oven gas has a range of 2 - 3.2%.

Considering these compositions and partial pressure requirements of various carbon capture solvent technologies[9], amine-based solvent technologies are deemed the most suitable for the Indian steel Industry. Table 9.4 presents an overview of technology developers, the exact solvent, key differentiating factors and the technology readiness levels of such solvent technologies.

Table 9.3: Flue Gas composition and parameters in representative Indian steel plants

Company			JSPL		Tata Steel Limited			SAIL		
Parameters			Basic Oxygen Furnace (BOF)	Blast Furnace (BF)	Coke Oven Gas (COG)	Basic Oxygen Furnace (BOF)	Blast Furnace (BF)	Coke Oven Gas (COG)	Basic Oxygen Furnace (BOF)	Blast Furnace (BF)
Physical parameters										
i	Flow rate	Nm3/hr	30,000	6,00,000	3,40,000	1,25,000	1,25,000	63,943	3,244	3,95,819
ii	Temperature	0C	<35	<35	30-35	30-35	30-35	-	-	-
iii	Pressure	mmWC	1,200	1030	800-1,000	1,500-1,600	200-350	-	-	-
iv	Particulate	mg/Nm3	11	10	-	05 - 20	07 - 20	-	-	-
v	Calorific value	kcal/ Nm3	1,800	900	4,000-4,200	1,700-1,800	800-1,000	4,000-4,400	1,550-2,000	790-955
Gas Composition										
i	CO_2	% v/v	15-17	20-23	2.8 – 3.2	13.0 – 15.0	17.0 – 19.0	2.0-2.3	15	17-18
ii	CO	% v/v	65-70	20-24	8.8 – 9.0	50.0 – 70.0	21.0 – 25.0	7.7-8.1	50-70	26.5- 28.0
Iii	CH_4	% v/v	-	-	21.0 – 23.0	-	-	24.0-24.4	-	-
iv	H2O	% v/v	-	7-7.5	-	-	-	-	-	-
v	H2	% v/v	1.5	03 - 06	53.0 – 55.0	2.0 -3.0	3.0 -6.0	58-59	2 - 3	3 - 6
vi	O2	% v/v	0.2	-	0.2-1.0	0.4-1.2	-	0.4-0.5	0.4-1.2	-
vii	N2	% v/v	13-15	43-47	Balance	-	Balance	4.6-5.0	15	50-51
viii	H2S	gm/Nm3	-	15	2500	-	-	2500	-	-
ix	NH3	gm/Nm3	-	-	40-300	-	-	40-300	-	-
x	CnHm	%v/v	-	-	2.0 – 3.0	-	-	1.8-1.9	-	-

Table 9.4: *Amine based CO_2 capture technologies that are suitable for the Indian steel industry*

Sr. no.	Technology Owner	Solvent	Key Differentiator	TRL
1	Air Liquide	Amine blend and activators	Low energy required (~2.5 GJ/t CO_2)	9
2	ION Clean Energy	Amine with an organic solvent	Low energy required (~2.5 GJ/t CO_2)	6
3	Kansai Mitsubishi	Hindered amine	High CO_2 purity (~99.9%)	6
4	Carbon Clean Solution	Tertiary Amine	Low solvent degradation	8
5	Honeywell UOP	Amine Guard	High thermal & chemical stability	9
6	Baker Hughes	Ammonium/ Ammonia carbonate	High pressure stripping possible	7

9.5.3. Cost of CO_2 capture

The capital costs and operation costs of different carbon capture technologies depend on the CO_2 source characteristics, i.e., pressure and CO_2 concentration, which mainly determine the choice of carbon capture technology. Additionally, the cost of capture also depends on the cost of consumables like steam and electricity and the scale of deployment. Figure 9.4 shows the relation between the carbon capture cost and the CO_2 concentration in the flue gas, as per IEA. It is seen that the capture cost increases exponentially below a certain concentration of 15-20%. The CO_2 concentration in the iron and steel units is at the inflection point below which the cost increases significantly. Nevertheless, the low concentration of CO_2 in the iron and steel units will be a challenge from the perspective of CO_2 capture cost.

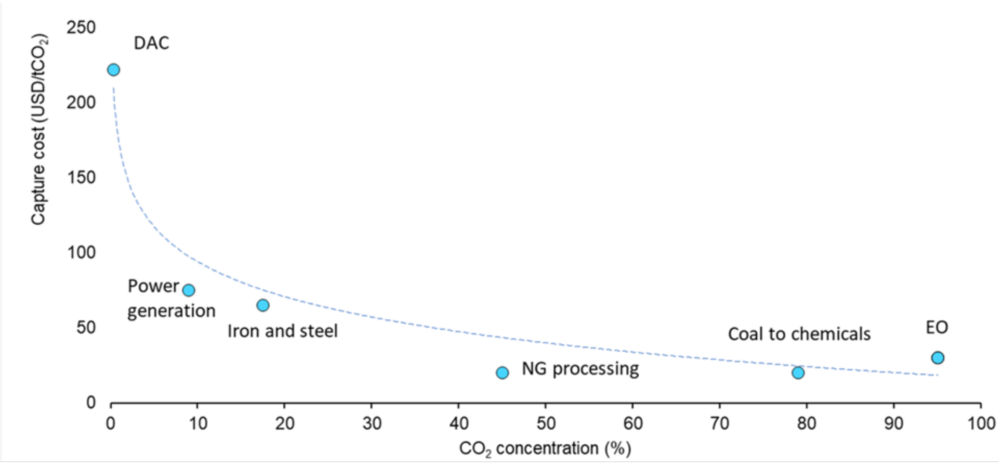


Figure 9.4: *Levelized cost of CO_2 capture by sector and initial CO_2 concentration[10]*

**Figure modified to match Indian context*

Note: NG = natural gas; EO = ethylene oxide; DAC = Direct air capture

It is seen that the costs indicated in Figure 9.4 are slightly higher than those indicated by the industry and listed in Table 9.1. Internationally, the cost of CO_2 capture is around 50 USD/ton, which is expected to reduce to 30 USD/Ton CO_2 by FY 2030-31 and subsequently stabilise at around 20 USD/Ton CO_2. Table 9.5 lists key operational and cost parameters of the 20 TPD carbon capture unit at NTPC, Vindhyachal plant. Steam and electricity are the major consumables for the CO_2 capture unit. Further, costs are also incurred for maintaining the plant.

Table 9.5: Key operational factors used to calculate cost of CO_2 capture for NTPC, Vindhyachal Plant

Sr. no.	Particulars	Unit	Value
1.	CO_2 Production Capacity	TPD	20
2.	CO_2 Plant Operation	days/year	330
3.	Sp. Steam Consumption	tonne/tonne CO_2	1.29
4.	Sp. Electric Consumption	kWh/tonne CO_2	117.6
5.	Sp. Solvent Consumption	kg/tonne CO_2	0.204
6.	Cost of Steam	INR/kg	0.36
7.	Cost of Electricity	INR/kWh	1.41
8.	Cost of Solvent	INR/kg	650
9.	Project Cost (20 TPD Plant)	INR lakhs	1500
10.	Equipment Cost (20 TPD Plant)	INR lakhs	1113
11.	Annual Fixed Cost	% of project cost	5%
12.	Annual Fixed Cost	INR lakhs	75

Figure 9.5 shows the cost build-up for 20 TPD plants set up by NTPC at its plant. For the 20 TPD size of the CO_2 capture plant, the total capture cost works out as approximately INR 2.74/Kg CO_2, i.e., approximately USD 35/Ton CO_2 – which is likely to decrease in a higher capacity unit due to economy of scale. It is seen that the capital cost for a carbon capture unit is lower than the operation and maintenance (O&M) cost. Therefore, further technology development is needed to reduce the O&M expense for a CO_2 capture unit.

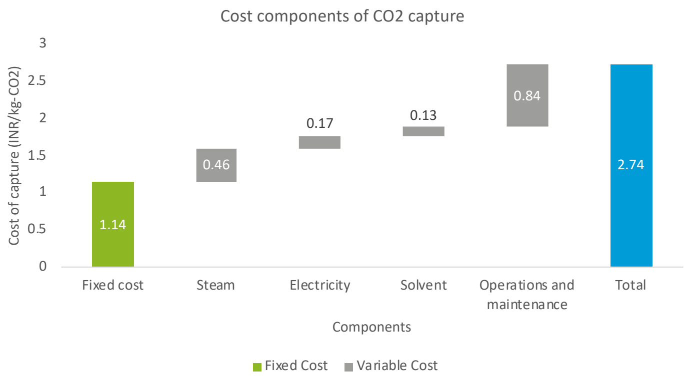


Figure 9.5: Cost build-up of CO_2 capture costs

9.5.4. Technology gaps and R&D opportunities in CO_2 capture technologies

Table 9.6 lists the gaps in technology that need to be bridged across solid and chemical type CO_2 capture systems. It also highlights the opportunities for R&D in the country.

Table 9.6: Gaps in CO_2 capture technologies

Sr. no.	Technology	Technology (Sub-type)	Technology Gaps	R&D Opportunities
1	Solid Adsorbent	Temperature Swing Adsorption	Poor efficacy with lean CO_2 concentration	Novel adsorbent architecture – it can quicken the process by 40-100 times
		Pressure Swing	Low energy required (~2.5 GJ/t CO_2)	6

2	Chemical Solvent	• Moderate energy intensity • Solvent life • Tolerance level with industrial SOx and other gaseous effluent	Advanced MOF (Metal Organic Framework) – exponentially high surface area

9.6. Carbon capture and utilisation technologies

The carbon capture and utilisation (CCU) pathway presents a strategic avenue for capturing emitted CO_2 and converting it into viable products to reduce India's import dependency. The process generally entails the capture of CO_2 from either point sources or direct air capture methods and then combining it with additives to generate valuable chemicals, fuels, and commodities within a processing facility. Firstly, captured CO_2 can be directly employed in sectors such as refineries and the food and beverage industries. Alternatively, it can serve as a raw material for producing various synthetic alternatives to chemicals derived from fossil fuels, thus being used in chemicals and fuel production. Additionally, CO_2 can passively be stored through mineral carbonation. Figure 9.6 summarises the various CCU applications. In addition to these utilisation pathways, CO_2 from the steel industry can be recycled by converting it to syngas, which can be used as a reductant.

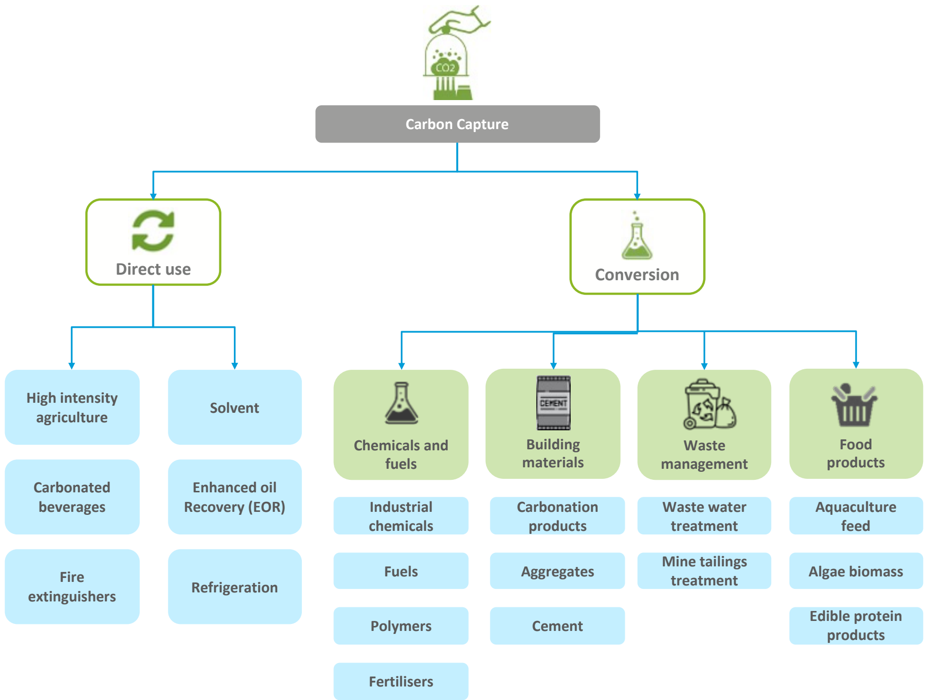


Figure 9.6: CO_2 utilisation pathways

Not all CCU applications are expected to be equal in terms of the cost of CO_2 abatement, and the amount of CO_2 abated, necessitating a strategic approach to choosing and deploying applications most suited to India's steel industry. There is a need to account for the differences in the cost of technologies vis-a-vis incumbent processes of producing these materials, technology readiness levels, and applicability in the steel industry. Table 9.7 compares various CCU applications across a set of criteria. It can be seen that most CCU applications are at TRL 6-8, and almost all applications need CO_2 purity exceeding 99%. Therefore, carbon capture, through which high concentration CO_2 stream is obtained, must be utilised across various pathways, as indicated in Table 9.7. A brief discussion on various CCU applications is done in sections 9.6.1 – 9.6.4.

Table 9.7: Comparative parameters of CCU pathways

Product(s)	Carbonates / Polycarbonate	Polypropylene carbonate	CO / Syngas	Methanol	Methanol	Methanol, DME	Ethanol / SAF	Precast Concrete	Aggregates/ Concrete	Carbon-negative Precast Concrete	SAF
Technology Type	Catalytic	Catalytic	Electro-chemical	Photo-chem	Thermo-catalytic	Thermo-catalytic	Gas fermentation	Curing for Precast Concrete	Mineral carbonisation	Mineral carbonisation	Thermo-catalytic
Current TRL	9	9	6-7	6-7	7-8	7-8	9	7-8	6-7	6-7	5-6
Technology Provider	Asahi Kasei	Saudi Aramco	Halder Topsoe, H2E, Twelve	Syzygy Plasmonics	Johnson Matthey, Haldor Topsoe, CRI	Toyo Engineering	Lanza Tech	Carbon Cure	Carbon8, Greenore Cleantech	Carbicrete	Honeywell, Ineratec, Synhelion, Infineum
Max current scale (TPA)	38k (Ethylene Carbonate) 70k (Dimethyl carbonate) 150k (PolyC)	5k	Piloting				90k	Piloting			

Product(s)	Carbonates / Polycarbonate	Polypropylene carbonate	CO / Syngas	Methanol	Methanol	Methanol, DME	Ethanol / SAF	Precast Concrete	Aggregates/ Concrete	Carbon-negative Precast Concrete	SAF
Input CO_2 purity, min, %	>99%						85%	>99%			
Additional raw material / catalyst inputs	Epoxide / Methanol	Epoxide	Water	Water	H2	H2	H2-	Ready mix concrete	Metal halides (Mg, Ca)	Steel Slag	H2
Restricted impurities	Sulphur, heavy metals (oxides)										
CO_2 conversion (%)	17.3	43	Not Known				95	Unspecified high			Not known

9.6.1. Carbon utilisation technologies - Carbonates

Out of all CCU options, two technologies for organic carbonates derived from industrial-scale reactions of carbon dioxide with lower alcohols and bisphenol have been established commercially. Since commercialising the world's first process to manufacture polycarbonate (PC) from CO_2 as feedstock at Chimei-Asahi Corporation in Taiwan in 2002, Asahi Kasei has licensed the technology to 6 companies in 5 countries with a total annual production capacity of approximately 900 KTPA of PC, equivalent to approximately 16% of the world's overall PC production capacity of approximately 6 million tons per year. Asahi Kasei has since extended the technology to produce high-purity ethylene carbonate (EC) and high-purity dimethyl carbonate (DMC), the first license was announced in 2021 but has not yet been commissioned. Each ton of carbonate by the Asahi Kasei process utilises almost 0.5 tons of CO_2, depending on the product made. As polycarbonates and solvent carbonates are imported into India, and the demand for solvent carbonates is growing fast because of Li-ion batteries (LIB), this may become a proven priority option for India's steel sector.

In 2016, Aramco completed the acquisition of "Converge" CO_2 -to-polyols technology from Novomer as part of the "Saudi Vision 2030" diversification and job creation drive with an added focus on sustainability. The Novomer technology produces polypropylene carbonate (PPC) polyols from waste CO_2 for use in higher-end coating, adhesive, sealant and elastomer applications, with flexible and rigid polyurethane foam at the forefront. Saudi Aramco plans to manufacture and market the polyols containing up to 50% CO_2 by mass along with "associated products," using a proprietary catalyst and drawing on its "abundant hydrocarbon feedstocks." The products are claimed to have about a third of the carbon footprint of conventional polycarbonate polyols. The plant capacity of various PPC-Polyols is estimated to be about 5 KTPA. This may also be considered seriously as PPC-Polyol capacities in India are dependent mainly on imported propylene oxide and propylene glycol.

9.6.2. Carbon utilisation technologies-Methanol/Dimethyl ether

The Methanol/DME pair of molecules represents an important fuel/chemical intermediate option for decarbonising India and reducing the import bill. It is estimated that approximately 330 MMT of fossil fuel (coal, petroleum, natural Gas) were imported into India in 2022, down from approximately 350 MMT in 2018. The reduction came mainly from the increasing use of domestic carbon resources (Ethanol, CBG) and lower dependence on fossil power (solar, wind growth in electricity generation).

CO_2 -to-methanol/DME technologies are reported at advanced pilot scales (TRL 7-8) by thermo-catalytic processes offered by a variety of internationally credible licensors, including Johnson Matthey, Haldor Topsoe, CRI and Toyo Engineering. The approach typically involves a Reverse Water Gas Shift Reaction (RWGS) followed by syngas conversion. There are also a series of efforts in progress within India, albeit at lower TRLs, notably involving NTPC and GAIL. While NTPC is focused on CO_2-to-methanol, GAIL has invested in developing dry reforming and tri-reforming processes that co-utilise CO_2 and methane, an even more potent GHG. These may be encouraged to achieve specific targets at pilot or demo scales benchmarked against the aforementioned international processes close to maturity.

DME, a zero-soot fuel, is a molecule of significant interest as it can be deployed for domestic cooking as an alternative to or in partial blend with LPG, a relatively clean-burning fossil fuel pivotal to women and child health but whose demand far outstrips domestic production capacity. Supply chains that envisage methanol pipelines or tanker fleets at the output of a CCA plant can be coupled to modular methanol-to-DME units co-located with LPG bottling plants.

Methanol-to-DME process technologies are available from a range of international licensors; CSIR-NCL is scaling up a domestically developed process to 2.5 TPA with assistance from CHT (MoPNG), IOCL and EIL.

9.6.3. Carbon utilisation technologies-CO_2 to acetic acid, lipids, ethanol and other oxygenates

There has been increasing global interest in direct conversion technologies for CO_2 to oxygenates, notably ethanol. The Department of Biotechnology (DBT) - Indian Oil Corporation Ltd (IOCL) Bioenergy Centre at Faridabad, Haryana, has announced a CO_2 -to-acetic acid-to-lipids pilot plant of 100L per day in partnership with LanzaTech, Inc. This will capture around 10 kilograms of carbon dioxide daily. LanzaTech, using its proprietary anaerobic gas fermentation process, will convert carbon dioxide to acetic acid, which will be subsequently converted into lipids. It will be able to produce around 700 grams of Omega 3 fatty acids suitable for nutritional applications or 700 grams of lipids suitable for biodiesel.

India is a lipid-deficit country, with current import levels of edible oils estimated at over 14 MMT per annum, over and above domestic edible oil production of ~11 MMT. Domestic production of non-edible lipids for industrial use, dominated by castor oil, is estimated to be less than 2.5 MMT. This deficit has also constrained the growth of lipid-based fuels, such as biodiesel and sustainable aviation fuel. Similarly, India is also the world's largest importer of acetic acid, with recent estimates indicating a domestic supply shortfall of nearly 1 MMT with an annual forex outflow of about USD 1 billion. Rapid scale-up of the IOC-DBT-LanzaTech process, therefore, offers significant economic potential coupled with decarbonisation.

LanzaTech's original patented technology, based on microbial gas fermentation, is designed to primarily utilise CO and hydrogen to produce ethanol, with 2,3-butanediol, a platform chemical, as a co-product. The process, however, has the unique ability to use up to 85% impure CO_2. Further, LanzaTech has demonstrated the conversion of H2 and CO_2 to ethanol through this same route, enabling broader use of CO_2 streams from industry. BFG (Blast Furnace Gas) and BOF Stack Gas may be amenable streams for this technology. In addition to four operating commercial plants in China, LanzaTech has one reference commercial plant owned and operated by ArcelorMittal at Ghent in Belgium. This 'Steelanol' plant has the annual capacity to produce 80 million litres of ethanol and is expected to reduce carbon emissions from the Ghent steel mill by 125 KMT annually.

9.6.4. Carbon recycling technologies – Reintroduction in ore reduction process

Recycling CO_2 involves the conversion of CO_2 into carbon monoxide through the reverse water gas shift reaction or any other technology, like solid oxide electrolysers, in the form of syngas. The CO/ syngas thus generated plays a pivotal role in steel production as a reducing agent, specifically in the production of Direct Reduced Iron (DRI). This is schematically illustrated in Figure 9.7. Since the CO_2 is reintroduced for reduction, this recycling process reduces the need for external reducing agents like coal and coke, effectively reducing the overall carbon footprint of DRI production. By recycling a certain amount of CO_2 within the process, the technology mitigates emissions that would otherwise contribute to the emissions. CO as a reductant can be introduced in conventional blast furnaces and in vertical shaft furnaces. Challenges to deploying this technology, which is at TRL 5-6, are reducing the energy requirement for the conversion of CO_2 to CO, developing a stable and suitable catalyst, and redesigning process flows that enable introducing CO into the reduction step. The Ministry is supporting research in this domain. In collaboration with JSPL, researchers from IIT Bombay are developing an electrocatalytic CO_2 to CO conversion technology, an energy-efficient, enzyme-inspired technology.

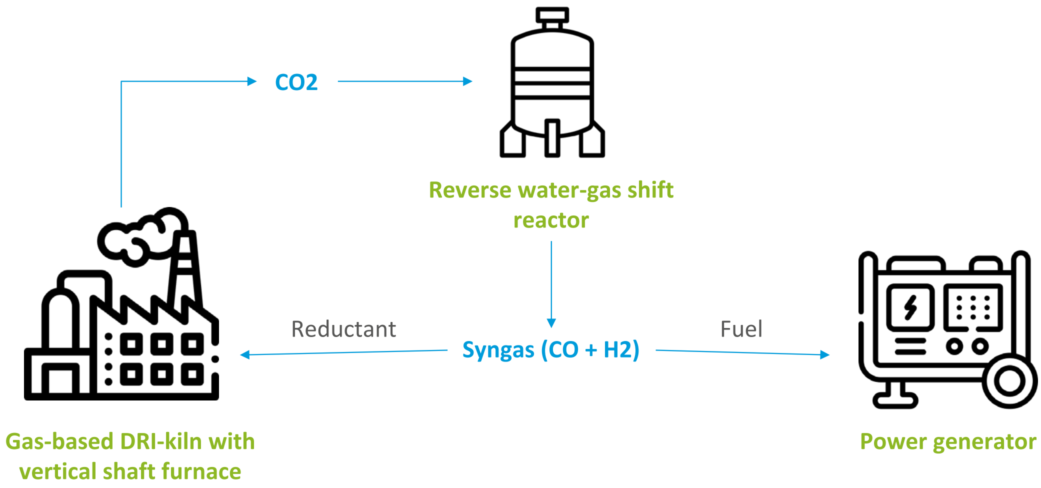


Figure 9.7: *Schematic representation of carbon recycling pathway*

9.6.5. Techno-economic comparison of CCU pathways

Most CCU technologies discussed in this section are at lower TRL levels. Therefore, there is no market for fuels and chemicals obtained from CCU technologies. Consequently, there is a significant uncertainty in the cost of fuels obtained from these pathways. However, Table 9.9. provides a comparison of select pathways reported in the literature. This table indicates the cost of CCU products at a green hydrogen cost of USD 3/kg and a CO_2 capture cost of USD 46/tonne. It is seen that the cost of CO_2 mitigation is significantly higher due to the high cost of green hydrogen. Unless the cost of green hydrogen is reduced to acceptable levels and in the absence of mandates to procure CCU products, it is unlikely that CCU-based fuels and chemicals will achieve the economies of scale needed to accelerate the decarbonisation of the steel sector. However, a few applications such as carbonates, have significantly lower premiums than CCU-based fuels and chemicals. This is because producing carbonates does not need green hydrogen, which is available at a premium today. Nevertheless, it is expected that most CCU products will be available at a premium, which impedes its adoption in the steel industry.

Table 9.8: *Green premium and abatement cost comparison of select CCU pathways*[11]

Sr. no.	Parameter	Fossil-based product cost	Green product cost	CO_2 abatement cost (USD/t-CO_2)
1	Methanol (USD/tonne)	173	963	503
2	Electrofuels / jet fuel (USD/bbl)	59	319	508
3	Olefin (USD/tonne)	690	3090	506
4	SNG (USD/GJ)	6	37	553
5	Carbonates (USD/tonne)	28	51	42
6	Baker Hughes	Ammonium/ Ammonia carbonate	High pressure stripping possible	7

9.7. Carbon capture and Storage (CCS)

Decarbonising industrial sectors like cement, steel, chemicals, and other manufacturing has been an essential focus of CCS efforts. In contrast to CO_2 utilisation discussed above, CCS storage entails the injection of CO_2 underground to prevent its release into the atmosphere over geological timescales. The CCS value chain involves capturing CO_2 from industrial emissions, compressing it, and transporting it to a safe storage site, such as a deep saline aquifer or depleted oil and gas reservoir, as depicted in Figure 9.8. The state-of-the-art know-how on the deployment of CO_2 storage has advanced significantly in recent years, with several key projects worldwide demonstrating the technology's feasibility and scalability.

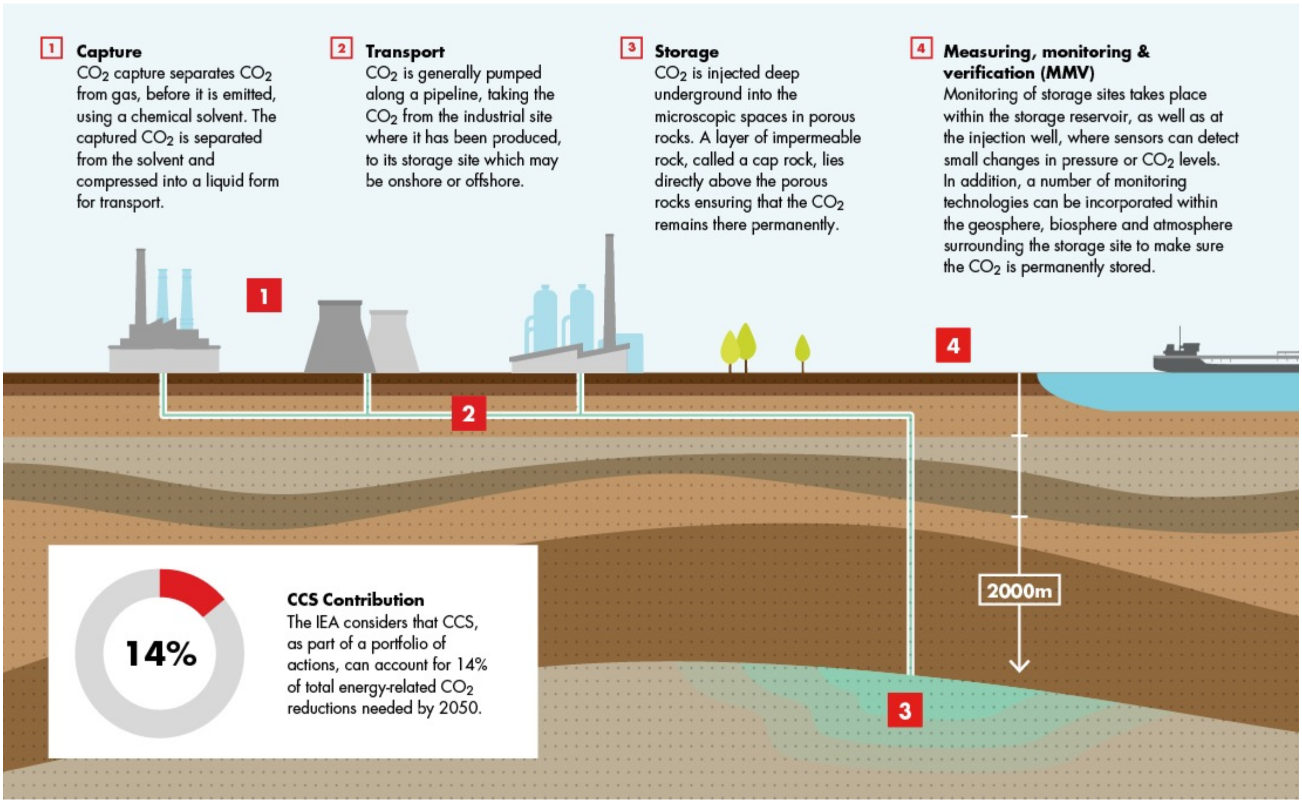


Figure 9.8: How does carbon capture and storage work?[12]

CO_2 storage started in the form of enhanced oil recovery (EOR) in the 1970s in several local basins, as shown in Figure 9.9. Nearly 425 MT of CO_2 has been stored via EOR. Moreover, 75 MT of CO_2 has been stored in saline aquifers, primarily in Norway. One of the most notable examples is the Northern Lights project in Norway, the world's first commercial cross-border CCS project. The project captures CO_2 from industrial facilities in Norway and transports it by ship to an offshore storage site in the North Sea. The project has been operating since 2022 and is expected to store up to 1.5 million tonnes of CO_2 annually. Another key example is the Petra Nova CCS project in Texas, USA.

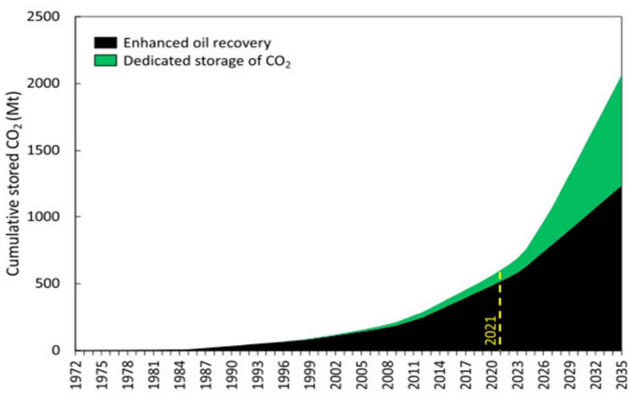


Figure 9.9: Volumes of historic and planned stored CO_2[13]

This project captures CO_2 from a coal-fired power plant and injects it for enhanced oil recovery. The project began operating in 2016 and has stored over 4 million tonnes of CO_2. While reduced crude oil prices led to its suspension from 2020-23, it has resumed operations recently.

CCS is also being employed in the steel industry. CO_2 captured from the Emirates Steel plant, in Abu Dhabi, UAE, is currently used in EOR operations. Annually, up to 800 kt of CO_2 is captured and injected into the Abu Dhabi National Oil Company's oil reservoirs. In addition to these large-scale commercial projects, several smaller-scale CCS projects are in operation or under development worldwide, as listed in Table 9.10. These projects are helping to test and refine different CCS technologies and to develop the necessary infrastructure and expertise for large-scale deployment.

Table 9.9: *Commercial CCS facilities worldwide by number and capture capacity*

Sr. no.	Commercial Status	Number of Facilities	Capture Capacity (Mtpa)	CO_2 abatement cost (USD/t-CO_2)
1	Operational	30	42.5	503
2	In construction	11	9.6	508
3	Advanced Development	78	97.6	506
4	Early Development	75	91.8	553
5	Operation Suspended	2	2.3	42
	Total	**196**	**243.9**	**7**

9.7.1. Source-sink matching and recommendations for pilot projects

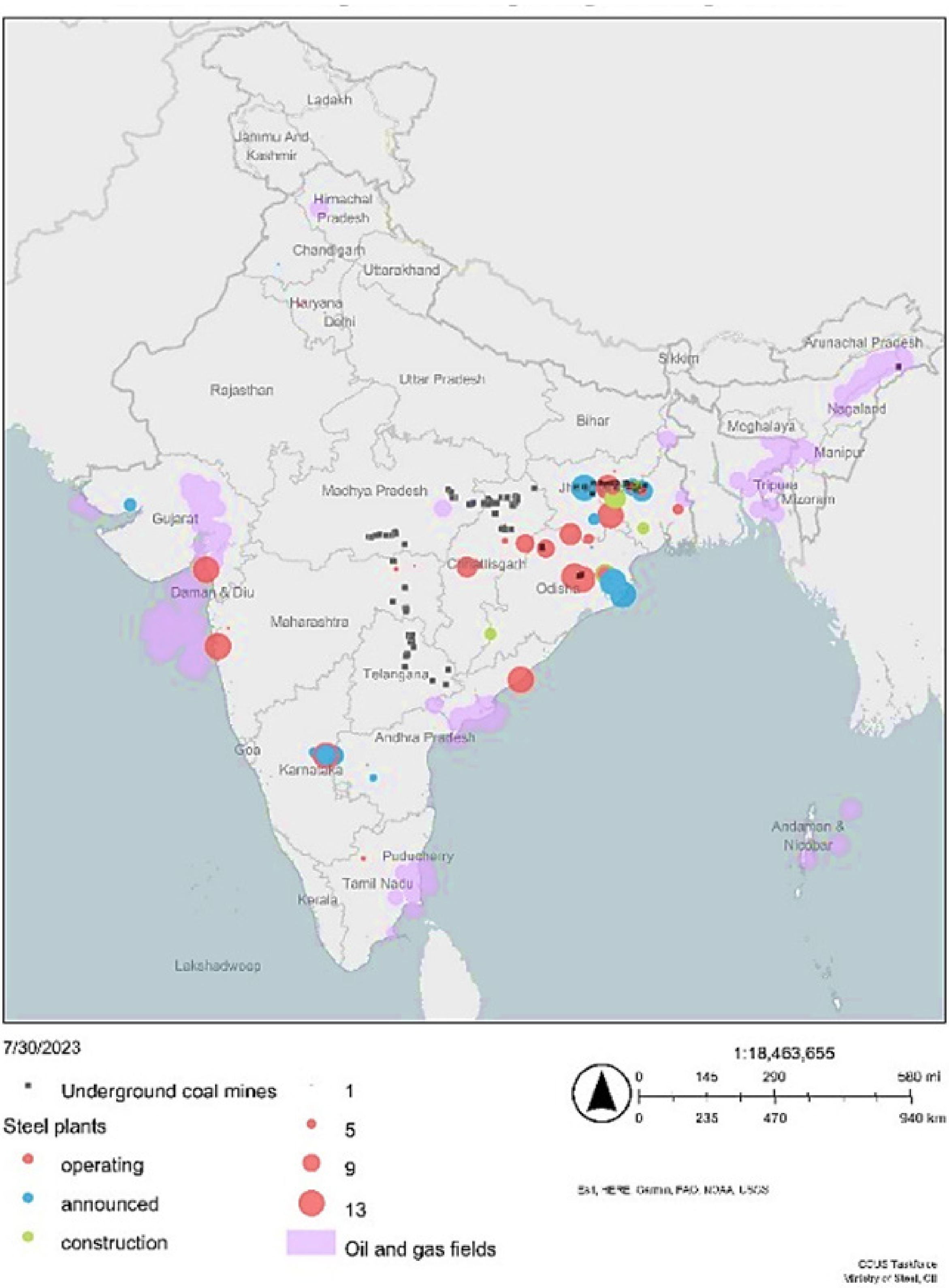
In India, the IEA projects that an estimated 53% of the emissions mitigation from the steel sector may come from CCUS[14]. Assuming that CCS accounts for half of this amount and the other half is contributed from CCU, the required sink capacity is roughly 4 Gt-CO_2 over 30 years of lifetime. The sinks can be depleted hydrocarbon fields, unminable coal seams, deep saline aquifers, and basalts.

The estimated theoretical potential in India is 395-614 Gt-CO_2[15], where saline aquifers consist of 291 Gt-CO_2 and basalt formations consist of 97-316 Gt-CO_2. Enhanced oil recovery (EOR) and enhanced coal bed methane recovery (ECBMR) represent relatively smaller storage potentials, 3.4 Gt-CO_2 and 3.7 Gt-CO_2 (Figure 9.4), but these have the potential to be the "first-mover" projects as EOR and ECBM are better understood than storing CO_2 in saline aquifers and basalts. The storage potential in saline aquifers must be re-evaluated to align with effective, viable and matched capacity. The current theoretical potential has large uncertainty because of the lack of exploration of aquifers beneath the depth of 800 m.

Table 9.11 provides a summary of CO_2 sink and steel plants in India. The steel plants in the table together constitute approximately 413 MT CO_2/year of estimated gross CO_2 emissions linked to existing and upcoming plants, while the available CO_2 sink capacity is significantly higher at 97 Gt. As indicated in Table 9.11, this 97 Gt corresponds to various types of CO_2 sinks like EOR, ECPMR and basalts. Therefore, the CO_2 sink near the existing steel plants is significant enough to meet the requirements of the industry. This can be verified by Figure 9.10, which provides the geographical distribution of steel plants juxtaposed with the locations of sinks. An extensive exercise in planning CO_2 pipelines is necessary to identify the most efficient paths to transport CO_2 from steel industry sources to nearby sinks.

Table 9.10: *Commercial CCS facilities worldwide by number and capture capacity*

Sr. no.	Region	Sink	Steel plants – existing and upcoming	Estimated gross emissions from existing and upcoming (Mt-CO_2 /year)	Available sink (Gt-CO_2) (theoretical potential)
1	Western – Gujarat, Maharashtra	Cambay basin (Gandhar basin EOR as early-mover)	Anjar (Welspun), Hazira (AMNS), Dolvi (JSW), Salav (JSW), Nagpur (Jayaswal Neco), Warthi (Sunflag)	82	16
2	Eastern – Jharkhand, West Bengal	Damodar basin (Jharia coalfield as early-mover); Bengal-Purnea basin	Patratu (JSW), Potka (JSW Bhushan Steel), Bokaro (SAIL), Bokaro (Electrosteel), Jamshedpur (Tata Steel), Patratu (JSPL), Burnpur (SAIL), Durgapur (SAIL), Kharagpur (Rashmi Metalliks), Purulia (Jai Balaji), Banskopa (Jai Balaji), Durgapur (Shyam Steel)	169	53
3	East Central – Chhattisgarh and Madhya Pradesh	Sohagpur coalfield as the early mover; Vindhyan basin for dedicated storage	Bhilai (SAIL), Raigarh (JSPL), Raipur (Jayaswal Neco), Raipur (JSW Ispat)	74	12
4	Southern – Karnataka	Deccan basalts; Cauvery basin	Bellary (NMDC), Hospet (Kalyani Steels), Koppal (Xindia Steels), Vijaynagar (JSW),	88	16
Total				**413**	**97**


Ladakh
Jammu And Kashmir
Himachal Pradesh
Chandigarh
Uttarakhand
Haryana
Delhi
Rajasthan
Uttar Pradesh
Sikkim
Arunachal Pradesh
Nagaland
Meghalaya
Manipur
Bihar
Tripura
Mizoram
Madhya Pradesh
Gujarat
Chhattisgarh
Odisha
Daman & Diu
Maharashtra
Telangana
Andhra Pradesh
Goa
Karnataka
Andaman & Nicobar
Puducherry
Tamil Nadu
Kerala
Lakshadweep
7/30/2023
Underground coal mines
Steel plants
operating
announced
construction
1
5
9
13
Oil and gas fields
1:18,463,655
0
145
290
580 mi
0
235
470
940 km

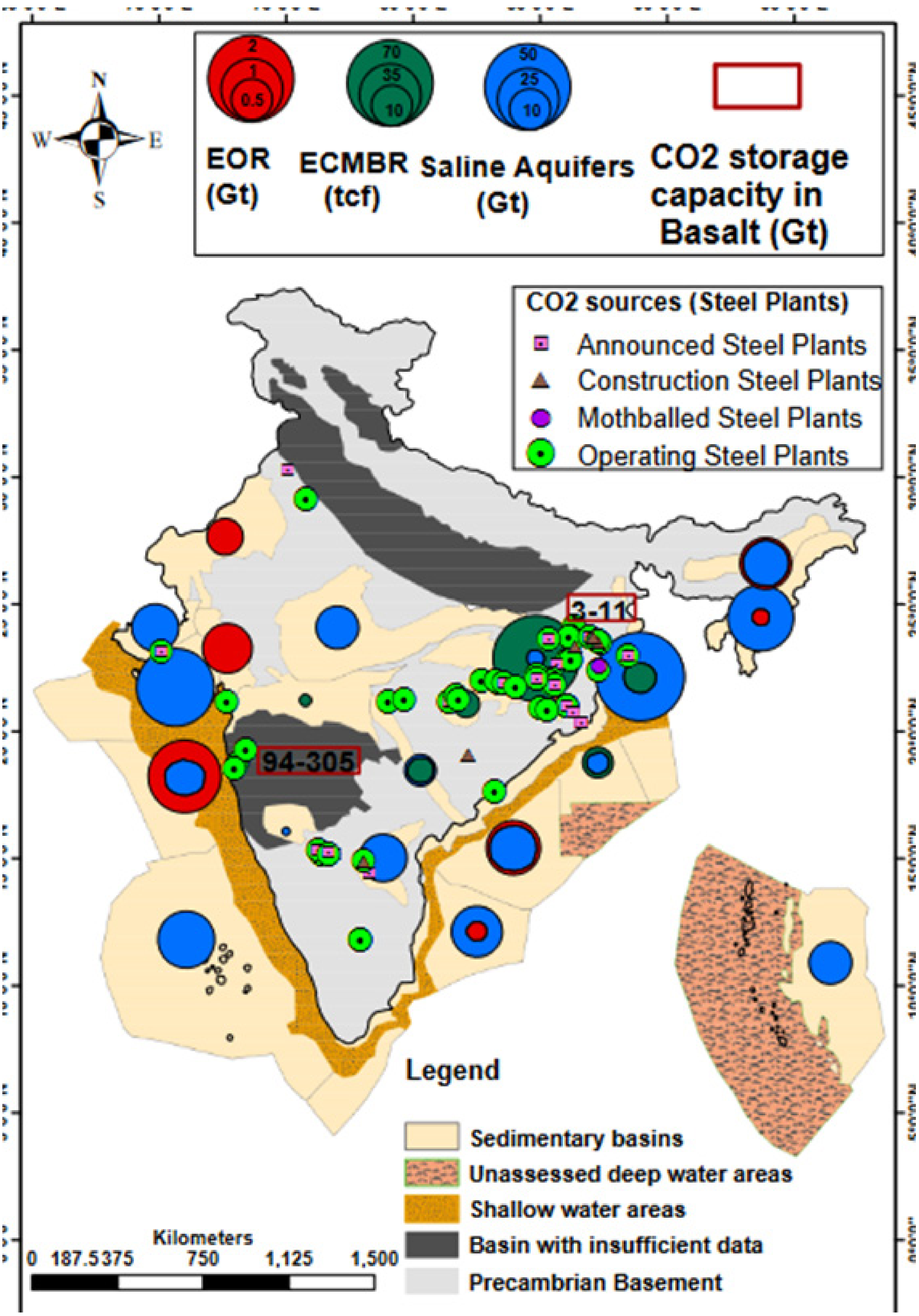


Figure 9.10: *Distribution of steel plants in India along with potential storage sinks.*

9.7.2. Enhanced coal bed methane recovery (ECBMR) potential

As discussed above, the total CO_2 storage potential in ECBMR is 3.7 Gt. However, significant uncertainty exists in the CO_2 storage potential in ECBMR, and the identified potential is most likely a conservative estimate as all the coking coal reserves and most semi-coking coal reserves were considered mineable when estimating the CO_2 storage potential. In addition, certain patches within well-delineated coalfields spanning an area of approximately 37,000 square kilometres, extending beyond the limits of regional exploration of coal and potential mining operations (in Jharkhand, West Bengal and Chhattisgarh). Besides the grey area coalfields, some concealed coalfields also exist in Rajasthan, Gujarat and Assam, wherein thick coal seams at depths beyond 1,000 m have been found. Preliminary investigation shows that they have considerable CO_2 storage potential. However, these coal reserves are not a part of the GSI inventory process as they have instead been encountered during oil, gas and CBM exploration. A robust estimate of total CO_2 storage potential in ECBMR can be developed only after accounting for these uncertainties.

Proposed cluster for pilot in ECBMR: The steel plants in Jharkhand and West Bengal cluster overlap with existing coal fields and provide an opportunity for the ECBMR project. As shown in Figure 9.11, the total emissions from the Jharkhand and West Bengal clusters offer the opportunity to store 1 Gt-CO_2. Besides the steel plants, many thermal power plants can provide CO_2 and reduce the cost of setting up the CCS cluster. Further, large ISPs in the area can act as a source of CO_2 that be stored in nearby coalfields. This is similar to the sequestration potential in all the coalfields (operational and grey areas).

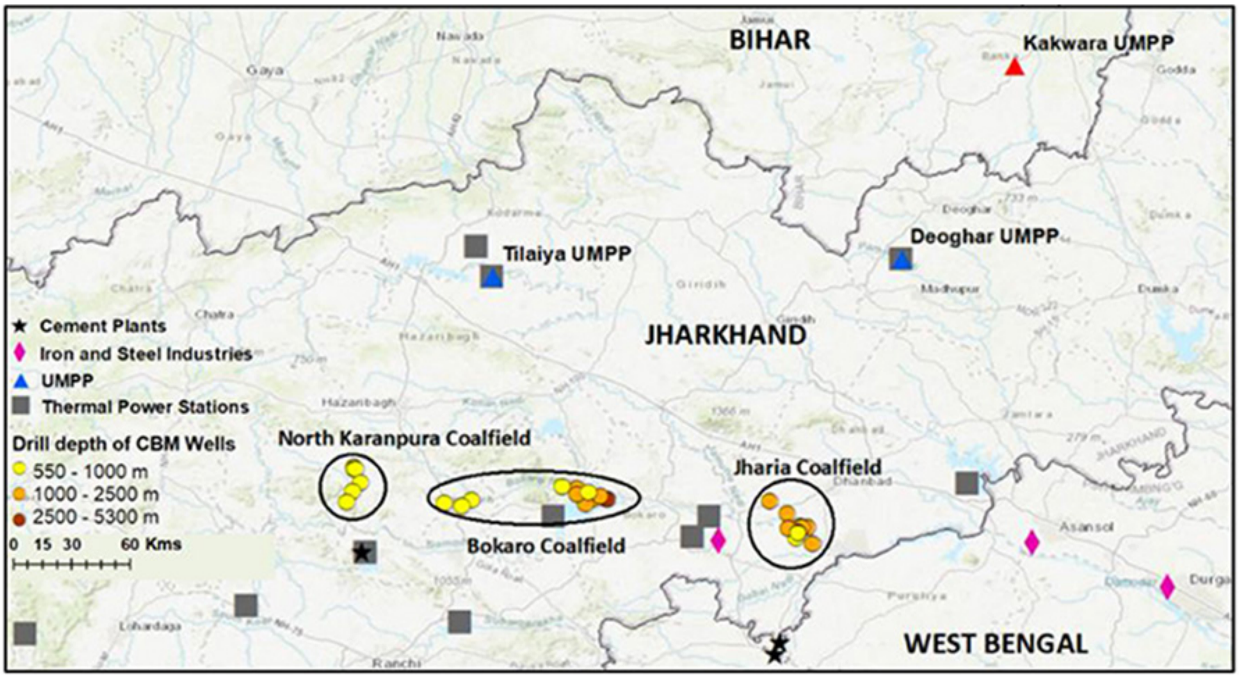


Figure 9.11: Proposed area for ECBM cluster in Jharkhand, with potential seams in West Bengal and Chhattisgarh

9.7.3. Enhanced oil recovery (EOR) potential

The Gandhar oilfield has been a primary prospect for a pilot CO_2 EOR project in the country. Several feasibility studies have been conducted in the field, and extensive exploration has been carried out in the area. The Oil and Natural Gas Corporation (ONGC) is formulating plans to initiate CO_2 injection operations from 2026-27. The source of CO_2 for this operation is proposed to be the Indian Oil Corporation Limited's (IOCL) Koyali Refinery, located approximately 85 kilometres away. Steel plants located in Gujarat and

Maharashtra may also be clustered and utilised for the EOR project as shown in Figure 9.12. The GGS-1 in the Gandhar oilfield is slated to be a major hub for these operations.

The proposed project boasts a substantial capacity of nearly 1500 metric tons of CO_2 per day. This indicates a significant scale of operation and potential impact on CO_2 management. The reservoirs within the Gandhar oilfield exhibit favourable characteristics for injection operations. Their porosity range is 16–20 %, and an average permeability is 200-300 mD. These parameters suggest promising

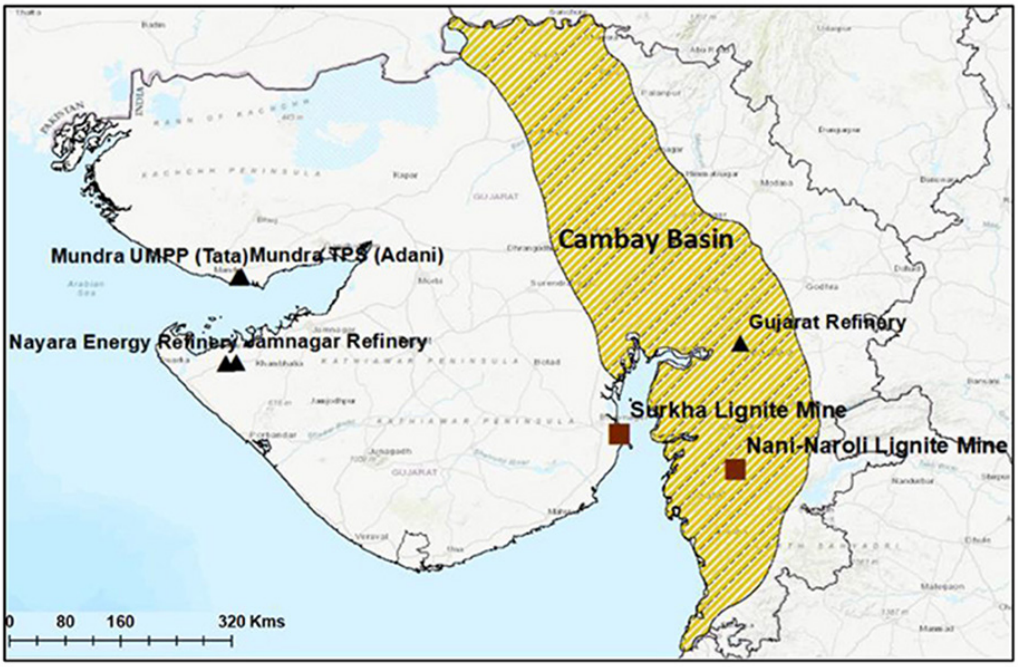


Figure 9.12: Proposed area for EOR cluster and a potential pilot project in the Cambay basin.

9.7.4. Basalt potential

Transforming CO_2 into minerals underground presents a natural and permanent storage solution. This transformation occurs when carbonated water interacts with underground basalt rocks, instigating the release of calcium, magnesium, and iron ions into the water stream. Over time, these cations react with the dissolved CO_2 to form carbonates. These carbonates subsequently fill the pores within the rocks, resulting in the permanent sequestration of CO_2. Basalt rocks are particularly suited due to their high reactivity and composition, which contain the necessary elements for the permanent solidification of CO_2, a process known as mineralisation. Additionally, these rocks are fractured and porous, providing ample storage space for the mineralised CO_2. Basalt is also the most common rock type on the Earth's surface, making it a readily available resource for this process.

Several projects have explored this method of CO_2 storage. The ongoing Carbfix Project at the Hellisheiði geothermal power plant in southwest Iceland began as a pilot in 2012 with 230 tons of CO_2 and has since scaled up to capture over 12,000 tons of CO_2 annually. The now-inactive Wallula Project involved injecting of 1,000 tons of pure liquid CO_2 into Columbia River flood basalts near Wallula, Washington.

In India, specific regions in the west, especially in Gujarat and Maharashtra, have been identified as potential sites for this process, as shown in Figure 9.13. However, there is a need to demonstrate the feasibility of CO_2 sequestration in Indian basalts to bring confidence in pilot projects.

Figure 9.13: Potential area for CO_2 sequestration in the basalts (Deccan Volcanic Province)

9.7.5. Timelines

Injecting CO_2 across different reservoir types depends on multiple technical and governance-related factors. A key challenge with CCS projects is the amount of time required from conceptualisation to actual injection in the reservoirs. Table 9.12 shows the timelines for various CCS projects in the world. It is seen that the CCS projects can take anywhere between 7 years to 21 years to materialise.

Table 9.11: Lead time for CCS projects world wide[16]

Sr. no.	Project	Country	Storage type	Injection (Mt/year)	Time taken from conceptualisation (years)	Status of capture potential (Mt/year)
1	Gorgon	Australia	Saline aquifer	2.3	21	3–4
2	Snohvit	Norway	Saline aquifer	0.7	17	0.7
3	Quest	Canada	Saline aquifer and EOR	1	10	Exceeded target while lowering costs
4	Uthmania	Saudi Arabia	EOR	0.8	9	–
5	Carbfix	Iceland	Basalt	0.04	7	
6	Wallulla	USA	Basalt	IGCC/Pre-combustion	8	Pilot project, currently non-operational

Based on the global experience, Table 9.13 identifies the expected timeline for CCS project in India. It should be noted that these timelines depend on multiple aspects like the type of reservoir, well economics, the region where the injection is to take place, time taken for clearances, and infrastructure.

Table 9.12: *Typical timeline for establishing a CO_2 storage project*

Timeline	Activities	Scale
Year 1 – Year 2	• Site identification • Geological screening and theoretical storage potential • Geochemical and geophysical lab tests • FEED • Reservoir modelling, site-specific lab experiments, techno-economic assessment, legal and permitting	-
Year 2 – Year 3	• FEED, Permits, logistics, pilot injection system design	-
Year 4 – Year 5	• Drilling of pilot • Construction of pilot injection system	-
Year 5	• Pilot injection operation and validation of reservoir	500 t-CO_2
Year 5 - Year 6	• Implementation of Injection system	100 kt-CO_2 /year
Year 6 – Year 9	• Full injection and CO_2 storage operation. • Continuous scaling up injection capacity through drilling new wells	Gradually upto 1 Mt-CO_2 /year

9.7.6. Techno-economic assessment (TEA) of CCS

The cost of CO_2 storage in sedimentary basins exhibits a wide range, from USD 2/t-CO_2 to USD 37/t-CO_2 as shown in Figure 9.14. This range reflects the variability in geological and engineering factors, as evidenced by global datasets. A few CCS projects can also result in revenue generation. However, the revenue generated from the sale of products via EOR or ECBMR is contingent on several factors. These include the productivity of the reservoir (measured as the volume of product per tonne of CO_2 injected), the production and recycling of CO_2, and the injection strategy employed. Economic viability for EOR and ECBMR can be achieved with a minimum cost of USD 160/bbl for oil and USD 6/MMBTu for Coal Bed Methane (CBM)[17]. Incentives such as cess, royalty, and tax credits can significantly impact the economic feasibility of these processes. For instance, when these incentives are factored in, a minimum crude price of USD 80/barrel is required for successful EOR operations. Strategies such as reusing exploration wells for injection and developing hubs and clusters can play a crucial role in reducing system costs associated with CO_2 storage. The identification of suitable reservoirs for CO_2 storage should be prioritised to ensure the efficiency and effectiveness of these operations. All these factors can be analysed through the TEA framework depicted in Figure 9.15.

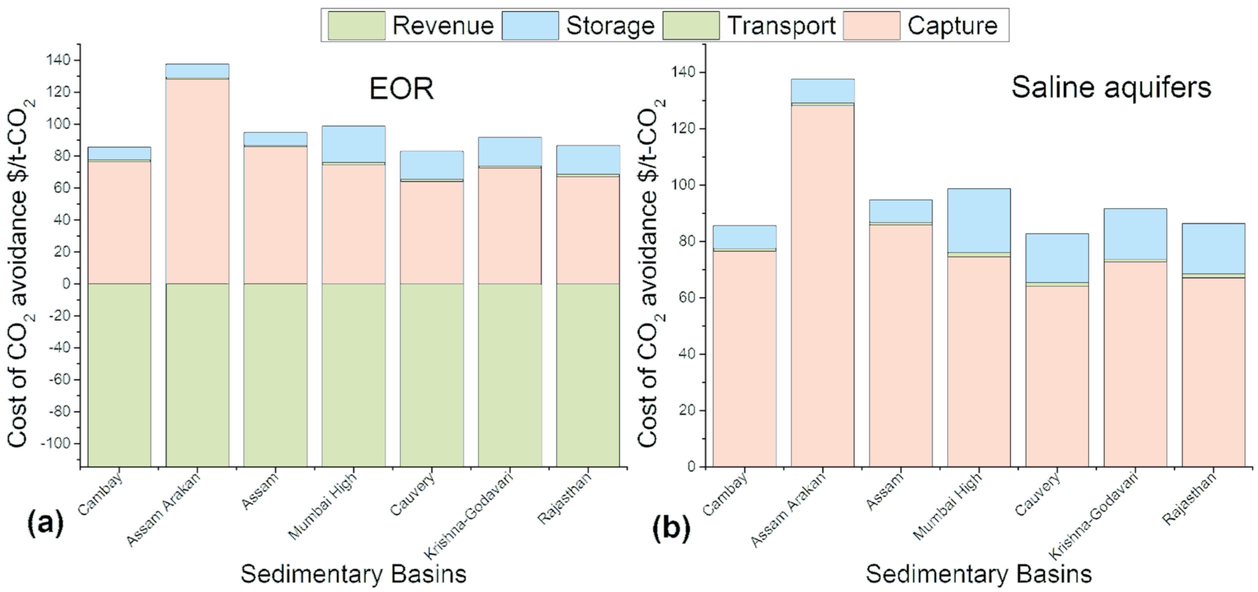


Figure 9.14: Cost of CO_2 avoidance for different sedimentary basins through storage and EOR17

ECBMR allows the steel industry to use CBM to produce iron by investing in shaft furnaces. This may be done at an investment of INR 6-8 crores (USD 0.8-1 million resulting in 20-25% fuel savings with a payback period of less than a year. An assured supply of CO_2 from steel plants can reduce the cost of CO_2 injection via economies of scale. At the same time, the steel industry can provide an assured market for the incremental CBM produced from CO_2 injection, thus de-risking such investments.

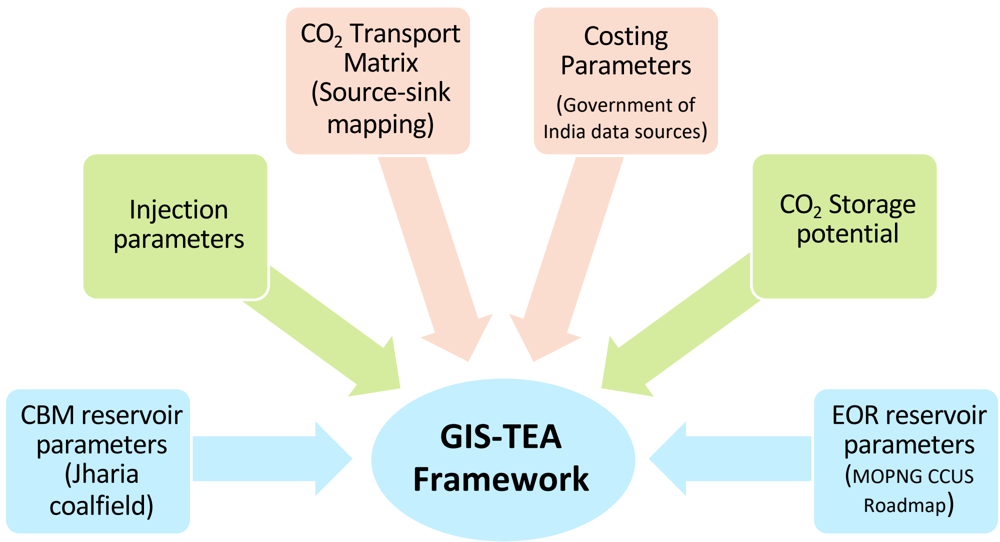


Figure 9.15: Techno-economic assessment (TEA) framework

9.7.6.1. Assessment for CO_2 ECBM

In the baseline scenario, the Enhanced Coal Bed Methane (ECBM) project demonstrates potential profitability at a pilot-scale level. Remarkably, it is projected to yield a net profit of INR 1604/t-CO_2 (USD 19/t-CO_2), even in the absence of governmental incentives. This profitability index is notably higher than the USD 6/tCO_2 benchmark established in the global context[18].

9.7.6.2. Assessment for CO_2 EOR

For the GS-4 reservoir (sink) in the Gandhar oilfield, the annual cost associated with CO_2 storage is estimated to be USD 45 million. This translates to a cost of USD 12.4 per metric ton of CO_2. This does not include the cost of capture, compression, and transport of CO_2.

9.7.7. Effect of CCUS on the price of steel

Deploying CCS involves significant capital expenditure. Table 9.14 shows the cost breakdown for different parts of the process. According to the literature, the cost of CCS for the steel industry is USD 64/tCO_2. The estimations from the International Energy Agency (IEA) show that 53%[19] of primary steel production by 2050 will need to be equipped with CCUS technologies while other literature sources show that for the BF-BoF steelmaking pathway alone, nearly 59% of emissions will need to be abated through CCUS, considering an emission intensity of 2.46 tCO_2/tcs[20]. Regarding the overall steel industry in India, 56 % will need to be abated through CCUS.

Table 9.13: *Estimated CCS cost breakdown*[21]

Sr. no.	Parameter	Current (USD/tCO_2)	Best case (USD/tCO_2)
1	Capture cost	37 (35 - 45)	20
2	Transport cost	7 (4 - 10)	4
3	Sequestration cost	20 (2 - 37)	2
4	Total CCS cost	64 (41 - 92)	26

The estimation of the increase in the cost of steel for various CCUS applications is summarised in Table 9.15. If the base price of steel produced through BF-BOF is taken to be USD 688/tcs and the cost of CCS is USD 64/tCO_2, the cost of steel increases by 14%, assuming that 59% of the total emissions are abated through CCS. However, if a lower cost range of CCS is taken as USD 26/tCO_2 with a capture cost of USD 20/ tCO_2, there is only a 5% increase in the price of steel. Therefore, the pace of CCS adoption will strongly depend on the cost, among other factors.

In the case of other CCU applications, as shown in Table 9.15, the increase in the cost of steel is the highest for the synthetic natural gas (SNG) pathway while the impact is similar in the case of methanol, sustainable aviation fuel (SAF) and olefins. If the cost of green hydrogen reduces significantly, the cost of abatement for these chemical and fuel pathways is bound to reduce and consequently, the impact on the cost of steel will be minimal. However, the lowest increment is in the case of carbonates at 9% since it does not depend on green hydrogen.

Table 9.14: *Increase in cost of steel produced through BF-BOF for various CCUS applications*

	CCS		CCU*				
	Basecase	Bestcase	Methanol	SAF	Olefins	SNG	Carbonates
Cost of steel (USD/ tcs)	688	688	688	688	688	688	688
Emissions intensity (tCO_2/tcs)	2.46	2.46	2.46	2.46	2.46	2.46	2.46

	CCS		CCU*				
	Basecase	Bestcase	Methanol	SAF	Olefins	SNG	Carbonates
Cost of abatement (USD/tCO_2)	64	26	503[22]	508[23]	506[23]	553[23]	42[23]
Share of emission abatement through CCUS (%)	59%[23]	59%[24]	59%[24]	59%[24]	59%[24]	59%[24]	59%[24]
Increase in cost of steel (USD/tcs)	92.89	37.74	730.05	737.31	734.41	802.62	60.96
Increase in cost of steel (%)	14%	5%	106%	107%	107%	117%	9%

**Cost of green hydrogen taken as USD 4.3/kg*

9.8 Action Plan and proposed studies

1. **Develop a dedicated policy for CCUS**: NITI Aayog, supported by DST, is currently leading efforts in developing roadmap of CCUS in India. Recognising the significance of CCUS for decarbonisation of Indian Iron and Steel Sector, the Ministry of Steel may coordinate with NITI Aayog and other Ministries/ Departments and extend support in developing a dedicated, objective-based and dynamic policy for CCU and CCS technology deployment. The policy may envision the deployment of CCU and CCS at the maximum scale of decarbonisation potential that India holds while ensuring socio-economic fairness, protection of environments and inclusive participation by all stakeholders involved. Further, the policy architecture may allow for transitions in the stages of technology deployment contingent on the maturity of the technology and the capability of all stakeholders involved.
2. **Techno-economic feasibility studies:** It is envisaged that there is no need to invest in setting up any new CO_2 capture demonstration plants based on existing CO_2 capture technology as Indian companies, both in the steel sector as well as other sectors viz power, chemical, etc, have already set up CO_2 capture plants ranging from 5 TPD to 2000 TPD. This has enabled these companies to fully understand and operationalise the CO_2 capture technology – including design, engineering, erection, commissioning, operations, maintenance, etc. Instead, emphasis may be placed on demonstrating new avenues of CO_2 utilisation technologies suited for the steel sector viz liquid fuel, gaseous fuel, syngas, fertiliser, etc. Some pathways for CO_2 utilisation are already licensed at commercial scale. Technology providers may be invited for detailed techno-commercial due diligence against specific proposals.
3. **Develop an RD&D roadmap for CCUS technologies:** There is a need for RD&D across the CCUS value chain to reduce the cost of CO_2 abatement through CCU and CCS pathways. The Ministry of Steel may develop an RD&D roadmap for scaling up CCUS technologies in the steel sector. The roadmap may focus on indigenising critical value chain components and establishing India as a leader in the manufacturing of these technologies.
4. **Risk assessment of CO_2 storage:** The Ministry of Steel may coordinate with other Government Organisations to support CO_2 storage capacities and risk assessment studies for secure storage of CO_2 that rely on available geological and geophysical data in India. CO_2 storage capacities and risk assessment studies for secure storage of CO_2 may be conducted using available geological and geophysical data in a) the

Western India region in the Cambay Basin, b) the Eastern India region in the Jharia Group of coalfields, and c) Basalts of Gujarat and Maharashtra and other geographies as required.

5. **Develop an MRV framework:** As specified under the CCTS scheme, a carbon-credits-based framework may be leveraged to enact and operationalise carbon credit transactions. Accounting and monitoring frameworks, safety standards, environmental compliance requirements, and certification standards may be developed and transparently shared with stakeholders.

6. **Clear and Stable Regulations:** The Ministry of Steel may advocate developing clear and stable regulations for CO_2 storage, transportation, and utilisation to provide certainty for investors and encourage long-term planning.

7. **Develop a policy for procurement of CCU products:** In line with international initiatives[24], the Ministry of Steel may coordinate with other Ministries to develop policy guidelines for preferential procurement of CCU products manufactured in steel plants to scale up the technology development and deployment in India. The policy guidelines may have provisions for providing viability gap funding for procuring the CCU products.

8. **Collaboration with International Partners:** MoS may partner with international organizations and countries with experience in CCUS deployment to learn from their best practices and accelerate technology adoption in India.

9. **Roadmap by all ISPs/Major steel producers for CCUS:** As adoption of CCUS technologies/strategies is time-consuming, a strategic vision by each company for the deployment aligned with BEE-mandated reduction in emission trajectory would be useful. Accordingly, companies will be encouraged to frame, report and implement such plans. The Ministry of Steel may work with the Ministry of Coal and Petroleum to explore the feasibility of carbonate production from steel plant emissions.

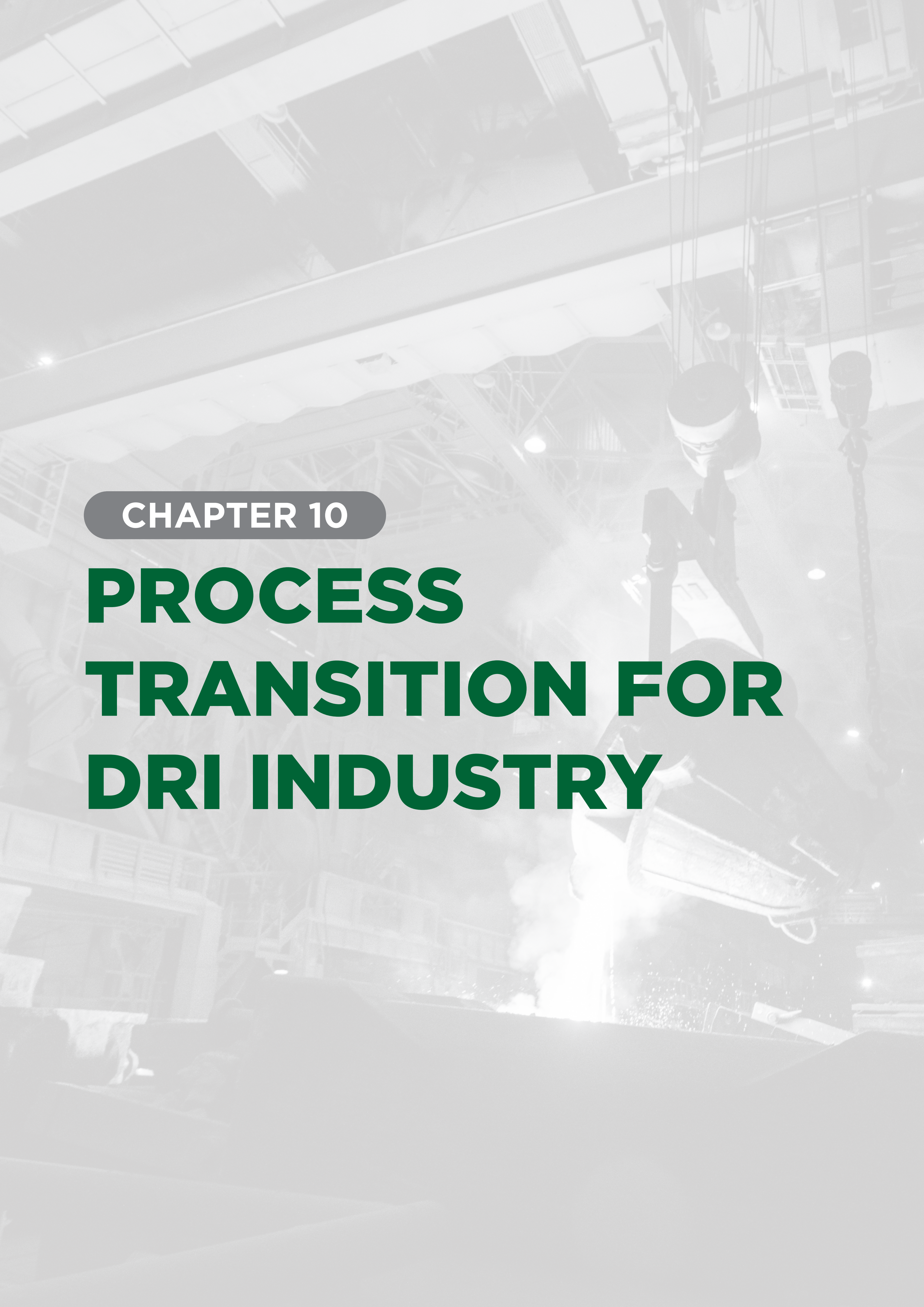
10. **Development of domestic technology providers for CCUS:** To promote domestic capacities in CCUS, MoS may assist in the developing and scaling up of indigenous technology providers and Original Equipment Manufacturers (OEMs) for CCUS. This may reduce the steel industry's dependence on imported CCUS technologies and reduce the costs of adopting CCUS in the sector.

Proposed studies

11. **CO_2 storage capacities and risk assessment studies:** A detailed study may be conducted to identify opportunities for large-scale, economically viable sub-surface storage of CO_2 in various geological formations in India. Such studies may include but not be limited to (a) site characterisation to understand the geology and storage potential in detail, (b) stratigraphic test well development to assess geological properties, (c) incorporation of new data into any existing field geological and numerical models to update storage site characteristics and reduce uncertainty in storage assessment, (d) pre-feasibility project assessment, including assessment of drilling costs, expenses for seismic surveys and well logging, planning pipeline logistics to fetch CO_2 from sources, and other front-end planning and (e) preparation of a pre-feasibility report to guide the commercial development plan.

12. **Evaluating the role of syngas production from CO_2 and water for the steel sector:** Co-electrolysis of CO_2 and water to produce syngas can be used to reduce iron ore. The proposed study may focus on the techno-economics of the process and evaluate the environmental benefits of such a technological pathway.

13. **Feasibility of CO_2 recycling technology for the steel sector:** The electrolytic reduction of CO_2 for producing CO ensures carbon circularity in the iron-making process. The proposed study may evaluate the feasibility and environmental benefits of the CO_2 recycling pathway for the steel sector.



CHAPTER 10

PROCESS TRANSITION FOR DRI INDUSTRY

10.1. Introduction

India is the world's largest sponge iron producer, with an installed capacity of 60.52 MTPA in FY 2023-24. Notably, India's DRI industry is predominantly coal-based. India does not have sufficient reserves of natural gas to meet the demand of its iron and steel industry. Imported liquefied natural gas (LNG) is significantly more expensive than coal-based processes. Consequently, the Indian DRI industry currently relies on coal-based rotary kilns to produce approximately 80% of the iron output. The Indian rotary kilns use domestic and/or imported non-coking coal for producing sponge iron. This also results in significant import dependency of India's sponge iron sector. Considering the high emissions intensity of coal-based DRI units when compared to gas-based DRI plants, there is a need to shift away from coal, first to gaseous fuel and eventually to the electrification of iron production technologies like SIDERWIN, Molten Oxide Electrolysis (MOE) and other emerging electric technologies.

Figure 10.1 shows a potential strategy for process transition in India's sponge iron sector. Coal-based rotary kilns and, to a limited scale, gas-based shaft furnaces are the current technology options for producing DRI in India. It is seen that the current expansion plan for ISPs is through the blast furnace route, whereas the sponge iron sector is planning for capacity expansion through the rotary kilns. The Sponge Iron Manufacturers Association (SIMA) projects that 27 MT of coal-based DRI capacity will be added by 2030. Therefore, in the medium term, after 2030, it will be necessary for the DRI sector to transition through natural gas-based shaft furnaces. However, the viability of this shift will significantly depend on the availability of natural gas at competitive prices.

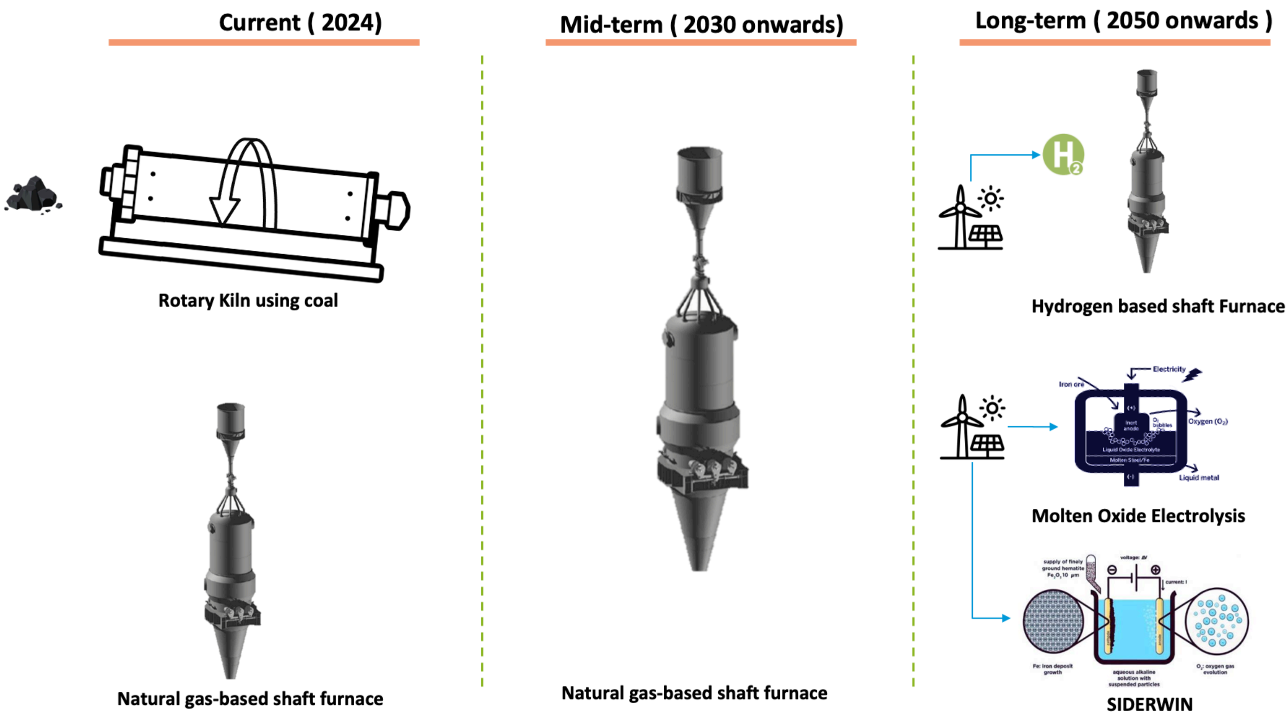


Figure 10.1: *Current, mid-term, and long-term process transition strategy for the DRI industry*

In the long term, beyond 2035, the focus for iron production might shift to electrification or green hydrogen. This can be achieved either by direct electrification through emerging technologies like Molten oxide Electrolysis[1] and SIDERWIN[2] or through an indirect route by using green hydrogen in shaft furnaces. India has a shaft furnace capacity of 12.2 MTPA. Depending on its cost, green hydrogen can be blended with natural gas or other gaseous fuels in the shaft furnaces in the initial phase. While there are technical challenges in moving to 100% green hydrogen in existing shaft furnaces, it is expected that new shaft furnaces will help with long-term plans to transition towards using 100% green hydrogen. However, a transition to 100% green hydrogen is yet to be proven on a commercial scale operation in shaft furnaces. The long-term process transition technologies like MOE and SIDERWIN are discussed in the RD&D chapter, and the green hydrogen-related aspects are discussed in the green hydrogen chapter. Therefore, this chapter discusses the prospects of using natural gas and other gaseous fuels for producing DRI.

10.2. Global Scenario

Figure 10.2 shows the trend in DRI production technologies across the world. As discussed earlier, India is the largest producer of sponge iron in the world, followed by Iran and Russia. Coal-based rotary kilns and gas-based shaft furnaces are the primary DRI production technologies globally. Further, Midrex and HyL are the leading original equipment manufacturers (OEMs) of vertical shaft furnaces while there are multiple OEMs for rotary kilns. It is seen that coal-based rotary kilns are primarily based out of India, whereas DRI production in other countries is predominantly done through gas shaft furnaces.

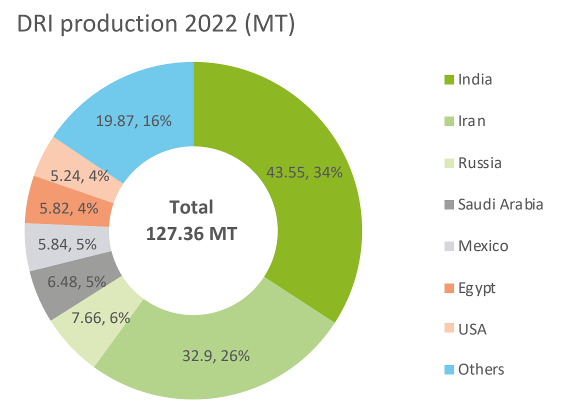
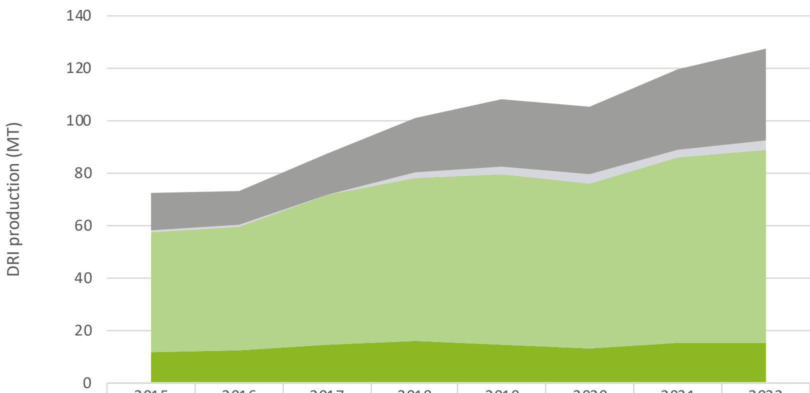


Figure: 10.2: *Global DRI production in 2022*[3]

Figure 10.3 provides a split across these OEMs and technologies. It is seen that from 2016, worldwide DRI output has grown by almost 54.78 MT, or nearly 75.33% (8.35 CAGR), primarily driven by the increase in coal-based DRI in India, new gas-based plants in Iran and the ramp-up of new gas-based capacity in Algeria, Egypt, USA, and Russia. The total global DRI production in 2022 was 127.36 MT, out of which rotary kiln-based coal-based DRI production contributed to about 27.9%, MIDREX plants contributed about 57.8%, and HyL plants contributed about 12.7%, towards world DRI production as shown in figure 10.3[4].



	2015	2016	2017	2018	2019	2020	2021	2022
Rotary Kiln	14.74	12.67	15.34	20.31	25.98	25.5	30.3	35.53
Others	0.51	0.24	0.44	2.62	2.49	3.29	2.83	2.93
Midrex	45.77	47.14	56.65	61.96	65.37	63.07	70.85	73.61
HyL	11.62	12.66	14.68	15.85	14.26	12.98	15.16	15.41

HyL Midrex Others Rotary Kiln

Figure 10.3: *Breakup of the DRI production by different processes (MT).*

10.3. Indian Scenario

The Indian DRI Industry, with 42 years of history, has been the world's largest DRI producer consecutively for the last 20 years. It continues to play an essential role in augmenting steel production in the country. The National Steel Policy 2017 has emphasised the importance of DRI and projected an 80 MT requirement by 2030-31. About 51.5 MT of DRI/HBI was produced in FY2023-24, with a growth rate of 18.1% compared to 43.62 MT produced in FY2022-23.

10.3.1. Structure and spread of the Indian DRI industry

Figure 10.4 shows the distribution of the 310 DRI plants in operation as of date, in terms of capacity, nature of operation and major reductant used. It is observed that there are 305 coal-based DRI plants and only 5 gas-based DRI plants in India. However, the gas-based DRI plants are larger in size and account for 22% of the total production capacity, while the remaining 78% is obtained from coal.

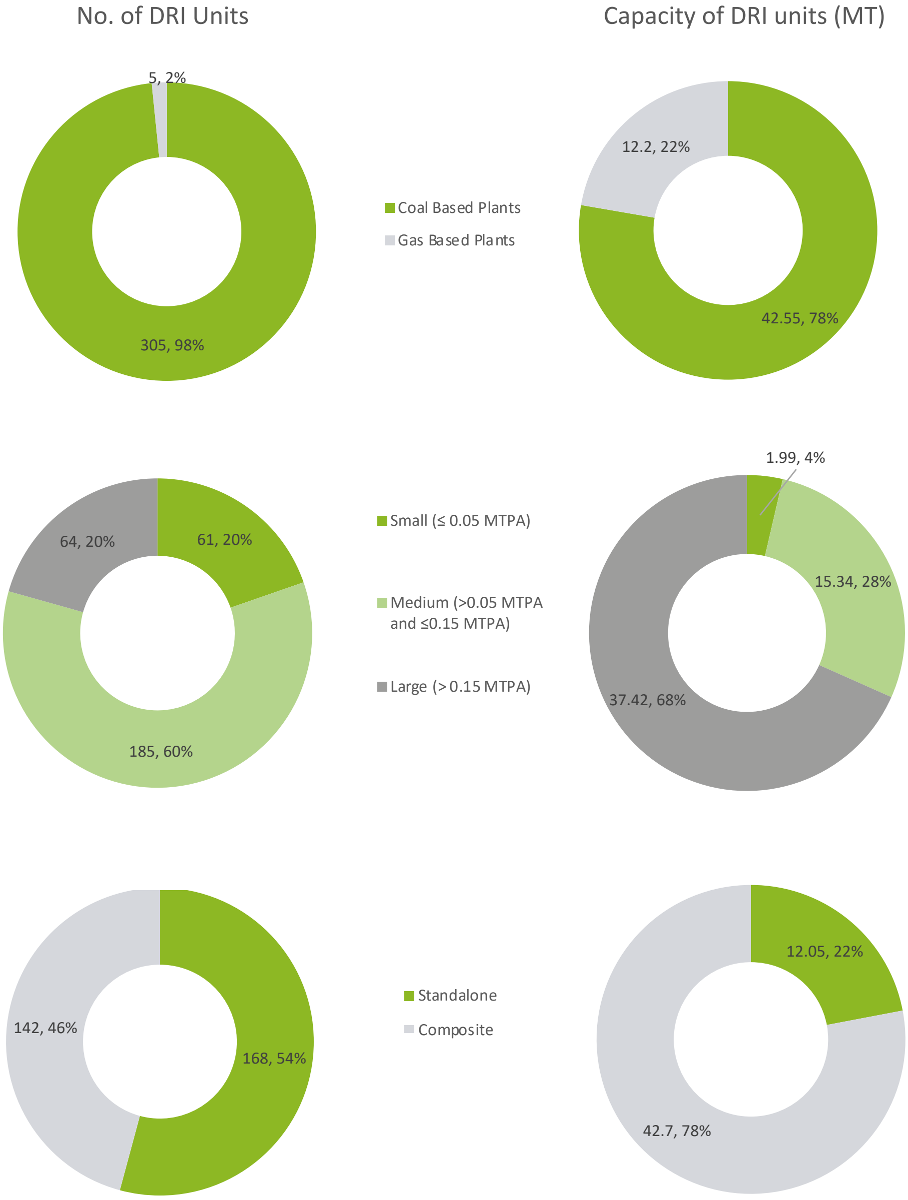


Figure 10.4: *Indian DRI industry by number of units and capacity*[5]

There is a significant disparity in terms of production capacity across various DRI units in India. Small (<0.05 MTPA) and large (<0.15 MTPA) capacity DRI plants each constitute about 20 % of the total number of plants. The 64 large DRI plants together constitute about 68% of the total production capacity. However, a significant 60% of DRI units in India are medium-capacity units that constitute only 28% of the total production capacity. Further, 54% of DRI plants in India are standalone units. Standalone units produce just DRI as their final product and are not coupled with downstream units like IF and EAF units. However, in terms of production capacity, the standalone units constitute only 22%, implying that most standalone units are small-capacity DRI plants.

The geographical spread of the DRI plants is quite often in clusters. Figure 10.5 shows the distribution of sponge iron production capacity across various states in India; the numbers after the state indicate the DRI production capacity in MTPA. There are 12 states that produce DRI in India. However, Odisha, Chhattisgarh, West Bengal, Karnataka and Gujarat are the country's largest sponge iron producers.

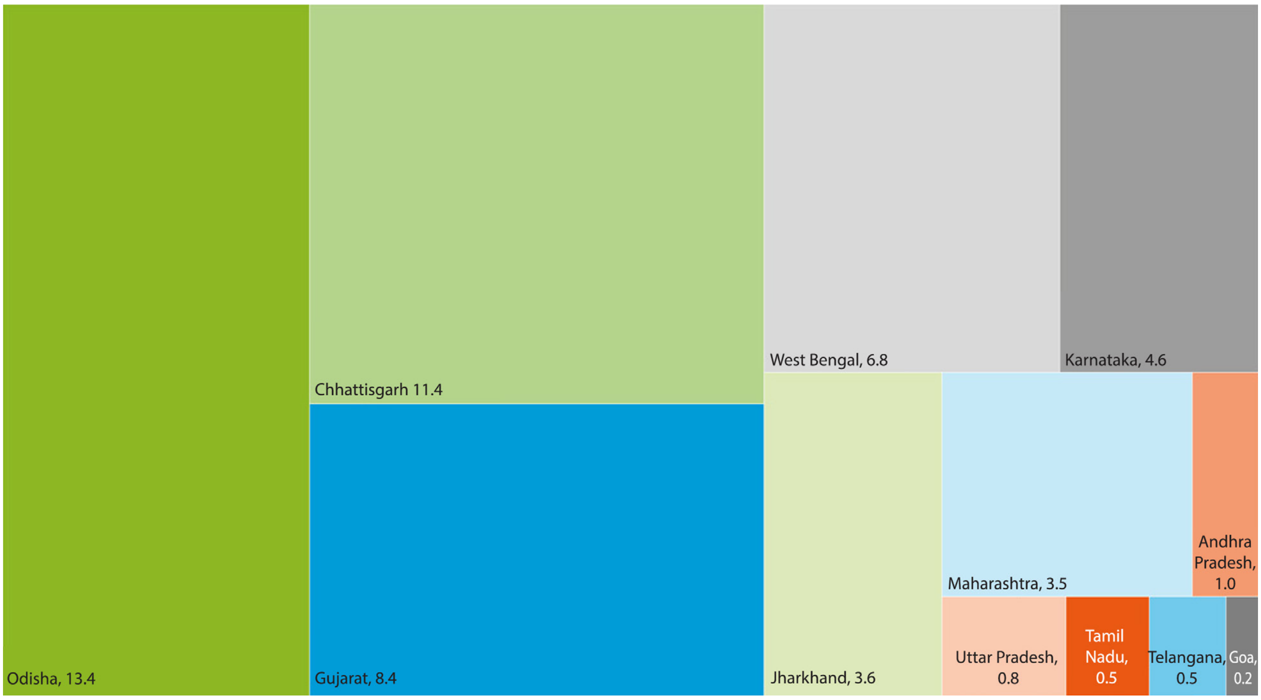


Figure 10.5: *DRI production capacity distribution across various states in India*

Figure 10.6 shows the distribution of DRI production plants across various baskets in all DRI producing states in India. India has 61 DRI units with a production capacity of less than 0.05 MTPA. Additionally, there are a significant number of plants with production capacities between 0.05 MTPA and 0.15 MTPA, totalling 185 units. Furthermore, there are approximately 64 plants with capacities greater than 0.15 MTPA. Figure 10.7 shows the production capacity across various states in India. Although the large capacity plants are fewer in number, their cumulative production capacity is the highest amongst all brackets considered in the assessment. Further, the production capacity is also high in 0.05 - 0.15 MTPA capacity DRI plants. Although, 61 DRI units have a capacity lower than 0.05 MTPA, their cumulative production capacity is very low due to the smaller individual plant size.

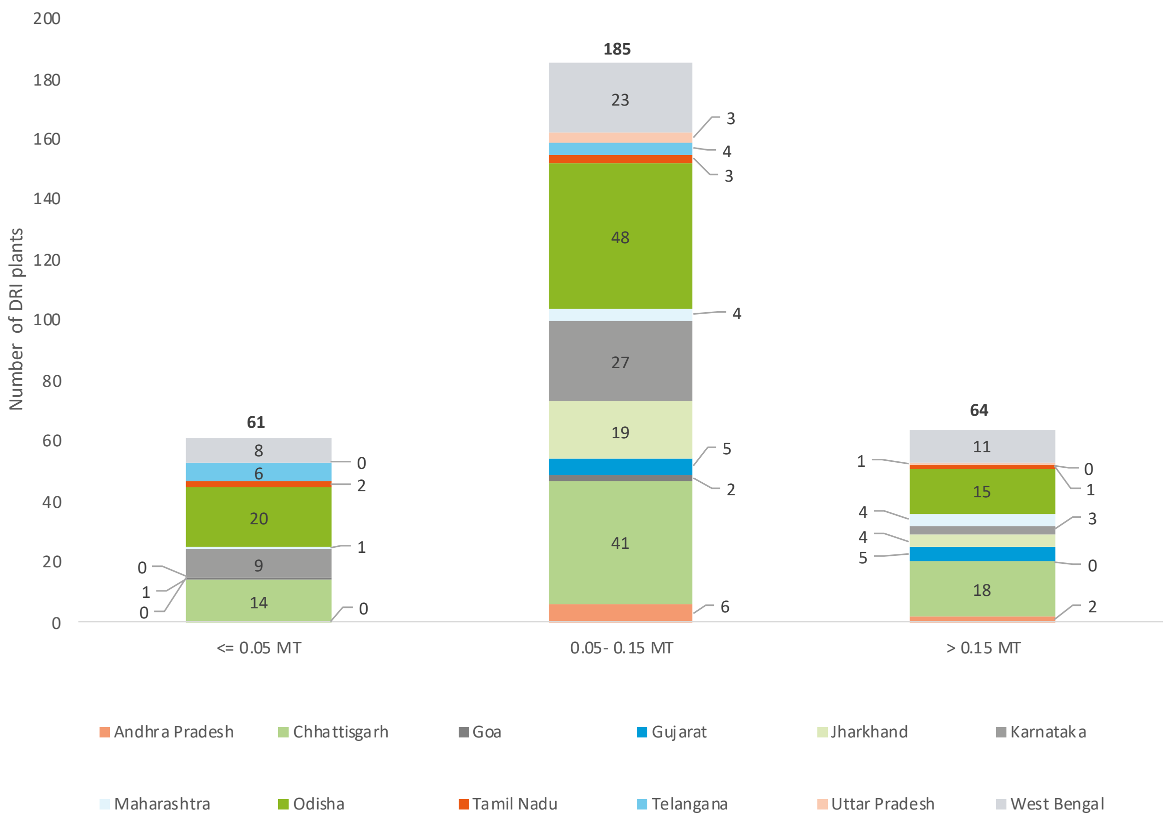


Figure 10.6: *Distribution of DRI production plants across various states in India*

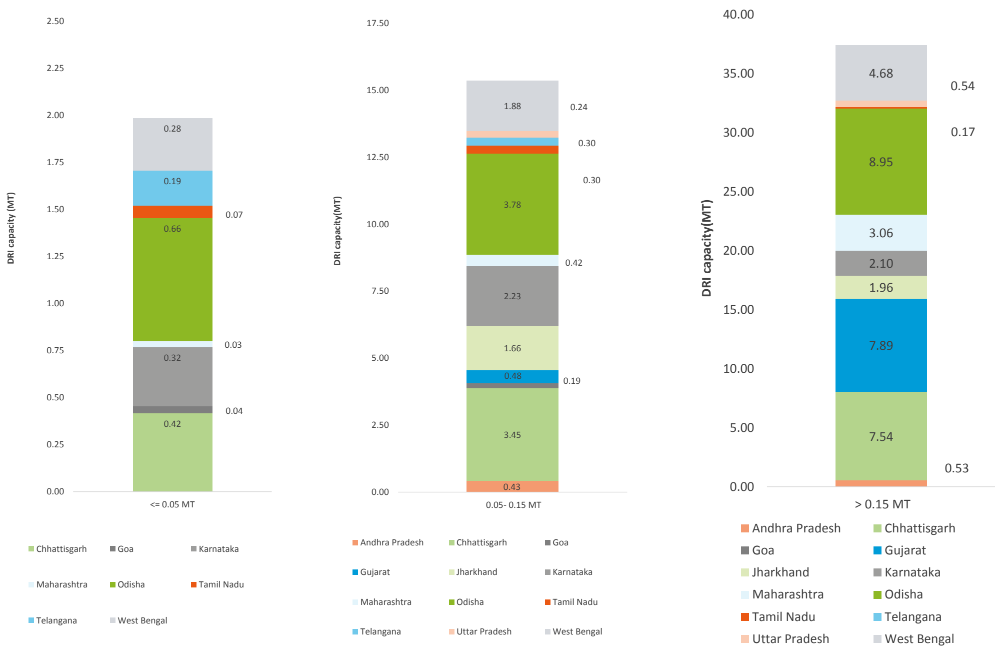


Figure 10.7: *Distribution of DRI production capacity across various states in India*

Figure 10.8 shows the locations of a few coal DRI clusters in India. There are 15 identified clusters in India, which comprise primarily of small and medium scale plants. There are about 141 sponge iron plants present in these clusters. Thus, about 40% of plants in the country are present in these clusters in terms of numbers. The cluster with the maximum number of plants is Siltara in Chhattisgarh (32 plants), followed by Kuarmunda in Odisha with 11 plants. These clusters contribute 36% of the coal-based sponge iron capacity in the country. Siltara is the cluster contributing the maximum in terms of capacity (2.95 MTPA), followed by Rengali (1.25 MTPA) and Chandil (0.74 MTPA). Kuarmunda has the second-highest number of plants in the cluster, but it contributes only 0.72 MTPA in capacity.

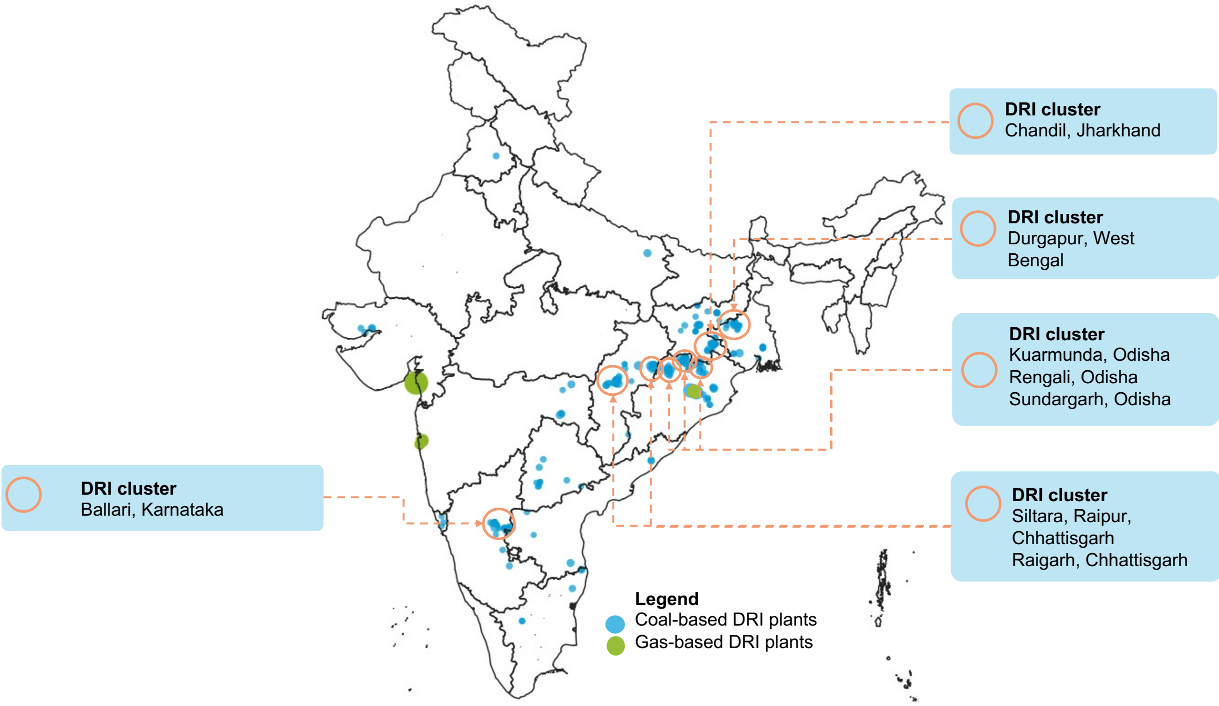


Figure 10.8: *DRI clusters in India*

10.4. Comparison of various DRI processes

This section of the report compares the coal and gas based DRI production processes on parameters like material input and product quality, specific energy consumption and life cycle emissions.

10.4.1. Inputs and Product Quality

Gas-based steel production is carried out in vertical shaft furnaces (as opposed to a near-horizontal reactor in the Rotary kiln process). It operates on the counter-current principle at normal and high pressure. As a result, gas-based DRI-making processes tend to be more chemically and energetically efficient than their coal-based counterparts due to increased gas-solid contact and improved kinetics in vertical shaft reactors, facilitating better heat and mass exchange between different phases. These lead to relatively better metallisation and proportionately less CO and CO_2 in the off-gas in the gas-based DRI processes such as Midrex and HYL III. Table 10.1 compares the inputs and product quality of coal-based and gas-based processes.

Table 10.1: *Comparison of Inputs for coal and gas-based DRI processes*

Sr. No.	Input	Coal based DRI	Gas based DRI
1	Iron ore	1.50 - 1.60 t	1.50 - 1.60 t
2	Coal	1.0 - 1.5 t	-

Sr. No.	Input	Coal based DRI	Gas based DRI
3	Natural gas	-	~ 0.330 t
4	Dolomite	0.03 – 0.04 t	-
5	Fuel oil	~ 3.50 litre	-
6	Power	90 – 100 kWh	40 – 130 kWh
7	Water	3.25 - 3.50 m3	3.25 - 3.50 m3
8	Hydrated lime	-	2 kg

Table 10.2 compares product quality obtained from coal and gas-based DRI processes. Gas-based DRI production has higher metallic content and metallisation. The carbon content is also higher in gas-based DRI production, whereas impurities like silica and alumina are lower. Therefore, it can be inferred that gas-based processes produce higher grade DRI than coal-based processes.

Table 10.2: *Comparison of products for coal and gas-based DRI processes*

Sr. No.	Product	Coal based	Gas based
1	Total iron	89% - 93%	90% - 94%
2	Metallic iron	80% (min)	85% - 86%
3	Metallisation	88% (min)	93% - 94%
4	Carbon content	0.08% - 0.12%	1.5% - 4.5%
5	Sulphur	0.03% (max)	0.03% (max)
6	Phosphorous	0.06% (max)	0.06% (max)
7	SiO_2+ Al_2O_3	6% (max)	3% (max)
8	Others	0.01% (max)	0.01% (max)

10.4.2. Energy consumption

Table 10.3 compares the specific energy consumption of coal and gas based DRI production processes. Energy consumption of coal-based DRI plants ranges from 17-23 GJ/t-DRI. In comparison, substantially less specific energy per tonne of DRI is needed in the gas-based processes. It is to be noted here that the electricity requirement of the gas-based processes is only a small fraction of the specific energy requirements (approximately 36 MJ/t as opposed to 10-11 GJ/t). Available information clearly indicates the superiority of gas-based DRI making processes over their coal-based counterparts in terms of energy efficiency.

Table 10.3: Specific energy consumption of coal and gas based Direct reduction process

Sr. No.	Processes	Specific energy consumption
1	Coal based	~17-23.4 GJ/t of product DRI
2	Gas based	11-11.5 GJ/t of product DRI

10.4.3. Life Cycle Analysis

It is important to compare the life cycle emissions from various processes for producing DRI. In literature, there are papers that employed a hybrid life-cycle inventory approach to compare the life-cycle GHG footprint of different processes of DRI making — coal-based rotary kiln, coal gasification-based shaft furnace, and natural gas-based shaft furnace processes4. This involved process modelling, literature data, and industry consultation to establish baseline process metrics, followed by a sensitivity analysis to address the impact of variabilities and uncertainties. Figure 10.9 compares the life-cycle emissions from these processes for producing DRI. Depending on the supply chain and process assumptions, emissions attribution approach to multi-product systems, and the specific choice of inputs and outputs, the life cycle GHG emissions associated with DRI production range from 1643.5 - 1842.4 $kgCO_2e$/t-DRI for the rotary kiln DRI process, 1817.4- 1969.1 $kgCO_2e$/t-DRI for the coal gasifier DRI process, and 1067.7-1160.1 $kgCO_2e$/ t-DRI for the NG reformer DRI process

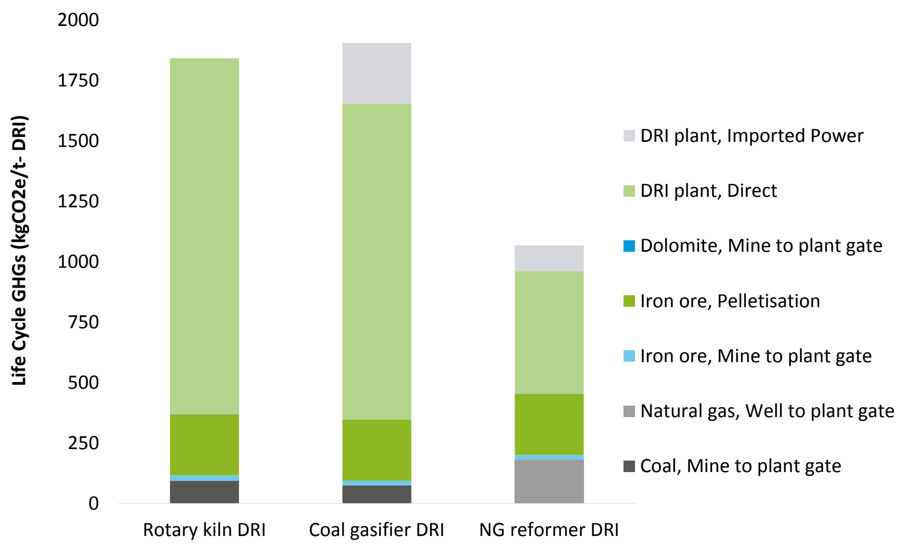


Figure 10.9: Relative greenhouse gas emission per tonne of DRI produced[6]

It is observed that the life cycle emissions from coal-based DRI and gasification plants are in a similar range. The emissions from coal gasification-based DRI plants can be attributed to the use of coal for meeting energy and power requirements. In the coal-based DRI process, the emissions can be attributed to using coal as a feedstock and fuel; surplus power is generated from the waste heat recovery (WHR) units that reduce the overall emissions intensity from the process. Nonetheless, this comparison establishes the natural gas-based process as the cleanest for DRI production, with the total life-cycle GHG emissions being more than 30% less than the coal-based DRI process.

10.5. Challenges in Indian DRI making

The Indian DRI production sector faces multiple challenges for transitions from the coal-based rotary kilns to gas-based shaft furnaces. This section discusses the challenges for process transition in the Indian DRI sector.

10.5.1. Coal-based rotary kilns

The coal-based rotary kilns face challenges for decarbonisation due to a lack of clarity on alternative fuels' role in mitigating emissions from the process, competing use of financial resources, low-quality domestic coal and lack of access to iron ore pellets at competitive prices. These challenges are further discussed in the section.

- **No reliable estimate on injection of alternative fuel:** Energy efficiency (EE) and Renewable energy (RE) have a limited role to play in decarbonising the coal DRI sector7. With the current state of understanding, after EE and RE, the primary lever for decarbonising the coal DRI process is CCUS, which is significantly expensive today. Alternative fuels can be an intermediary lever between EE/RE and CCUS for mitigating emissions from the rotary kilns. Given this context, there is a need to evaluate the role of alternative fuels in reducing coal use and consequently mitigating emissions. However, today, there are no reliable estimates of the amount of alternative fuels that can be injected into rotary kilns.

- **Lack of adoption of energy efficiency through waste heat recovery:** As discussed in section 10.3.1, there are a large number of small and medium rotary kilns of less than 0.15 MTPA capacity (246 units with a total of 17.33 MTPA capacity, as seen in Figure 10.6). Compared to ISPs, setting up rotary kilns of low capacity requires a relatively smaller capital expenditure. Most small-scale rotary kilns fall outside the purview of initiatives like the PAT scheme and are unlikely to be included in the Indian carbon market as well. Consequently, there is a lack of financial incentive for these players to invest in energy efficiency measures like waste heat recovery. Moreover, the cost of implementing energy efficiency measures often rivals the expense of purchasing a new rotary kiln. This discourages the rotary kilns sector from prioritising energy efficiency measures, and they tend to prioritise capacity expansion.

- **Lack of good quality coal in India:** Since Indian coal has high ash content, domestic coal production typically yields ash contents ranging from 15% to 45%, with the majority falling within the 35% to 45% range8. In contrast, imported coal has significantly lower ash content, typically ranging from 10% to 20%9. Due to the higher ash content of Indian coal, producing each ton of DRI requires a larger quantity of coal compared to using imported coal. Consequently, the emission intensity of DRI produced using domestic coal is higher than that of imported coal. The Indian steel industry is constrained to use domestic high-ash coal due to the high cost of imported coal and to be cost-competitive with other ironmaking processes, leading to higher emissions.

- **Use of low-grade iron ore and high cost of pellets:** Most DRI players in India do not have access to captive iron ore mines. These industries depend on the availability of iron ore in the open market. To be cost-competitive, these DRI players use low-grade iron ore or low-grade iron ore pellets, which increases coal consumption and, consequently, emissions from DRI production. In most cases, the cost of pellets does not compensate for the productivity and efficiency gains arising from its use. The use of iron ore/pellets by the small players is decided purely on economic considerations and their local availability.

10.5.2. Natural Gas-based DRI production

The natural gas-based route for producing DRI faces challenges due to the unavailability and high prices of piped natural gas and the larger size of shaft furnaces. The challenges for transitioning to natural gas-based shaft furnaces in India are expounded in this section.

- **Natural gas availability in India's iron belt:** India currently has a gas pipeline network of 24,723 km, with an additional 10,498 km under construction10 across the country. A significant portion of India's ironmaking capacity is located in the eastern states of Chhattisgarh, Jharkhand, Odisha and West Bengal, which do not have access to piped gas with the Jagdishpur-Haldia-Bokaro-Dhamra pipeline (JHBDPL) still to complete 594 km of its authorised length of 3,546 km till December 2023. This poses a challenge for steel plants located in the eastern states to adopt natural gas routes for DRI production.

- **Cost of Natural Gas:** For natural gas-based shaft DRI to be competitive with coal-based routes, the delivery cost of natural gas per Metric Million British Thermal Unit (MMBtu) should be USD 6 to 8. However, the delivered cost of gas is significantly higher because of reliance on LNG and priority given to domestically produced gas in other sectors. This increases the cost of producing steel using natural gas compared to coal-based processes.

- **Lack of small-capacity shaft furnaces:** The absence of small-capacity shaft furnaces presents a significant challenge in the Indian DRI industry. The majority of rotary kilns in the country are designed with capacities ranging from 0.05 to 0.015 TPD, with a total capacity of 15.34 MTPA, as shown in Figure 10.6. The minimum size of a gas shaft furnace is 0.8 MTPA (2,285 TPD). This difference in capacity poses a considerable obstacle for smaller rotary kiln operators who lack the financial resources to invest in larger gas-based shaft furnaces.

10.5.3. Syngas based DRI production

Globally, only one plant uses the coal gasification route for DRI production. In 2014, JSPL set up a coal-gasification DRI plant in Angul, Odisha, with a capacity of 2 MTPA. Therefore, there is limited experience in DRI production using syngas. This section elaborates on the challenges of using the coal gasification route to produce DRI in India.

- **High ash content of domestic coal:** One key objective of the coal-gasification DRI process is to reduce India's import of coking coal used in blast furnaces. However, as discussed earlier, Indian coal has high ash content, which poses significant challenges to the coal gasification process as gasification plants are primarily designed for imported coal that has low ash content. Further, high ash content can decrease the efficiency of the plant, increase operational costs due to ash accumulation, and extend the maintenance schedule.

- **Unavailability of Indigenous coal gasification technology**: The imported technologies for coal gasification have been developed to cater to low-ash coal available in foreign geographies. Today, there is a lack of indigenous technology for coal gasification. Although there have been several pilot projects aimed at showcasing coal gasification within India, these endeavours have encountered difficulties in scaling up to commercial levels.

- **Greenhouse gas emission reduction potential of coal gasification**: From Figure 10.9, it can be seen that the emission intensity of Coal DRI and Syngas DRI is very similar (1391.1-1880.0 $kgCO_2e$/t-DRI for the rotary kiln DRI process, 1565.5-1969.1 $kgCO_2e$/t-DRI for the coal gasifier DRI process). Therefore, there is no significant reduction in emissions intensity with the coal-gasification process. The emissions from coal-gasification based DRI production can only be mitigated through the use of CCUS technologies that are prohibitively expensive today.

- **High capital expenditure requirement:** The coal gasification plant uses components like shaft furnaces and coal gasification units, amongst other capital-intensive technologies. The small-scale rotary kilns do not have the financial wherewithal to invest in the capital-intensive technologies required for setting up coal gasification DRI units. Further, the gestation period for coal gasification DRI units is also significantly higher, which might not be acceptable to smaller DRI units. The coal gasification project by JSPL was initially launched in 2007 and was commissioned in 2014.

- **Technology lock-in:** Industries that invest extensively in coal gasification infrastructure will become dependent on this technology due to the high capital sunk in the project. This reliance can result in a technology lock-in situation for components like coal gasifier units, making transitioning to cleaner or more sustainable options difficult due to financial and infrastructure constraints.

10.5.4. Green Hydrogen based DRI production

The challenges related to the green hydrogen-based DRI route are discussed in detail in the green hydrogen chapter and not repeated here for brevity.

10.6. Transition in coal based DRI

As discussed earlier, there is limited experience in injecting alternative fuels in rotary kilns. However, experimentation has been done with using syngas in rotary kiln DRI plants. IIT Roorkee is carrying out a project along these lines. Typically, the rotary kiln uses solid coal for both thermal energy requirements and reduction reactions to transform iron ore into sponge iron. In a rotary kiln, 40%-50% coal of size 8-20 mm is fed along with raw materials at the feed end. About 50%-60% of coal of size 0-8 mm is injected along with low-pressure air at the discharge end. The coal injected at the discharge could be potentially replaced with syngas. Figure 10.10 shows that syngas may also be used in rotary kilns, where syngas can be produced through coal gasification; however, this is still at a conceptual stage and has not been demonstrated yet.

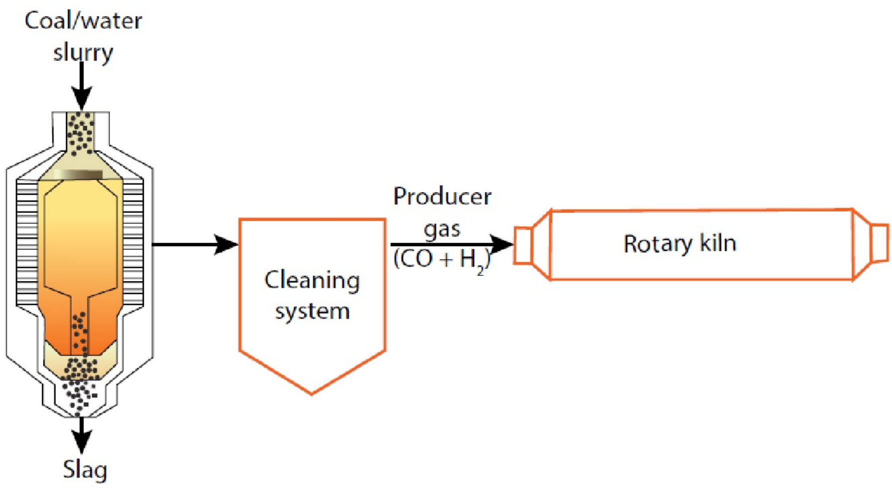


Figure 10.10: Coal gasification system for rotary kiln in sponge iron production

The expected advantages of using syngas in coal-based DRI are:

- Reduction of coal consumption
- Improved the percentage of metallisation in the kiln
- Optimum use of energy
- Reduction of fly ash and wet ash
- Reduction in residence time inside the kiln

10.7. Coal gasification efforts and plans in India

To achieve 100 MT coal gasification11 projection in India by 2030-31, the Ministry of Coal has taken several steps. All coal companies have been advised to appoint a nodal officer and to prepare an action plan for gasification for at least 10% of their coal production. Further, in all future commercial coal block auctions, a provision has been made for a 20% rebate in revenue share for the coal used for gasification purposes, provided the coal quantity used for gasification is at least 10% of total coal production. Carbon conversion efficiency of 90 -99% can be attained in the gasification process. The major advantage of gasification is that coal is converted into a gaseous fuel, which is easy to handle and is a comparatively clean form of energy. The synthesis gas has a wide range of applications. It can be used in an Integrated Gasification Combined Cycle (IGCC) system for efficient and clean electric power generation. It is suitable for manufacturing hydrogen and basic chemicals such as ammonia, methanol, substitute natural gas, coal to liquid (CTL), reduction gas in the steel industry, etc. It can be used in complex plants for the simultaneous production of electric power, chemicals/fertilisers, and reduction of gas and fuels, which also improve the economics of coal gasification. Further hydrogen injection is also possible in coal gasification-based plants.

Existing and planned operations

The different coal gasification units in operation in India are as follows:

- **Jindal Steel & Power Limited (JSPL):** JSPL has installed the world's first DRI plant based on coal gasification technology using domestic coal, which is already operating in the Angul District of Odisha, for steel making. The syngas production capacity of the coal gasification plant is 69.84 million Nm3. JSPL had tried mixing imported coal with domestic coal for gasification (currently in operation, running sub-optimally).
- **BHEL:** BHEL has set up a pilot plant in Trichy and has produced 6.2 MW power, but the plant has faced many issues in handling high ash coal.
- **Thermax:** Thermax has also set up a pilot plant in 2014 for coal to methanol production with DST funding under the aegis of NITI Aayog in Pune.

Large coal gasification projects that have been planned are as follows:

- **Talcher Fertiliser Plant:** A joint Venture Company named Talcher Fertilizers Limited (TFL), comprising Rashtriya Chemicals and Fertilizers Limited (RCF), Coal India Limited (CIL), Gas Authority of India Limited (GAIL), and Fertilizer Corporation of India Limited (FCIL), has been constituted to set up a Surface Coal Gasification based integrated fertiliser complex using high ash coal from nearby Talcher Coalfields mixed with pet coke from Talcher refinery. Coal blended with pet coke up to 25% may be gasified to produce syngas, which may be converted into Ammonia and subsequently to 1.27 MT of neem coated Urea annually. TFL Board approved the coal gasification technology of Air Products (earlier Shell) for the proposed plant.

- **Dankuni Coal to Methanol Plant:** In pursuance of the initiatives towards the development of Clean Coal Technology and alternate use of coal, CIL has floated a tender for the engagement of an agency on a Build-Own-Operate (BOO) basis for setting-up a coal-based Methanol plant of a 2050 metric tonne methanol per day capacity in the premises of Dankuni Coal Complex (DCC) near Kolkata. Coal sourced from Raniganj coalfields may potentially be gasified to produce syngas, which may be subsequently converted into methanol. The project will come up with an investment of about INR 5800 crores, and 1.5 MT Coal will be supplied from Sonepur Bazari Mines of Eastern Coalfields Limited (ECL).
- **Other proposed projects:** CIL has further identified four different coal gasification projects in ECL, South Eastern Coalfields Limited (SECL), Western Coalfields Limited (WCL) and Central Coalfields Limited (CCL), wherein methanol, ammonia, ammonium nitrate and urea are expected to be produced. Neyveli Lignite Corporation India Limited (NLCIL) has also taken up one lignite to methanol project at Neyveli.

The Ministry of Coal has planned to execute the vision of establishing the commercial scale projects in a three-fold implementation strategy:

- **Phase I:** Setting up a project on a Pilot basis: Gasification of 4 MT of coal through 2 projects - The Talcher Fertilizer Plant & the Dankuni Methanol Plant.
- **Phase II:** Upscaling efforts towards coal gasification: Coal India Limited has identified 4 key gasification projects across its subsidiaries, ECL, SECL, CCL and WCL to gasify 6 MT of coal and produce various downstream products including synthetic natural gas (SNG).
- **Phase III:** Gasification of 90 MT coal: After successfully setting up technology in Phase II, more projects may be identified. Stakeholders are expected to be active participants in the gasification roadmap for India, for which the Ministry of Coal may extend support for sourcing of coal. It is worth noting that no provisions exist for diverting a portion of the above produced syngas for steel making.

10.8. Natural gas efforts and plant for the Indian steel sector

Natural gas is a transition fuel for the Indian iron and steel industry. It offers an opportunity for the Indian steel industry to move away from coal-based production pathways to green hydrogen with natural gas as an intermediary fuel. This section reviews the uptake of natural gas in India's steel sector, identifies the proliferation of natural gas infrastructure in the country, and develops a natural gas cost curve for the country's steel sector.

10.8.1. Natural gas uptake in the Indian iron and steel industry

Figure 10.11 shows the relationship between gas availability and the gas-based DRI production. It can be seen that historically, most of the gas requirements for DRI production have been met using Regasified Liquefied Natural Gas (RLNG). However, over the years, with an increase in the availability of domestic gas and the higher price of RLNG, the Indian iron and steel industry has started using domestic gas for producing DRI.

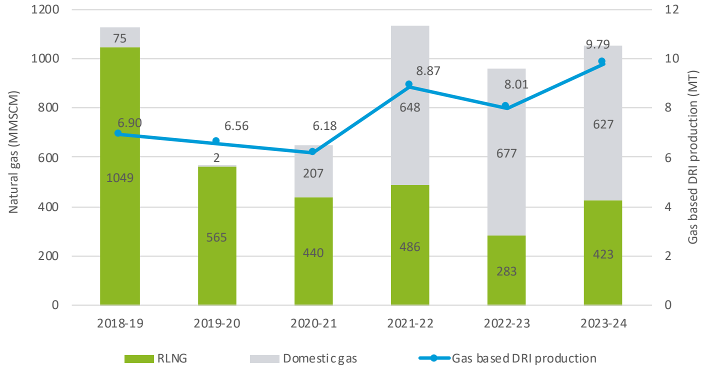


Figure 10.11: Natural gas use in gas based DRI production and overall DRI production through gas shafts[12] .

Access to affordable natural gas is a challenge for the Indian iron and steel industry. Therefore, the industry uses a mix of natural gas and other gaseous fuels such as syngas and off-gases for producing DRI. Based on the overall natural gas consumption for DRI production, as indicated in Figure 10.11 and assuming 280 SCM/t-DRI of natural gas consumption, DRI production through natural gas and other off-gases can be estimated. Figure 10.12 shows the overall production of DRI using natural gas and other gaseous fuels, including coal gasification. It can be seen that natural gas contributes to roughly 31% 58% of the total DRI production in India. Therefore, it can be inferred that, while India has some amount of gas-based DRI production, not all of it is exclusively through gas-based DRI and other gaseous fuels are also used for producing DRI in India.

Figure 10.12: DRI production using Natural gas and other gaseous fuels

10.8.2. Natural gas proliferation in India

Figure 10.13 provides, in a nutshell, the present and planned NG distribution circuits for India. With the existing natural gas pipeline network, only 21% of the existing BF capacity and 5% of the coal-based DRI capacity have access to gas pipelines (i.e., assuming they are within 25 km of a gas transmission pipeline). Only ISPs have the wherewithal to finance gas shaft based DRI and thus it is important to connect even BF units with natural gas pipeline. However, with the addition of the planned and under-construction pipeline capacity, around 80% of the BF capacity and 77% of the coal-based DRI capacity will be placed within 25 km of a gas transmission pipeline. Most plants can be provided with access to natural gas, especially once the Jagdishpur-Haldia-Bokaro-Dhamra pipeline (JHBDPL) in the Jharkhand-West Bengal-Odisha region is established.

Unlike sensitive sectors like fertiliser, power, compressed natural gas (CNG), and residential piped gas, domestically produced gas is not allocated to the steel industry at a subsidised rate. Therefore, for the industry to switch to the gas-based route, they need to import LNG at prevailing high prices or buy it from domestic suppliers at market prices, making it uncompetitive with the coal-based route. The country has large coal-bed methane (CBM) reserves located near steelmaking regions, although they are mainly in heavily forested areas. The pricing of CBM gas has also not reached competitive levels thus far.

Coal import prices have increased after the pandemic, and the future of steady coal exports by other countries is uncertain due to potential policies to reduce coal mining and exports in other countries. The upcoming Indian carbon market will further incentivise clean fuel transitions. The gas-based technology can directly switch to green hydrogen when it becomes more affordable, thus making the issue of gas procurement and distribution only a small- to medium-term issue. Therefore, the Indian steel industry can further explore the gas-based route for capacity expansion. One possibility to obtain more favourable prices is by pooling demand for the entire industry (i.e., those willing to switch) and negotiating a long-term contract for the pooled volume for better price discovery. In addition, as the green hydrogen transition begins in fertiliser plants and refineries towards 2030-31, more gas volumes may be liberated for uptake in other industries.

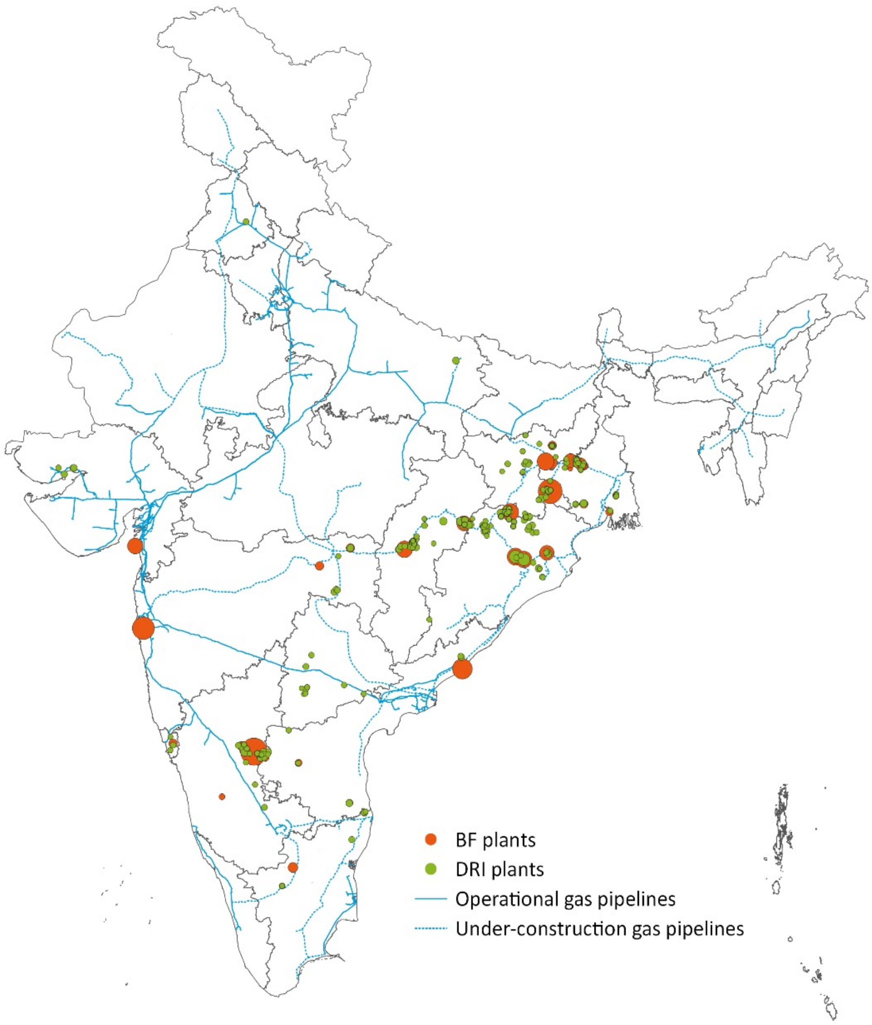


Figure 10.13: *Existing and upcoming pipelines in India and their proximity to steel plants*

10.8.3.Natural gas cost curve for India

Given the challenges associated with natural gas pricing, the Ministry of Steel proposes to adopt an approach where demand would be aggregated from the major steel industry, and price negotiations can be conducted with major LNG suppliers and gas distributors in the country. A detailed questionnaire was prepared as a first step, and inputs were sought from major steel companies to generate a natural gas cost curve for the steel industry. The results from the survey are presented in Figure 10.14. The natural gas cost curve links the projected demand for natural gas for a certain share of steel production in the country by 2030 with the natural gas price. Based on the survey response, a peak natural gas demand of 10 billion cubic meters (BCM) is expected at a price of USD 4/MMBtu. It progressively decreases with the increase in gas price and is virtually zero for prices beyond USD 10/MMBtu.

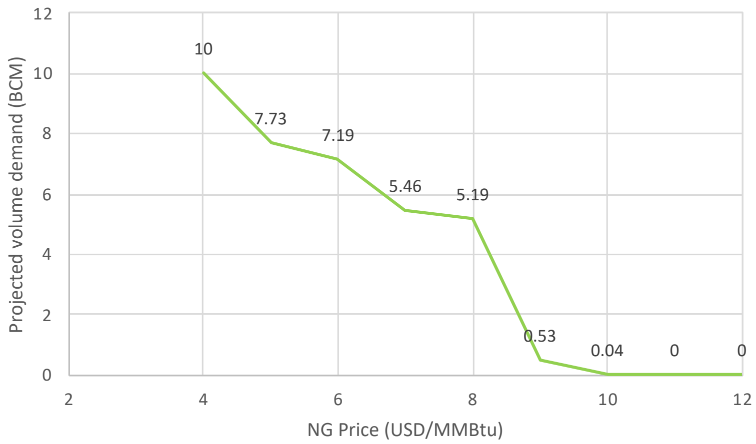


Figure 10.14: *Natural gas cost curve for the steel sector in India*

The survey reveals that nearly all the steel manufacturing entities in the country have planned for greenfield expansions through the blast furnace route by 2030. The industry is willing to consume 10 BCM of NG if the delivered cost is around USD 4/MMBtu. The industry data indicates that the maximum NG can be consumed in the blast furnaces alone. One industry has indicated an interest in purchasing gas for greenfield capacity expansion, only if the delivered cost of natural gas is as low as USD 6/MMBtu. However, as shown in Figure 10.15, the average import price of LNG in FY2021-22 was USD 11/MMBtu, and it increased to USD 16.5/MMBtu in FY2022-23; although, historically, lower prices have been recorded. When additional transportation costs are added to this import price, it is unlikely that gas prices will ever be available at a price of USD 6/MMBtu. Consequently, price negotiations in such a scenario might have a limited effect, as 0.53 BCM gas uptake at USD 9/MMBtu might not be a significant volume that interests the LNG players. It should be noted that Figure 10.15 shows gas prices, which are an average of long-term agreements and spot prices of natural gas.

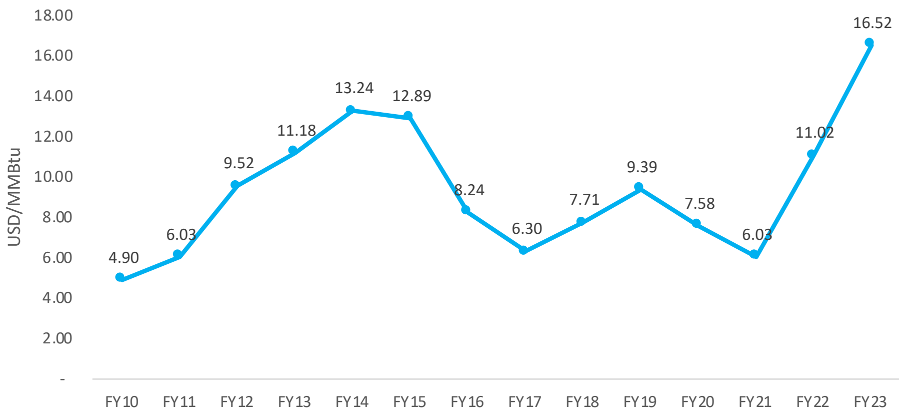


Figure 10.15: *Average LNG import prices*[13]

10.9. Coke oven gas uptake for DRI production

As discussed in the previous section, since natural gas is unlikely to be available at the desired price of USD 6-8/MMBtu, other fuels like coke-oven-gas (COG) need to be explored as a replacement for incumbent fuels. The gross calorific value (GCV) of COG is around 4200 Kcal/NM3, mainly because of the high CH_4 content with a GCV of above 9000 Kcal/NM3. By contrast, H2 is a low GCV gas in volumetric terms but much higher GCV in weight terms. In industry, typically, COG is mixed with low GCV gases such as BF and BOF top-gas, and used for multiple applications. It can be used for power generation in a captive power plant (CPP), injected in a shaft furnace for DRI production, and used as a source of heat in reheating furnaces. In fact, currently, most of the COG is used for reheating furnaces and the residual amount is used in captive power plants. This section details some of these applications and highlights the feasibility of COG use for DRI production.

Table 10.4 lists the process conditions for the uptake of COG as a fuel for DRI production. Given a coke rate of 300 kg/tHM, the net COG available after accounting for its use in auxiliary applications is 32 Nm3/tHM. Currently, the BF production capacity in the country is 88 MTPA. The net COG use for DRI would result in a national production capacity of 4 MTPA, for a DRI and hot metal (HM) metallisation factor of 85% and 94%; in such a scenario, the emission reduction due to COG use will be 0.09 tCO_2/tHM. It is assumed that the power previously generated through COG is now offset by RE power. If, however, coal is used to make up for power generation in a CPP, the emission reduction is estimated to reduce to 0.05 tCO_2/tHM. In total, COG used for DRI production will mitigate 7.8 MT of CO_2. Alternatively, if coal is used for power generation in the CPP, the total emission reduction will be 3.4 $MtCO_2$. Table 10.4 also lists the parameters in a scenario where the coke rate is 420 kg/tHM.

Table 10.4: *COG use for DRI production*

Sr. No.	Details	Unit	Case 1	Case 2
1	Coke rate	kg/tHM	300	420
2	Net CoG available	NM3/tHM	32	45
3	SEC for DRI	GJ/tDRI	10.5	10.5
4	DRI production from COG	tDRI/tHM	0.05	0.07
5	Present BF production capacity	MTPA	88	88
6	Potential DRI generation capacity	MTPA	4	6
7	DRI metallisation	%	85%	85%
8	HM metallisation	%	94%	94%
9	Emission reduced due to Iron production	tCO_2/tHM	0.09	0.12
10	Emissions increase with added thermal coal due to COG unavailability (in CPP)	tCO_2/tHM	0.00 (0.05)	0.00 (0.07)
11	Emissions increase because more electricity is needed for DRI production.	tCO_2/tHM	0.00	0.00
12	Net Emissions reduced	tCO_2/tHM	0.09 (0.04)	0.12 (0.05)
13	Total emission reduction	$MtCO_2$	7.8 (3.4)	11.0 (4.8)

Currently, a significant share of COG is used in reheating furnaces that can only work with gaseous fuels. OEMs indicate that while their shaft furnaces can use COG, steel plants do not have spare COG that can be used for DRI production. Also, the capacity of the shaft furnace that can be deployed by using COG is small compared to the BF capacity. For every MTPA of BF capacity, only 0.05-0.07 MTPA shaft furnace can be installed based on COG availability. Therefore, COG use in shaft furnaces can only materialise for large-scale ISP, or the plant might need to blend NG (or other gaseous fuels) with COG. The reheating furnaces can be converted for solid fuels, though it will incur significant retrofitting cost.

There are also challenges with respect to the chemical composition of COG. COG has 24%-26% of CH_4 and 55%-58% of H2, with CO content as low as 6%-9%. Although, H2 has good reduction properties, its combustion is endothermic. Additionally, a significant amount of CH_4 will need to be reformed to CO and H2 to be utilised as a reducing agent through a dry reforming process since the cracking of CH_4 is also an endothermic reaction. However, the CH_4 and hydrocarbons can be reformed in situ in modern shaft furnaces such as the ENERGIRON ZR, which is capable of using 100% NG directly while simultaneously reducing the iron ore and carburising the DRI. This is schematically represented in Figure 10.16. In such a process, the catalyst is the iron (Fe) in DRI that is being produced and also continuously supplied. To fulfil the energy requirements of reforming, reduction and carburisation, the temperature of the reducing gases is required to be more than1050°C. This is achieved through the partial combustion of the fuel with oxygen before it is input into the shaft furnace. In principle, the destruction of H2 present in the COG will take place in the shaft and can be achieved through the patented scheme for in-situ destruction of benzene, toluene, and xylene isomers (BTX) and Hexahydrocannabinol (HHC). This highly efficient process is currently in operation in many industrial facilities worldwide. In the case of COG, with approximately 25% CH_4 and a trace amount of hydrocarbons, the ENERGIRON ZR process would be preferable since it is a much less demanding scheme as compared to NG. In conclusion, 100% COG can be used in the ENERGIRON process plants.

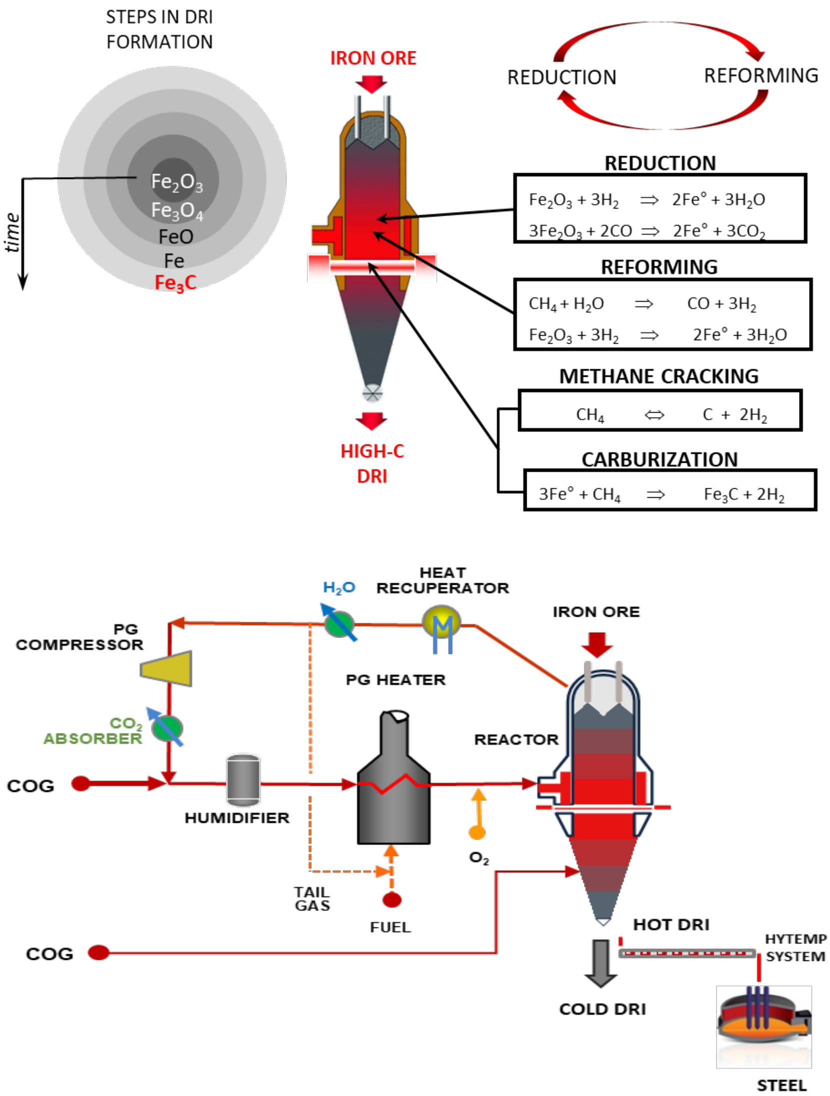


Figure 10.16: DRI production process in modern shaft furnaces

Direct use of 100% COG for DRI production has been recently proven in a demonstration plant operated by HBIS (HBIS Group Co, Ltd.) in China. It was shown that as compared to the use of 100% NG, 100% COG use required certain provisions when compared to a standard DRI plant. These are listed as follows:

- COG needs to be injected into the cone for the destruction of BTX and heavy hydrocarbons, as per the patented scheme.
- Some COG can be fed to the transfer line.
- The DRI shaft should have provisions for injection/extraction of COG
- Lower CO_2 absorption vs. NG scheme
- Lower Oxygen injection vs NG scheme

COG has multiple impurities like tar etc., that could cause problems with the operation of the furnace. To mitigate this, quality restrictions on COG need to be implemented for its use in the shaft furnace. In case the composition of residual materials in the COG exceeds the prescribed limits, it has to be treated prior to its injection in the shaft furnace. The prescribed limits are listed as follows:

- BTX ≤2000 mg/Nm3
- CnHm (hydrocarbons) <4% vol.
- Tar ≤2 mg/Nm3
- O2 <0.5% vol.
- N2<6% vol.
- Sulphur ≤20 mg/Nm3 (depending on DRI quality & environmental restrictions)

It was also found that the size of the DRI plant influences the feasibility of COG use for DRI production. Steel plants across the world use shaft furnaces of varying capacities. Steel plants such as HBIS and Baosteel in China use 0.6 and 1 MTPA capacity shaft furnaces respectively, while larger plants like Suez Steel in Egypt and Salzgitter in Germany deploy 2 and 2.1 MTPA shaft furnaces respectively. If COG is injected into these furnaces, 10 GJ/tDRI would be required. In a scenario where H2 is separated from the COG and used in the above furnaces, 18-20 TPH of hydrogen would be required for a 2.5 MTPA DRI plant. In energy terms, this amounts to 8.3 GJ/tDRI of hydrogen. In addition, COG is available at a pressure of 0.02 bar, whereas the pressure requirement for injection into shaft furnaces is approximately 9 bar. Therefore, the COG stream needs to be compressed in a 2-stage industrial compressor, which also partially removes H2 and tar condensates.

Globally, research laboratories have conducted feasibility studies, and some steel companies even have operational facilities that produce DRI using COG. They are listed as follows:

- Demonstration plant tests at Monterrey facilities; 1978-1982, 1997.
- Laboratory tests at AHMSA, Mexico, to prove the destruction of BTX with hot DRI; 1980's
- Tests carried out at Zdzieszowice, ArcelorMittal COG facilities in Poland to confirm the above scheme; 2008.

Current successful industrial operation of HBIS plant with 100% COG (H2-enriched approximately70% vol.) reaching 100% production in a few days after start-up in 2023.

10.10. Hydrogen-based DRI production plans

Globally, efforts are underway to increase the Hydrogen percentage in the Syngas / reformed Natural Gas so that, in the future, such facilities can be converted into Hydrogen iron making as and when such technologies become techno-economically viable. However, the Gas/Syngas based DRI process can be utilised as an entry point for H2-DR.14. The operating gas mixture could be gradually enriched with hydrogen, but hydrogen availability, emissions, prices and process requirements restrict its contribution. Green hydrogen can also be injected into coal gasification-based shaft furnaces. This will require the coal gasification unit to be ramped down to accommodate a certain blend of green hydrogen. The potential for using green hydrogen in shaft furnaces has been discussed in the green hydrogen chapter in detail and not expounded here for brevity.

10.11. Risks associated with coal and natural gas-based supply chains

The Indian steel industry is heavily dependent on imported coal. India's DRI industry imports around half of its non-coking coal requirements from South Africa, Indonesia, Mozambique and Australia. South Africa and Indonesia are both part of Just Energy Transition Partnerships with the EU, United States, United Kingdom and others, which will support the clean energy transition of these countries through an investment plan.15,16. Both countries will, therefore, accelerate the shift from coal, potentially restricting future import sources for India.

Apart from changes in internal and global policies, the global fossil fuel industry will see significant reductions in investments as banks, especially those in developed countries, face increasing restrictions. Therefore, major mining companies may become unable to acquire the necessary funds for investment in new mining operations and the upkeep of existing operations in the coming decades.

Although natural gas supplies encounter similar challenges as other fossil fuels, the associated supply chain risks are significantly less severe. Diversification of natural gas sourcing is easier as several exporting countries (especially the Middle East and Russia) may continue to have favourable policies towards gas compared to coal. However, geopolitical events can disrupt and distort gas supply chains and lead to price fluctuations. Therefore, the Indian steel industry should plan for these supply chain disruptions while devising the energy transition strategy.

10.12. Action plan

The action plan for ensuring the process for enabling the transition to gas-based DRI making is discussed below, with timelines:

1. **Leverage scale for process transition to natural gas:** The expansion of steel production capacity should be leveraged to decarbonise the steel industry. The Ministry of Steel may consolidate the natural gas demand from the steel sector, particularly for new capacity, akin to the approach taken by the Solar Corporation of India Limited for renewable power and, more recently, for green hydrogen. The aggregation of these large volumes will allow the country to secure favourable long term contracts on liquefied natural gas supplies for the industry as a whole. The Ministry of Steel should coordinate with the Ministry of Petroleum and Natural Gas and other relevant stakeholders such as the steel producers and GAIL to develop this approach.
2. **Develop natural gas cost curve for India:** The Ministry of Steel may confer with all steel plants and industry associations to develop a natural gas cost-curve on an annual basis to reflect international dynamics such as fluctuating LNG prices and national dynamics like carbon price arising from the

India Carbon Market (ICM). Further, with the support of relevant government stakeholders, the Ministry of Steel may aggregate natural gas demand in the steel sector and negotiate with LNG suppliers to benefit from the economies of scale.

3. **Providing access to natural gas in India's iron and steel belt:** The Ministry of Steel, in consultation with all stakeholders, may accelerate the availability of piped natural gas in India's iron and steel belt. Efforts may be made to provide natural gas for all ISPs and steel clusters. A fact check on natural gas availability, distribution plans vis-à-vis geographic locations and the amount that may be available on a year-wise basis for steel production may be documented and publicised for the consumption of all steel industry and industry associations.

4. **Developing modular shaft furnaces:** The Ministry of Steel may confer with the established OEMs of gas-based DRI making and encourage them to provide smaller units that can be used by the coal-based DRI industry. Efforts may be made to develop indigenous manufacturing capacities for shaft furnaces.

5. **Group captive gas-based DRI production:** The Ministry of Steel may assess the feasibility of using common gas-based DRI plants to benefit from the economies of scale. In this concept, multiple private steel producers may jointly own and invest in setting up large gas-based steel capacity for DRI production. Efforts may be undertaken to supply gas at affordable rates to such projects. This approach is expected to distribute investment risks while advancing the uptake of clean technologies in the steel sector. It is envisaged that a pilot common gas-based DRI plant could be the first step towards demonstrating this concept.

6. **Co-developing and scaling up technologies for gasifying high-ash domestic coal:** The Ministry of Steel may collaborate with relevant stakeholders to co-develop and scale up technologies for gasifying high-ash domestic coal.

7. **Feasibility of a centralized coal gasification plant:** The Ministry of Steel may evaluate the feasibility of using a common coal gasification plant that can supply syngas to various small DRI units within SSI clusters.

Proposed studies

8. **Assess the role of coal gasification for process transition in the steel sector:** The Ministry of Steel may support a study to assess the role of coal gasification for process transition, primarily for large steel makers but also for smaller producers who use rotary kilns to produce DRIs. Detailed techno-economic and Life Cycle Analysis (LCA) of the coal gasification process and its comparison with other alternatives may help assess the prospects of this route for producing steel. Further, the study may also evaluate the role of using indigenous coal in the coal gasification process, identify related bottlenecks, and find appropriate solutions.
9. **Assess the role of alternative fuels for decarbonising rotary kilns:** The Ministry of Steel may support a detailed study to assess the role of various alternative fuels like biomass, natural gas, hydrogen, etc., for mitigating emissions from the rotary kiln. It is envisaged that the study may develop reaction kinetics or computational fluid dynamics (CFD) models, which may be validated by collecting actual data from the plants. Further, it is envisaged that pilot-scale operation for injecting various alternative fuels may be demonstrated in actual kilns.

CHAPTER 11

BIOCHAR FOR THE IRON AND STEEL INDUSTRY

11.1. Introduction

The iron and steel sector primarily relies on coal and coke to meet process heat requirements and as a reducing agent in steel production. To achieve the country's decarbonisation goals, there is a growing urgency to find environmentally friendly and sustainable substitutes for coal and coke in steel production. Biomass, as a renewable material derived from plants, holds promise for reducing emissions in steel production. Biochar is produced from biomass using different processes and has comparable metallurgical properties to coke. Biochar is a sustainable alternative for decarbonizing the steel industry and can potentially reduce the industry's environmental impact. It is a renewable carbon resource with the potential to substitute coal/ coke in iron and steel making. However, its widespread adoption in the industry faces stiff competition from traditional coal-based fuels. Biochar can be used along with coal through co-firing, which is recognised by United Nations Framework Convention on Climate Change (UNFCCC) to mitigate carbon emissions.

11.2. Global Scenario

Globally, the use of biomass in the production of iron and steel has been steadily rising, though it is still far less than that of conventional fossil fuels. Several countries across the globe have been investigating biomass co-firing, gasification, and direct reduction techniques through field trials to partially replace coal and coke in the production of steel. The iron and steel industry's ongoing research and development initiatives in various countries focus on improving biomass-based process scalability and efficiency[1]. The sections below present the status of biochar utilisation for steel-making.

11.2.1 Brazil

Biochar has a vital role to play as part of a broader decarbonisation portfolio for Brazil. The carbon-neutral biochar has been used in place of coal in small-scale blast furnace route to reduce the emission intensity of steel production by an estimated 0.4 T CO_2/tonne of crude steel (tcs). A study estimated that a substantial scale-up of biomass use alongside recycling could abate emissions by up to 65% in the steel sector. Brazil's integrated long steel producer, Aços Verde do Brasil (AVB), has become the world's first carbon-neutral steel producer and uses Eucalyptus charcoal instead of traditional coking coal, with plantations in 50,000 hectares for sustainable charcoal production. In 2020, AVB achieved negative emissions of about 0.04 T CO_2/tcs, while the world average emission was 1.88 T CO_2[2].According to the verification, AVB did not exceed 0.10 T and 0.06 T CO_2 per tcs, respectively, while the world average was 1.81 T and 1.83 T during the same period. To achieve this, AVB has adopted several measures and implemented various technologies, including biochar utilisation in BF-BOF. The Greenhouse Gas (GHG) Protocol and the Intergovernmental Panel on Climate Change (IPCC) have ratified the concept that charcoal is a carbon-neutral raw material. AVB plans to invest in developing a patented carbonisation furnace, which, if successful, will be used to produce all AVB's charcoal needs. This furnace will further help AVB reduce its CO_2 emissions and production costs.

11.2.2 Australia

The national science agency of Australia, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia developed a novel, self-sustaining pyrolysis method to produce charcoal, or "designer biochar," with the assistance of industry partners. Through the pyrolysis process, the innovative method generates biochar, a metallurgical grade of biocarbon that could potentially replace coal or coke in blast furnaces and electric arc furnaces within the iron and steel industry. A pilot plant can produce up to 1,000 tonnes of charcoal annually[3]. CSIRO has successfully acquired an exclusive global license deal from Pyrochar. In order to meet the criteria of these agreements, Pyrochar has already negotiated Memorandums of Understanding (MOUs) and off-take agreements for manufacturing biochar[4]. The Australian start-up is opening its first large-scale production facility, producing furnace-ready biocarbon for the heavy industry. Bamboo is the major feedstock for Pyrochar's initial production facility in Malaysia[5]. BlueScope, OneSteel, and CSIRO carried out a significant research and development program between 2006 and 2014 with the goal of developing novel, workable technologies that replace fossil fuels like coal with renewable biomass materials. The program included theoretical and pilot-scale combustion experiments demonstrating the higher performance of biochar relative to coal for blast furnace injection, as well as bench-scale testing of a revolutionary large-scale pyrolysis process and preliminary investigations of biomass supply in Australia. BlueScope has been researching the use of biochar as a coal substitute for part of the 400,000 tonnes of PCI coal injected annually in Port Kembla Steelwork's (PKSW) blast furnace. The University of New South Wales' Shen Lab will take the lead in developing a novel Renewable Injections-Sustainable Burdens (RISB) process for blast furnace iron-making. The renovation will cost $18.07 million and take five years to complete, beginning on March 1, 2021[6].

11.2.3 Sweden

FerroSilva — a joint initiative between KTH Royal Institute of Technology, Chalmers University of Technology, Ovako, Sveaskog, and several other organisations — has developed an innovative manufacturing process for fossil-free sponge iron. Initiated in 2020, the FerroSilva project produces biomass gas from forest byproducts, such as chipped branches and tops, in a fluidized bed to produce synthetic natural gas (syngas). The syngas produced has a similar carbon monoxide and hydrogen composition to reformed natural gas for use in iron ore pellet reduction via a regular shaft furnace process. FerroSilva's feasibility study revealed that the new method would be cheaper than other initiatives to make green sponge iron in Europe. The project's energy-efficient manufacturing process also generates several industrial inputs, including biochar and biogenic carbon dioxide. The project plans to construct its first factory at Ovako's Hofors plant, aiming to start production in 2026 with a production capacity of 50,000 tonnes per annum. FerroSilva has signed a letter of intent with Sveaskog for its input materials.

11.2.4 Canada

A group of French and Canadian businesses, including SUEZ, Groupe Rémabec, and Airex Energy, are investing C$80 million to build the largest biochar production facility in North America. This program demonstrates how biochar's potential for improving soil and sequestering carbon is becoming more recognised on a global scale. The factory will be situated at Port-Cartier, Quebec, Canada, on the Saint Lawrence River's northern bank.

11.2.5 United States of America

The biochar market in the USA was estimated at USD203.4 million in 2022 and is expected to expand at a compound annual growth rate (CAGR) of 11.3% between 2023 and 2030[7]. The U.S. Department of Energy (DOE) announced the selection of 33 projects to be awarded up to USD6 billion in funding aimed at advancing technologies to help significantly reduce emissions across hard-to-decarbonize industries across sectors, including steel, among others. Integrated producers, US Steel and Cliffs could reduce CO_2 emissions from their blast furnaces by 20-30% by the increased use of DRI, replacing pulverized coal injection (PCI) coal with biochar, and by increasing the use of scrap in the BOF (via preheat and melting).

11.3. India Scenario

The iron and steel manufacturers in India, such as Tata Steel and JSW and power generator National Thermal Power Corporation (NTPC), are utilising biochar on an experimental basis, which is discussed below.

11.3.1 Tata Steel

Tata Steel is one of the world's most geographically diversified steel producers, with an annual crude steel capacity of 34 million tonnes per annum (MTPA). Tata Steel is one of the few steel producers that are fully integrated – from mining to the manufacturing and marketing of finished products. Tata Steel has set a target of becoming net zero by 2045 in its strategy to achieve this ambition. Biochar has been identified as an alternate fuel to replace fossil fuels for Carbon Direct Avoidance (CDA) in the short- and medium-term. Biochar injection in blast furnace was envisaged to replace 10 % of the PCI[8].

11.3.2 Jindal Stainless Steel

Experiments studies show that bio-coal, made primarily of coconut shells, can function as a comparable reducing agent in terms of metallurgical characteristics. The advantages of the adoption of bio-coal include a reduction in carbon emissions, enhanced environmental performance, and a more sustainable method of producing steel. The findings of this study provide significant insights into the transition towards a cleaner and more sustainable practice for the steel industry.A carbon recovery rate of 76% on average is attained for various grades of stainless steel. More than 85% carbon recovery in grades like 201 & and JSLUDD demonstrates how effective bio-coal blends are as reducing agents in the steel-making process. This could also be a key enabler in transitioning from a high to a low carbon economy and a successful driver to achieve NetZero ambitious path for any Industry as well as the Nation[9].

11.3.3 Other industries

National Thermal Power Corporation (NTPC) has successfully demonstrated 20% co-firing of torrefied biomass along with thermal coal) at its 110 MW thermal power plant in Tanda Uttar Pradesh. this test was a part of its effort to reduce emissions its emissions intensity by expanding biomass cofiring across its coal-fired fleet. Currently, the company co-fires 7–10% non-torrefied biomass at the Dadri power plant near Delhi, which is owned by NTPC. In a statement issued by NTPC, it states that torrefied biomass can be used at greater co-firing percentages without requiring major changes to the system. Additionally, the cost and gross calorific value (GCV) of torrefied biomass pellets are comparable to those of imported coal. In the long run, costs may decrease as technology and the industry mature. Contracts for the delivery of biomass totalling approximately 5.2 million tonnes (MT) have been given by NTPC to 20 of its own power plants and one joint venture facility. It is constructing a 50 TPD non-torrefied pellet plant in Dadri and a 100 TPD torrefied and non-torrefied pellet plant at the joint venture Aravali Power's Jhajjar plant.

11.4. Categorisation of Biomass and surplus availability

Biomass can be broadly grouped into the following categories

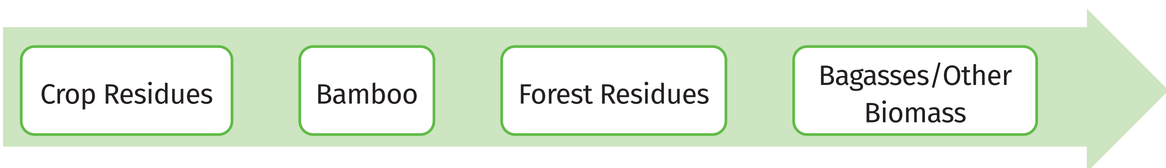


Figure 11.1: *Different categories of biomass resources*

11.4.1 Crop residues

Ministry of New & Renewable Energy (MNRE) has commissioned a study that quantifies the surplus biomass of different crops in three crop growing seasons (Kharif, Rabi, and Summer) in 254 districts spread across 28 states and eight Union Territories of India. The total area used for the selected 54 crops is 198.11 million hectares with a total biomass potential of 745 MT, and the total surplus biomass was estimated as 228.52 MT[10]. Cotton, rice straw, wheat straw, and maize are the top four crops, followed by sugarcane. At least 50% of the total cotton stalks and 20% of the total rice and wheat straw are available as surplus. The share of different regions of the country in total surplus availability of biomass is shown in figure 11.2.

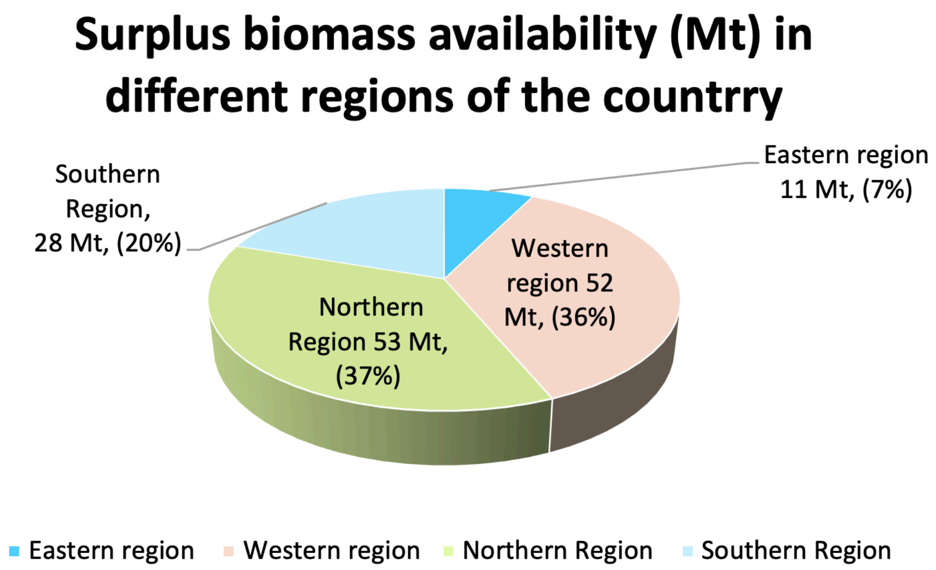


Figure 11.2: *Surplus biomass available and region-wise distribution of major crop residues*

11.4.2 Bamboo

India is the second-largest producer of bamboo in the world. The total bamboo-bearing area of the country has been estimated to be 15 million hectares, with an estimated green weight of bamboo culms at the national level of 402 MT, of which green sound bamboo contributes 66%, and dry sound bamboo is the remaining 34%. Total bamboo with culm size above 5 cm is 156 MT, of which green sound bamboo is 70% and the remaining is dry sound bamboo. The North-East region constitutes 44% of the total bamboo production. The major bamboo production areas with green sound culm are Arunachal Pradesh (38.08 MT), Assam (33.98 MT), Nagaland (24.04 MT) and Karnataka (50.58 MT). Major dry sound culms weight-bearing areas are Andhra Pradesh (14.96 MT), Karnataka (14.43 MT) and Maharashtra (13.26 MT).

The Government of India launched a restructured National Bamboo Mission (NBM) in 2018 with the objective of increasing the area under bamboo plantations in non-forest government and private lands to supplement farm income and contribute towards resilience to climate change as well as the availability of quality raw material requirements of industries. The prevailing NBM policy framework provides a window of opportunity for the steel industry to explore the feasibility of bamboo as a raw material to substitute coal and coke to explore the true potential of the bamboo market for high-value addition. The viability of bamboo in the steel sector can address the short-term goals of net zero emissions committed by the Government of India.

11.4.3 Forest residues

The annual net and gross pine needles yield in 2018 was estimated to be 68 MT and 59 MT, respectively. India produces 470 million tonnes of Lantana Camara annually, and it is among the top ten most harmful and invasive weeds in nature. Most herbivores avoid eating Lantana Camara; Lantana poisoning has caused severe economic losses and was the dominant cause of livestock mortality and morbidity. It matures faster than any other woody plant, taking an average of three years. While India has a rich diversity of forests, Lantana Camara has successfully invaded most parts of the country and threatened forest diversity. This weed kills native species of plants on which herbivores thrive and thus threatens forest diversity.

11.4.4 Bagasse/other biomass

Sugarcane bagasse (SCB) is one of the world's most abundant agricultural residues. About 100 MT of bagasse is produced annually in India. Current use of SCB is restricted to cogeneration of steam and power and as raw material for agro-based pulp and paper mills. Lignocellulosic biomass is the most energy-efficient type of biomass and is suitable for use as a source of thermal energy. Lignocellulosic biomass comprises of yard trimmings, energy crops, forestry waste, and agricultural waste. It is also one of the best possibilities for industrial application due to its widespread availability around the globe, low cost, and minimal greenhouse gas emissions.

11.4.5 Proximate analysis of biomass sources

The proximate analysis of various biomass sources is shown in table 11.1.

Table 11.1: *Proximate analysis of biomass sources*

Biomass species	Calorific value (kcal/kg)	Volatile Matter (%)	Ash content (%)	Fixed Carbon (%)
Crop residues				
Jowar stalk	4,465	78.50	9.50	12
Musturad Stalk	4,473	77.40	8.20	14.40
Musturad Shell	4,300	78.90	3.70	17.40
Soybean Husk	4,219	77.90	7.20	14.90
Wheat Straw	4,150	77.30	8.00	14.70
Sweet Sorghum Stalk	4,124	76.00	7.40	16.60
Wheat Stalk	3,912	78.70	5.70	15.60
Rice Husk	3,618	67.00	17.60	15.40
Gram stalk & Husk	3,600	72.00	11.00	17.00
Paddy straw	3,470	72.70	15.50	11.80
Forest residue				
Lantana	4,762	78.70	1.80	19.50
Pine needle	4,750	72.40	1.50	26.10

Eucalyptus	4,321	81.00	1.20	17.80
Subabul	3,980	85.20	1.00	13.80
Bamboo				
Bamboo	4,218	76.50	5.80	17.70
Bagasse/Other biomass residues				
Bagasse	4216	82.00	3	15.00
Coconut shell Char	7,538	14.20	1.20	84.60
Arecanut shell	4,750	78.30	0.90	20.80
Plywood	4,711	74.20	4.00	21.80
Babool	4,707	77.10	0.90	22.00
Groundnut shell	4,680	77.90	2.30	19.80
Cashew nut shell	4,606	79.80	1.40	18.80
Cotton shell	4,360	72.20	4.60	23.20
Palm Kernel	4,317	76.40	4.10	19.50
Jowar stick	4,465	78.50	9.50	12.00
Kikar	4,472	77.90	1.90	20.20
Rice husk	3,300	65.00	20.40	15.00

Source: *Grover et al. 2002*

11.5. Definition of biochar and production processes

Biochar is a carbon-rich solid material derived from biomass, produced through thermochemical transformation of biomass feedstocks. Biochar has the potential to reduce GHG emissions and mitigate the use of fossil-based materials in iron ore sintering, coke-making, and iron-making processes. The properties of biochar, such as its density, compression strength, calorific value, reactivity, and electrical properties, vary depending on factors like the type of biomass used and the carbonisation temperature. It is recognised as a superior reductant (FAO, 1983) compared to coke. Pulverised biochar can also be injected into a blast furnace in place of PCI.

11.5.1 Production of biochar

Biochar can be produced from biomass using different processes, of which torrefaction and pyrolysis are the most widely adopted processes globally. These are explained below:

11.5.1.1 Torrefaction

Torrefaction is a thermochemical process typically at 200-350°C in the absence of oxygen, at atmospheric pressure with low particle heating rates and a reactor time of one hour. The process causes biomass to decompose partly, creating torrefied biomass or char, also referred to as “bio-coal”. Bio-coal has a higher energy content per unit volume, and torrefaction followed by pelletisation at the harvest sites facilitates transport over longer distances.

11.5.1.2 Gasification

Gasification is the thermochemical conversion of solid materials (biomass or waste) to combustible gas and biochar. Typically, gas (which can be used for various purposes like generating heat and power, as well as in making fuels and chemicals) has been seen as the main product. In a typical gasifier, thus, the focus was on more gas generation and less biochar production. However, the latest technological developments in the sector allow more biochar generation. There are downdraft gasifiers now available which can generate up to 25-30% biochar (this is as high as biochar generated by pyrolyzers). Gasifiers have the added advantage of generating gas that can be used for a variety of applications. Gasifiers thus allow for the use of almost 85% of the input energy. The fixed carbon in biochar can be as high as 85%, depending on the type and properties of the biomass used.

11.5.1.3 Pyrolysis

Pyrolysis is a thermochemical decomposition of biomass into a range of useful products, either in the total absence of oxidizing agents or with a limited supply that does not permit gasification to an appreciable extent. Here, carbonisation takes place at noticeably excessive temperatures. Pyrolysis of biomass is typically carried out in a temperature range of 300-650°C compared to 800-1,000°C for gasification and 200-300°C for torrefaction. Slow pyrolysis is performed under the conditions of slow heating rates, low temperatures, and longer residence times in the inert atmosphere. This type of pyrolysis produces solid, liquid, and gaseous products in significant amounts.

The comparison of process conditions of biochar and coke are given in table 11.2. As can be seen from the table, the yield is low for biochar compared to coke. However, biochar has the advantage that it can be produced at relatively low temperatures and has better thermal conductivity and specific heat compared to coke.

Table 11.2: *Comparison of coke and biochar process conditions*

Coal to coke yield: 0.81	**Biomass to bio-char yield:** 0.25
Coking temperature: 1000 °C	**Biochar temperature:** 400-800 °C
Coal density: ~ 1000 kg/m^3	**Density of agro residues:** 600 kg/m^3
Thermal conductivity of Coal: 0.25 W/m/K	**Thermal conductivity of Biomass:** 0.10 W/mK
Specific heat of coal: 1.26 kJ/Kg/K	**Specific heat of Biomass:** 1.75 KJ/KgK

The mechanical properties of biochar, coal, and coke are provided in table 11.3.

Table 11.3: *Mechanical properties of biochar, coal, and coke*

Sample	Mechanical durability (%)	Compression Strength (N)	Fixed Carbon (Wt. % dry basis)	Volatile matter (Dry basis)	Ultimate analysis (Wt. %, dry basis)				
					C	H	N	O	S
biochar	91.8-93.6	20-60	82.8 – 85.2	13.1- 15.9	83.5 – 88.1	1.95 – 2.51	<0.50	7.14 – 8.68	<0.01
Coal	99.4	50	59.3	38.8	78.3	4.72	1.61	13.77	0.35
Semi-coke	99.8	80	88.6	5.4	88.5	1.24	1.44	2.64	0.31
Metallurgical Coke	99.8	100	87.9	0.9	87.7	0.21	1.75	0.31	0.57

11.5.2 Pyrolysis process - CAPEX and OPEX estimates

The estimates of the capital expenditure (CAPEX) for establishing the facility and the operational expenditure (OPEX) for the slow pyrolysis process of one ton per day capacity are provided in the table 11.4 and 11.5, respectively.

Table 11.4: *CAPEX for slow pyrolysis process*
(Capacity: 1 Ton biochar/ day)

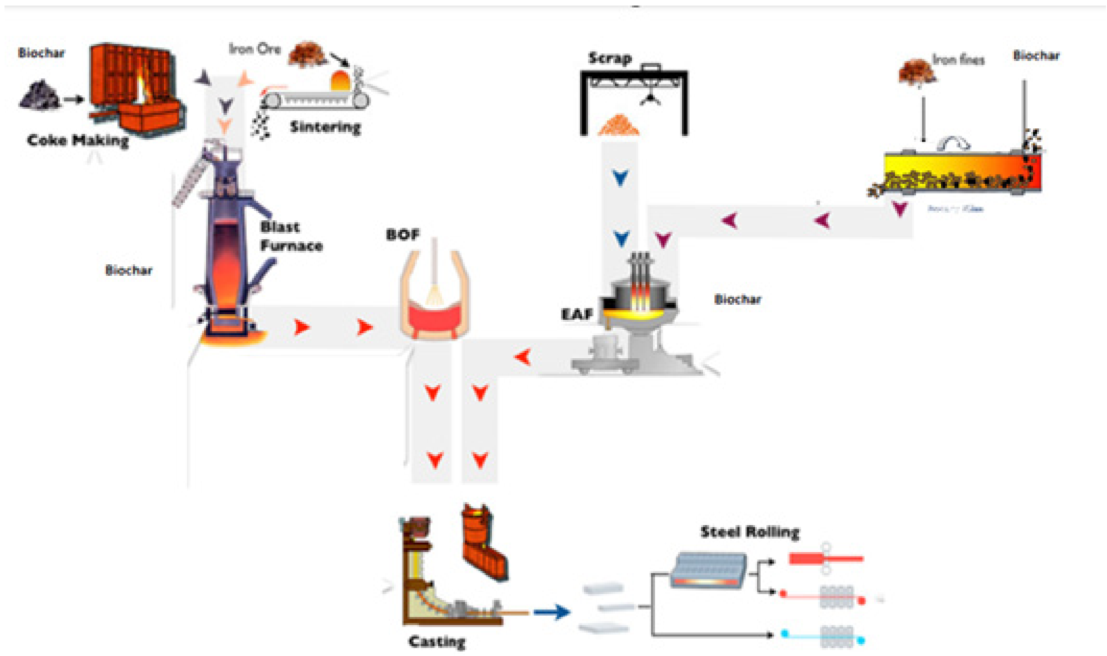
Description	Cost (INR)
Slow Pyrolysis Reactor	10,00,000
Installation	200,000
Land Preparation	100,000
Exhaust Wet Scrubber	150,000
Miscellaneous Costs	50,000
Total CAPEX	15,00,000
Wheat Stalk	3,912

Table 11.5: *OPEX for slow pyrolysis process*
(Capacity: 1 Ton biochar/ day)

Description	Cost (INR)
Labor Costs	3,000
Biomass Procurement	4,000
Utilities (Electricity, Water)	1500
Maintenance	200
Miscellaneous	200
Total OPEX per Day	8,900
Wheat Stalk	3,912

The Biochar used shall be in terms of Kcal of energy being replaced of Coal/Coke and the rate to be adjusted accordingly.

11.6. Suitability of Biochar for the Iron and Steel Industry



The schematic diagram of biochar usage in iron and steel making is given in figure 11.3.

Source: https://www.akademiabaru.com/doc/ARSRV2_N1_P19_40.pdf

Biochar's thermochemical and mechanical properties make it a potential resource for the iron and steel industry, both as fuel and reductant and it can replace coal/coke in various subprocesses. The potential applications of biochar for the steel industry are as follows:

1. Biochar as fuel in iron ore sintering
2. Biochar as raw material mix in Pellet making
3. Biochar as coal blend in coke making
4. Biochar in Blast furnaces for replacing PCI
5. Biochar in mini blast furnaces
6. Biochar for replacing non-coking coal in DRI production in horizontal rotary kilns
7. Biochar utilisation in electric arc furnaces

The sections below describe the above-mentioned applications of biochar in detail:

11.6.1. Biochar as fuel in iron ore sintering

Coke breeze or coal with low volatiles can be used as fuel for sintering in the amount of 3 – 5 % (kg/kg). Biomass, after severe torrefaction, allows partial replacement of coke breeze and/or anthracite at 20–25 % (kg/kg)[14,15] without degrading the properties of the iron ore sinter. The biochar demand in sintering is estimated at 1.01 MTPA. Despite challenges, findings suggest feasible substitution levels without compromising sinter quality, highlighting the potential for sustainable fuel alternatives in iron ore sintering[24].

11.6.2 Biochar as raw material mix in pellet making

Biochar can be used as a raw material mix in pellet making. The total production of the pellet industry is 94 MT in 2023-24, as per the Joint Plant Committee (JPC). The production of pellets involves making a batch mixture of iron ore, coal, coke, and dolomite and binding chemical (bentonite) into green balls, followed by heating green balls in an induration furnace at a temperature of up to 1350^{0}C. The typical energy consumption for pelletisation ranges from 0.36 to 0.40 Gcal/t output . Apart from the thermal energy requirement in pellet production, coal with low volatiles is used in the raw material mix for pellet making in the amount of 0.05 – 0.14% (kg/kg), depending upon the pellet manufacturing technology. The requirement for coal is practically the same in pellet mix as that for the sintering process. Assuming coke breeze/ coal replacement at 20-25% without degrading properties of pellets, a practicable maximum level of biochar demand in pellet making is estimated as 0.23 MTPA.

11.6.3 Biochar as coal blend in coke making

Biochar can be used as a coal blend in the coke-making process. During the coke-making process, coking coal undergoes several chemical and physical changes, including softening, swelling, shrinkage, and re-solidification, which are requirements for forming a strong coke structure. Coke quality should meet strict requirements for application in blast furnaces because they are the main consumers. A part of the coal in the coal blend can be replaced by biomass and obtained at a temperature of 1100°C to produce biocoke. Biocoke meets the requirements of blast furnace grade coke, but it is more challenging, as part of the coking coal is replaced by carbon bio-carriers. Biocoke has increased porosity, coke reactivity index (CRI), and reduced strength after a reaction with CO_2 Coke Strength after Reaction (CSR) compared to the coke from which it is made. Biocoke has a sufficiently high Fixed Carbon and low Volatile Matter. Compared to conventional coke, biocoke has a lower value of ash and sulfur due to the replacement of coal within the blend.

Raw biomass can be added to the coal blend only in a small amount of up to 3 % (kg/kg)[10], which does not adversely affect the properties of the coke. However, after preliminary heat treatment and compaction of the biomass, its use can be increased up to 10 % (kg/kg)[11]. The use of torrefied biomass in coke making is limited because it adversely affects the coke quality. The torrefied biomass in the coal blend acts as an inert material, reducing the caking ability of the blend[12]. Generally, the advantage of using biocoke compared to coke breeze is that the ash content is much lower, guaranteeing a smaller particulate matter content in the flue gas. Coking coal despatch from Indian mines in 2022-23 was 59.413 MTPA[18], while import in 2022-23 was 56.053 MTPA[19]. Thus, a total of 115.466 MTPA coking coal may be assumed to be consumed in India, and 11.5 MTPA of torrefied and compacted biomass can be consumed through biocoke production.

Biochar has the potential to substitute coke in steel industries, but the extent to which it can substitute coke has to be explored in full potential and it majorly depends on the fixed carbon range, calorific value, and other physiochemical properties. Biochar from the forest residues has the potential to substitute or blend with the coke by at least 5%, which requires 24.64 MT of bamboo.

Currently, research is going on biochar utilisation in blast furnaces in the following areas:

- Research in substituting fossil-based reducing agents with renewable biomass-based alternatives, particularly in the blast furnace, has mainly focused on charcoal
- Potential substitution rates, especially with charcoal injection, could reach up to 200 kg/tHM. Current findings suggest a 5% share of charcoal in coal blend for metallurgical coke production
- Optimising coke production processes and exploring sustainable alternatives[31].

Comparative strength values of coal, biocoke, and metallurgical Coke are provided in Annexure III.

11.6.4 Biochar in blast furnaces for replacement of PCI

In conventional PCI technology, non-coking or weakly coking coals are injected into the raceways of a blast furnace to partially replace the coke. This technology is the most efficient method of replacing non-renewable fuels in the blast furnace with different carbon carriers like waste plastics and biomass. Biochar can potentially be substituted for pulverised coal currently injected directly into blast furnaces. Biomass injection into blast furnaces, at a level of up to 1.8 GJ/thm[20], is already applied commercially in Brazil. The high yield of Volatile matter (VM) in torrefied biomass limits the replacement of coal in PCI between 20 to 40 % (kg/kg)[21]. Biochar demand in blast furnaces in iron-making is estimated at 5.2 MTPA.

11.6.5 Biochar in mini-blast furnaces

Globally, some blast furnaces currently operate entirely using biomass. The differing mechanical properties of charcoal compared to coke means that these are smaller furnaces. Charcoal is used in mini blast furnaces with a production capacity of 40,000 – 350,000 tpa[23]. The advantages of the mini blast furnaces are low emissions, low sulfur content in the iron, and low slag volumes. The carbonisation temperature for charcoal can range from 300 – 700^{o}C, depending on the quality requirements. In Brazil, where charcoal use in steel production is currently quite prevalent, blast furnaces running almost solely on charcoal contribute only a small proportion of national production.

11.6.7 Biochar for replacing non-coking coal in coal-DRI process

The surplus availability of biomass shows that about 36.76 MT of biochar can be produced, which can substitute 100% of non-coking coal in the DRI steel-making process. However, the type of biomass used for biochar processing will be dependent on the regional-specific biomass and the physiochemical properties of that specific biomass-based biochar.

11.6.8 Biochar in Electric Arc Furnaces

The use of torrefied biomass is practically limited in EAFs even though there are no strict requirements for the strength of the carbon source for use in an EAF. Instead, the use of biocoke up to 100 % (kg/kg) as a carbon source is possible even with a high additive amount of torrefied biomass up to 50% within the coal blend because it can meet the requirements for this process in terms of the VM and has sufficient amount of FC > 85% for carburizing the steel or creating foaming slag to improve the energy efficiency of the melting process. A practicable maximum level of biochar demand in EAF may be assumed as 0.365 MTPA. Considering 43.5 MTPA of DRI production in the country, there is a scope of demand for 0.8 MTPA of torrefied biomass that can be consumed as biocoke in EAFs. Biochar's calorific value typically lies in the range of 6500-7500 kcal/kg and fixed Carbon in the range of 65-75%. Considering the calorific value of Coke ~7200 kcal/kg and fixed carbon value of 86%, the typical replacement ratio of biochar would be as shown in the table 11.6.

Table 11.6: *Typical replacement ratio of biochar in EAF*

S.no	Description	Ratio
1	Energy content	0.9 - 1.04
2	Reduction	0.76 - 0.87

Source: *Chemistry test of biochar samples at JSW Dolvi and vendor reports*

The applicability of biochar in iron and steel-making sub-processes, discussed above, is summarized in table 11.7:

Table 11.7: *Biochar applicability in various sub-processes of iron and steel making*

S.no	Iron and steel processes	Type of biochar/biofuel	Type of energy/fuel replacement in existing setup
1	Sinter	Severely torrified biomass	Coke breeze/anthracite – heating for agglomeration
2	Pellet	Severely torrified biomass	Coke breeze/anthracite/coking coal – heating for agglomeration
3	Coke	Heat-treated/compacted biomass	Replacement of coking coal in blend – used as reductant and for heating in Blast furnace
4	Iron making – BF	Torrified biomass having low VM	Replacement of coking coal used in PCI for heating and reductant requirements
5	Iron making- DRI	Heat-treated/compacted biomass	Replacement of coking coal in blend – used as reductant and for heating in Blast furnace
6	Steel- EAF	Heat-treated/compacted biomass	Replacement of coking coal – used as charge carbon, foaming agent and steel recarburizer in EAF

11.7. Emission reduction potential of biochar in steel industry

Biochar can be used in BF-BOF and the EAF route. The biomass-derived materials are being produced renewably, i.e., the CO_2 emitted through their use is balanced by CO_2 captured from the atmosphere for its growth. The emission reduction potential of biochar utilisation in various subprocesses of iron and steel making is given in table 11.8.

Table 11.8: *CO_2 reduction potential of different processes using biochar*

Sr. No.	Iron/Steel making process	Biochar usage limit in existing setup without major modification	Emission reduction potential (tCO_2/TCS) (depending upon the replacement of existing fossils)	Emission reduction potential range In percentage (%)	Break-even cost of bio-char (Rs./Kg)
1	Sinter making	Modification is not required for replacing up to 20-25% Coke Breeze (by weight)	0.12 - 0.32	5-13 %	17 - 27
2	Pellet making	Modification is not required for replacing up to 20-25% Coke Breeze (by weight)	0.12 - 0.32	5-13 %	17 - 27
3	Coke making	Modification is not required for replacing up to 3% coal in blend (by weight)	0.02 - 0.11	1-5 %	21 - 28
4	Iron making - BFs	Modification is not required for replacing up to 20-40% PCI (by weight)	0.41 - 0.55	17-24 %	15 - 22
5	Iron making - Coal DRI	Modification is not required for replacing up to 50-60% coal (by weight)	0.99-1.19	40-50 %	17 - 27
6	Biomass in EAF	Modification is not required for replacing up to 100% coal (by weight)	0.029 - 0.057	1-3 %	17 - 27

Source: *Use of Biochar in the iron and steel industry - John Mathieson et al. 2011 (In view of the Price of Biochar Rs/ Kg to replace Fossil fuel to be considered while estimation)*

Hence, there is a total replacement and emission reduction potential of 0.7 - 1.29 t-CO_2/tcs for the integrated route and 0.029 - 0.057 t-CO_2/tcs for the EAF route. This analysis indicates that the largest potential gains are within the integrated route, where BF pulverised fuel injection has the greatest impact and is a crucial area for further R&D.

Carbon credits and carbon markets: The Government of India intends to create the Indian Carbon Market (ICM) to decarbonise the Indian economy by putting a price on GHG emissions through a trading scheme for Carbon Credit Certificates. The Bureau of Energy Efficiency, the Ministry of Power, and the Ministry of Environment, Forest & Climate Change are developing the Carbon Credit Trading Scheme for this purpose. The ICM is also planning on developing methodologies for estimating carbon emissions reductions and removals from various registered projects and stipulating the required validation, registration, verification, and issuance processes to operationalise the scheme. Monitoring, Reporting, and Verification (MRV) guidelines for the emissions scheme are also expected to be developed through this process. The Ministry of Power has also announced a carbon offset market, where the obligated entities may be given a target for emissions reduction in the compliance mechanism. In contrast, non-obligated entities can register their projects as per the published sectoral methodologies for accounting GHG emission reduction, removal, or avoidance for issuance of Carbon Credit Certificates in the offset mechanism. India's compliance carbon market is set to kick off in 2026 with the most hard-to-abate sectors such as steel, iron ore, refineries, petrochemicals, aluminium, etc.

Using biochar in the steel sector could be a valuable policy that supports India's decarbonisation aims while they earn carbon credit certificates for obligatory or voluntary emissions reductions.

While these processes come into play, the steel-producing units may also choose to start their learning curve through other voluntary reduction options. The global voluntary markets are also open to biochar-based emissions reduction certification. The voluntary markets offer exchangeable carbon dioxide removal credits (CDRCs) for biochar applications in a newly emerging marketplace. Several voluntary marketplaces have either developed or adopted GHG reduction estimation methodologies from biochar to enable biochar producers and users to obtain carbon removal credits and financing. Verra and Gold Standard - two of the most significant carbon registries and certification agencies for voluntary reductions have put in place methodologies and provisions for biochar projects. This market has been operational for more than two years. Indian steel and biochar production units may use this to finance their blending initiatives. The amount of funds generated here would depend on the actual emissions reductions due to the blending initiatives as well as the price of Carbon in the voluntary/ mandatory markets.

11.8. Abatement accounting

The standards provided by World Steel Association (worldsteel) do not impose any restrictions on charcoal consumption, considering zero as the emissions factor for all charcoal input sources. However, other EU regulations, such as CBAM guidelines, provide a more comprehensive accounting standard, with checks on meeting sustainability criteria for agricultural/forestry biomass, state, installation year, meeting of GHG saving criteria, etc., before assuming zero as the emissions factor for the biomass fraction.

11.9. Cost-effectiveness of Biochar utilisation for the steel industry

The adoption of alternate fuels such as biochar is heavily reliant on the switch-over to cost positive/ neutral. Table 11.9 below summarises the max cost of bio-char for each of the two scenarios calculated as per this:

Table 11.9: *Break-even cost of biochar*

		Emission factor	Replacement ratio	Fuel cost	Break-even cost of bio-char w/o C-tax
1	UOM	(kg CO_2/kg fuel)	(kg fuel/ kg biochar)	(Rs./kg)	(Rs./kg)
2	Coke	3.15	0.76 - 0.87	28-32	21 - 28
3	Coking coal	2.92	0.82 - 0.94	21-29	17 - 27

		Emission factor	Replacement ratio	Fuel cost	Break-even cost of bio-char w/o C-tax
4	PCI	2.5	0.95 - 1.1	16-20	15 - 22
5	Nut coke	3.15	0.76 - 0.87	28-32	22 - 28

Source: *WSA guidelines for CO_2 emissions accounting, charcoal vendors*

11.10. Projection of bio-char demand in iron and steel industry

The key challenges associated with the production and utilisation of biochar in the iron and steel industry are summarised in this section. The big challenge is the availability of biomass in the desired quantity to meet the demand of the iron and steel industry. The estimated demand for carbon offsetting in the iron and steel industry for the immediate, short, and long term is estimated and provided in table 11.9 below, with different percentages of partial replacement of coal with biochar.

Table 11.10: *Detailed estimates of biochar demand in the Iron and steel industry for the immediate term, short-term, and long-term*

S.no	Parameter	Annual
1. Typical estimation of practicable biochar demand in sintering		
a	Hot metal production in FY2024, MTPA[15]	87.04
b	Gross sinter production (assuming 1.3 times hot metal production), MTPA	113.15
c	Coke breeze consumption in the Sinter Plant (assuming 0.04 times gross sinter production), MTPA	4.20
d	Biochar demand (considering 25% replacement) MTPA	1.05
2. Typical estimation of practicable biochar demand in BF		
a	Hot metal production in FY 2024, MTPA[16]	87.04
b	Assuming PCI injection, kg/thm	150.00
c	PCI consumption, MTPA	13.00
d	Biochar demand (max 40% replacement) MTPA	4.80
3. Typical estimation of practicable biochar demand in EAF		
a	Crude steel Production in FY 2024 in India, MTPA[17]	144.3
b	Share of electric route in FY 2024 in India, %4	57
c	Ratio of EAF/EIF steel capacity in India5	1.17
d	Crude Steel by EAF, MT	31.6
e	Typical coal consumption in EAF, kg/ts	20.00
f	Coal consumption in EAF in India, MTPA	0.73
g	Biochar demand (max 50 % replacement), MTPA	0.37

4. Iron making - Coal DRI (coal (by weight))		
a	Sponge Iron Production in FY2024 in India	52.6
b	Domestic coal consumption per ton of HM (ranges from 1.4 to 1.6 tonne-coal/ tonne-DRI (t-coal/t-DRI))	72
c	Biochar demand (max 50 % replacement), MTPA	24.93
5. Typical estimation of practicable biochar demand in Pellet making (Coke breeze)		
a	Hot metal production in FY 2024, MTPA[22]	87.04
b	Gross pellet production (as per the estimates of Hot metal production in 2024) MTPA	26.69
c	Coke breeze consumption in the Pellet Plant (assuming 0.04 times gross sinter production), MTPA (Considering coke consumption of 40 kg per tonne of pellet)	1.07
d	Biochar demand (considering 25% replacement) MTPA	0.27
6	**Biochar requirement in Coke making (coal in blend (by weight))**	1.09
7	**Total estimated demand for biochar in the Iron and steel-making industry in MTPA**	32.50

11.11.Challenges Associated With Biochar Availability

- Biomass production, collection, and storage: Biomass is a very dispersed resource and is available in bulk quantities in a very narrow window of 15 days every 5 to 6 months interval after the harvest of Karif and rabi crops. Lack of mechanisation in the farm residue management process, storage infrastructure, high cost of transportation, and absence of market mechanisms make it economically unavailable to collect and process the same into biochar. Feedstock planning can be improved, where an NGO-based cultivation program can be launched and implemented under the Public Private Partnership (PPP) mode. Absence of storage infrastructure and market mechanisms: although India has been successful in establishing storage facilities for agricultural products, on the contrary, at the present absence of farm residue storage infrastructure discourages farmers from collecting the farm residue, and hence, the farmers are forced to fire the farm residue in the field causing air pollution.
- Inadequate players in the ecosystem: The absence of storage infrastructure and market mechanisms for biomass collection, storage, and trade have been a stumbling block to attracting private sector investments and, hence, low participation by the private sector.
- The constraints include the absence of scientific data on the availability of biomass resources, the data associated with the benefits of Biomass in the existing steel-making process and the type of modifications or retrofitting required for efficient utilisation of biochar in the existing furnace.

11.11.1 Challenges associated with access to technology.

- Lack of large-scale biochar production facilities largely accounts for the lack of access to preprocessing technologies for efficient conversion of Biomass into different grades of biochar production for utilisation in the steel industry.
- Lack of indigenous technologies: Since this area of research could not attract sufficient funds for research and development activities, many of the technological challenges associated with biochar production technologies and utilisation in the existing steel manufacturing plants at a commercial

scale are unanswered.

- Lack of partnerships with the global steel community with an emphasis on Technology transfer associated with the biochar production and utilisation of Biomass in the steel industry.

11.11.2 Challenges associated with financial instruments and incentive mechanism

- Absence of public as well as private sector investments into the building an ecosystem for biomass collection, storage, and transportation

- Since the bulk of the Biomass is available in a very short period and the material needs to be stored and utilised for the rest of the system, the small-scale biomass aggregators face the challenges associated with the working capital

- In the past, the lack of demand for biochar resulted in sub-critical participation of the private sector, consequently attracting limited financial investments. Hence, there is a need to establish a buy-back guarantee for the biochar to attract private-sector investments in this sector in the future. Also, exemption from Goods and Services Tax (GST) and other tax incentives would act as a catalyst to attract private sector participation in this sector.

11.11.3 Challenges associated with energy plantation.

Currently, there are limited schemes and incentives in a few states to promote energy crop plantations such as bamboo, hence limited participation from the farmer community.

11.12. Action plan

The ministry proposes the following action plan for the promotion of biochar in the Iron and steel industry:

- **Support Research and Development Activities:** Ministry of Steel (MoS) may support R&D in the field of Biochar to develop and promote indigenous technologies both for conversion technologies for the production of biochar from different kinds of biomass and for customising existing furnaces to adopt biochar in iron and steel making, engaging diverse stakeholders such as academia, research institutes, central and state government agencies, think tanks, and industry. In view of feedstock availability issues, it is recommended that pilots be introduced in states with steel manufacturing plants in proximity to the feedstock to optimise feedstock/bio-char transportation costs (reducing scope 2 emissions). Off-take based mandates for bio-char utilisation in steel players would also ensure private investor confidence.

- **Development of ecosystem for biochar production:** Special emphasis may be placed on the development of the ecosystem for biomass production (plantation), biomass conversion, collection, storage, transportation and trading. The support provision may be included under programs similar to the Clean Energy Research Initiative (CERI). A PPP model may also be promoted for this purpose.

- **Blending mandate:** To meet the decarbonisation goals, the iron and steel sector may be encouraged to use biochar from farm waste, bamboo, and agri-residue-based in steel production. MoS may develop a policy framework for mandating a certain percentage blend of biochar along with coal after assessing the techno-economic feasibility, safety aspects, etc. A graded bio-char blending mandate can be introduced for steel players with off-take agreements for 10 years, with higher mandates depending on technology maturity and cost economics stabilisation.

- **International collaborations to facilitate technology transfer:** Global Biofuel Alliance (GBA) was launched during India's presidency at the G20 summit held in September 2023. GBA may be leveraged to promote biochar for the steel industry, which may be included under the activities of the Alliance. Such global partnerships may be explored to identify global best practices and cross-learning in setting up the ecosystem, as well as exchange technologies for efficient conversion of Biomass to Biochar and its utilisation in iron and steel making and pilot demonstration projects.

- **Market mechanisms:** MoS may coordinate with relevant ministries to bring different types of biomass suitable for biochar-making under a Minimum Support Price Scheme of the Ministry of Agriculture and Farmers Welfare applicable across India under the commercial crop category, similar to raw jute. Fair and Remunerative Price/ State Advised Prices, as in the case of sugarcane procurement for ethanol and sugar production, could be a model to be followed for all types of biochar feedstocks. The Ministry of Steel, in consultation with relevant stakeholders, may evolve a similar system for procuring agri-residue and other biomass feedstock for biochar plants. This would ensure minimum profits for the cultivators and a floor price for the biochar units that are procured. The pricing may be based on quality-based type and grading of biomass feedstocks. The existing structure developed under the Agricultural Produce Market Acts and the National Agriculture Market (NAM) may be leveraged to create a unified, transparent market for biomass for biochar. In addition, this may complement the state-level planning of biomass resources to ensure sufficient availability and prevent competing uses.

- **Working Capital Support for biomass aggregators:** One of the models for feedstock procurement for biochar plants could be the aggregator model, wherein an independent player undertakes the efforts to collect the agri-residue like rice straws from the farms during the relevant cropping seasons and ensure appropriate storage for smooth supply across the year. The aggregators become a valuable player in the ecosystem, whereas the steel plants are not directly involved in biomass-to-biochar conversion. In such a case, supporting and encouraging the aggregators becomes very crucial. Incentives to ease access to working capital under programs similar to the Mudra Loan Yojana may go a long way in promoting the aggregators. Detailed estimates of the funds required need to be assessed. Special incentives may also be announced for biomass aggregation on similar lines as the Bio-CNG model, where biomass aggregation machinery is supported through financial assistance programs)

- **Tax exemption or tax holidays:** MoS may coordinate with other relevant Ministries to reduce GST on Biochar meant for the blending scheme from 18% to 5%, which would bring down the cost of uptake of biochar in the steel industry.

- **Support for plantation activities:** Although not a direct subsidy but a payment against work, the Mahatma Gandhi National Rural Employment Guarantee Act (MGNERGA) scheme provides direct cash transfers. The government may incentivise and promote bamboo cultivation through the Employment Guarantee Act by providing subsidies to the farmers who take up bamboo cultivation. The pilot scheme is being implemented by states in several districts. The scheme provides for co-financing under MGNREGA worth INR 7 lakhs/ha of bamboo cultivation over three years. The central MGNREGA act and the employment guarantee acts of various states may choose to undertake similar provisions for promoting bamboo and biochar feedstock cultivation. MoS may coordinate with relevant ministries to address this. Additionally, the source of biomass being used should also come with verification of Chain of Custody (CoC) certification covering all stages (from sourcing-transfers-processing) such that the product is managed in a way that preserves bio-diversity and benefits the lives of the locals.

- **Priority sector lending:** MoS may take appropriate action so that the priority sector lending scheme of the Government of India may be extended to the biochar production industries for certain non-staple energy crops like bamboo through two routes as described in the RBI Notification (RBI/FIDD/2016-17/34) / Direction (Master Direction FIDD.CO.Plan.2/04.09.01/2016-17).

  1. **Agriculture:** It is a priority sector where lending terms include - Ancillary Activities, including crop loans to farmers, which will consist of traditional/non-traditional plantations and horticulture, and loans for allied activities; Loans for Food and Agro-processing up to an aggregate sanctioned limit of 100 crore per borrower from the banking system.
  2. **Micro, Small and Medium Enterprises (MSMEs):** For support in investment in plant and machinery/ equipment for manufacturing/service enterprise, as notified by Ministry of Micro, Small and Medium Enterprises, vide S.O.1642(E) dated September 9, 2006.

The bamboo and other biochar feedstock cultivators may access priority loans under the non-traditional plantations option. In contrast, the biochar processing units may be eligible for priority loans under the MSME scheme. Through various banks, the Reserve Bank of India (RBI) could provide the funds as part of the existing arrangement of dedicated funds for priority sector lending.

Pilot demonstration (business models): The Ministry of Steel may bring together industries and the private sector through incentive schemes to evolve workable business pilot models for biochar generation and utilisation in the iron and steel industrial sector in a cluster-based approach.

- **Proposed Studies**

1. A study to assess the geographic availability of different kinds of biomass in India and their suitability for conversion to biochar to be utilised in iron and steel making. It will also assess the potential biomass requirement in the steel industry and map it with its availability.
2. Further, studies to assess the exact potential usage of biochar in the Iron and steel sector, its requirement and the break-even cost and mechanisms to promotethe usage of biochar in the steel industry.

CHAPTER 12

RESEARCH, DEVELOPMENT & DEMONSTRATION (RD&D)

12.1. Introduction

Research, development, and demonstration (RD&D) activities are critical for enabling a sustainable transition in the Indian steel sector and positioning India as a leader in technology development. The Indian steel sector is already significantly import-dependent on technologies used for producing steel. There is limited domestic availability of energy-efficiency technologies used in the steel sector. Further, although the Indian steel industry has undertaken initiatives to pilot various technologies such as the injection of green hydrogen in blast furnaces as well as carbon capture and utilisation (CCU), there are minimal research efforts on transformational and path-breaking technology development. As India strives to achieve its climate goals, it would also be important to position India as a research and innovation hub for developing both incremental and path-breaking technologies that will support the development of the country's indigenous manufacturing ecosystem.

The focused and concentrated RD&D activities will help India realise the above-mentioned goals. The evidence generated through RD&D activities highlights the underlying challenges and helps scale up the technologies to higher technology readiness levels (TRLs). Appropriate policy responses can then be decided to overcome gaps in regulations, financing, infrastructure and supply chains. This chapter presents a roadmap for enabling a progressive and momentous RD&D ecosystem in green steel technologies in India.

12.2. Technologies in steel manufacturing

Major routes of iron and steel making in India are BF-BOF, Rotary Kiln DRI-EAF/IF and Vertical Shaft-EAF/IF. The research on the decarbonisation of the blast furnaces and rotary kilns is important in the Indian context, as India has a large existing capacity of coal-dependent blast furnaces and rotary kilns, and a significant share of greenfield expansion is also expected to be through these routes. Blast furnaces have a life of 40-50 years, and any new blast furnaces installed today will remain operational for long. Research on reducing the carbon intensity of these routes with technologies such as alternative fuel injection, carbon recycling and carbon capture, utilisation and storage (CCUS) and with material and energy efficiency measures is critical for the decarbonisation of India's steel sector.

Beyond these conventional steelmaking routes, six alternative routes of steelmaking are described in Table 12.1. These routes have captured global attention due to their potential to substantially reduce the emission intensity of steelmaking. Near-zero emissions can be by four routes - hydrogen-based direct reduction with an electric arc furnace (H-DRI-EAF), molten oxide electrolysis, electrowinning, and hydrogen plasma smelting reduction, if renewable electricity is used to power them. Details of conventional as well as futuristic alternative routes for steel manufacturing are covered in Section 12.3.

Table 12.1: *Conventional and alternative routes of steelmaking and associated technologies*

Sr. no.	Steel manufacturing routes	TRL	Organisations involved	Emissions intensity
1	BF-BOF	TRL 9	Multiple private and public-sector steel manufacturing companies in India	2.2-2.6 t CO_2/ tonne-crude steel (tcs)
2	NG DRI-EAF	TRL 9		1.4-1.6 t CO_2/tcs
3	Coal DRI-IF	TRL 9		2.7-3.1 t CO_2/tcs

Sr. no.	Steel manufacturing routes	TRL	Organisations involved	Emissions intensity
Alternative routes of steelmaking				
4	Hydrogen-based direct reduction with EAF (H-DRI-EAF)[1]	TRL 6-8	HYBRIT project by LKAB, SSAB and Vattenfall, H2 Green Steel	Near zero with fossil-free hydrogen and renewable electricity
5	Molten Oxide Electrolysis (MOE)[2]	TRL 5-6	Boston Metal[3]	Zero emission with renewable electricity
6	Electrowinning[4]	TRL 5-6	SIDERWIN[5] - Consortium led by ArcelorMittal	~0.3 t CO_2/tcs
7	HIsarna[6]	TRL6	Tata Steel[7] Ijmuiden and Rio Tinto	0.4 t CO_2/tcs, after CCS
8	Hydrogen Plasma Smelting Reduction[8]	TRL 5	SuSteel[9] - Viostalpine AG, Austria	Zero emission with renewable electricity
9	High-intensity smelting (HIsmelt)[10]	TRL 9	Rio Tinto, Nucor, Mitsubishi, Shogang corp., Kwinana, Australia[11] Molong Petroleum Machinery Ltd, China[12]	1.6 t CO_2/tonne-hot metal (thm)
10	Rotary Hearth Furnace	TRL 9	Nippon Steel and Sumitomo Metal Corporation, Japan[13] Posco and Nippon Steel Joint Venture, Pohang Works, Korea[14]	1.3 t CO_2/tonne-DRI, or 1.6t CO_2/ tcs

12.3. RD&D scenario in green steel technologies

12.3.1. Global scenario

The Leadership Group for Industry Transition[15] has developed a tracker that covers green steel technology development projects worldwide over multiple stages - research and development partnerships, pilot projects, demonstrations and full-scale deployment projects. Based on the technological domain, the featured projects in the tracker can be split into seven categories. These include developing technologies such as hydrogen-based DRI, transition from natural gas to H2 in gas-based DRI, CCUS, smelting, biogenic reduction, as well alternative routes such as Molten Oxide Electrolysis (MOE) and the electrowinning process. The use of hydrogen in the direct reduction of iron ore (H-DRI) is the most prominent research topic worldwide, with 46 RD&D projects underway. Figure 12.1 captures the global RD&D efforts on green steel technologies according to the stages discussed above.

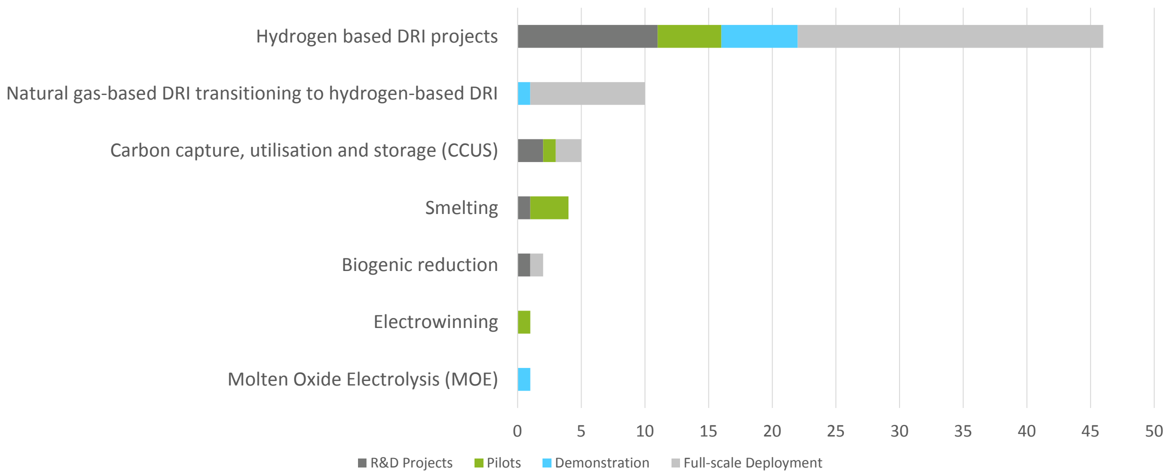


Figure 12.1: *Research in steel decarbonisation focuses on utilising green hydrogen*

The tracker features 69 international RD&D projects and research partnership agreements worldwide. Research in green steel technologies has been spearheaded by European nations as 45 projects are based out of Europe, which include the R&D efforts in the initial years as well as the full-stage deployment of green steel technologies. Only eight projects have been announced in Asian countries - South Korea, China and Malaysia. No RD&D project from India features in this tracker to date. A lack of information from developing countries might also imply that the data set is not very comprehensive. Nevertheless, this is the only database that captures major developments in RD&D in the steel sector, and hence, insights on RD&D initiatives globally are derived from this database. Figure 12.2 captures the regional progress on RD&D initiatives worldwide.

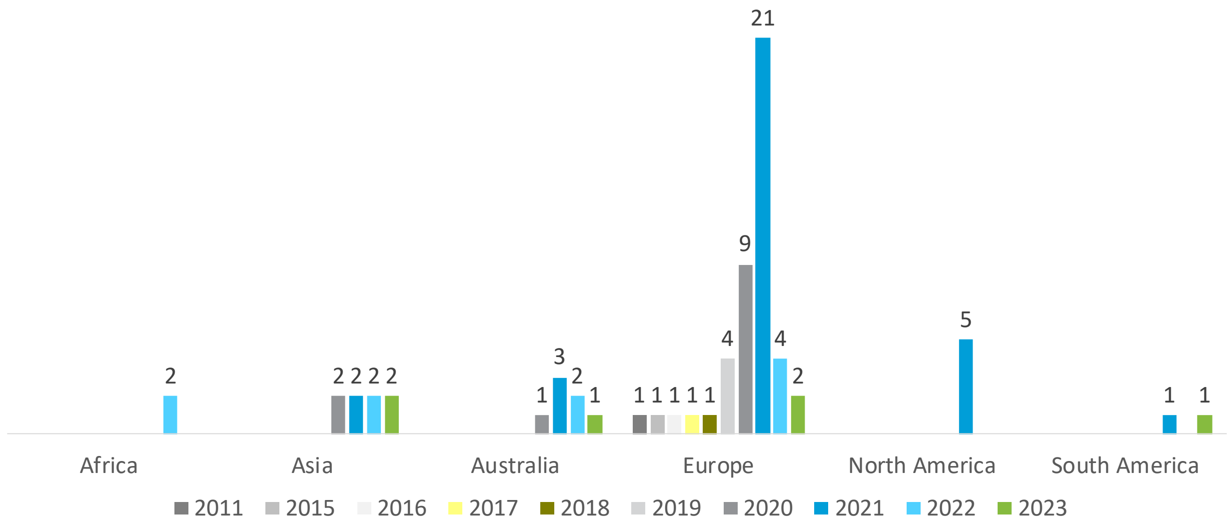


Figure 12.2: *Geographical spread of announced RD&D projects worldwide*[16]

The project announcements across various countries also disclose the investments required to achieve the targets. Table 12.2 provides a breakdown of the average size of investments across various types of projects. On average, it is seen that for R&D and pilot scale projects, the investment sizes do not exceed USD 50 million. The average investment requirement increases to USD 200 million for demonstration projects. Compared to R&D, pilot and demonstration projects, the average investment for full-scale deployment of projects is in the range of USD 0.76 - 4.6 billion per project. This shows that significant investment is needed to scale up projects from laboratory to full-scale deployment.

Table 12.2: *Average size of investment required for the announced RD&D projects (USD million)*

Sr. no.	Continent	R&D partnerships	Pilot projects	Demonstration projects	Full-scale deployment
1	Asia	15	-	-	4,631
2	Australia	1	-	1	760
3	Europe	12	51	241	2,554
4	North America	-	-	200	990
5	South America	-	4	-	-

12.3.2. Breakthrough technology development globally

Three breakthrough technologies are being focused upon globally due to their decarbonisation potential. While the level of maturity is still low in these technologies, India could consider venturing into research along these technologies. These technologies are based on direct or indirect electrification of the ironmaking route. SIDERWIN[17] and MOE[18] technologies focus on the direct electrification of the ironmaking process. Unlike SIDERWIN and MOE technologies, green hydrogen offers an opportunity to indirectly electrify the ironmaking process by using it as a reducing agent in existing shaft furnaces. This technology route has already been demonstrated on a pilot scale in the Hydrogen Breakthrough Ironmaking Technology (HYBRIT[19]) project in Sweden.

SIDERWIN and HYBRIT projects are being executed by respective consortia. The entities participating in the consortia range from industry players in the steel sector to energy providers, academic institutions, funders, and government entities associated with the iron and steel sectors. Boston Metals, a startup from the Massachusetts Institute of Technology's (MIT) Deshpande Center for Technological Innovation,[20] is developing the MOE technology. This section provides a brief description of these breakthrough technologies.

12.3.2.1. SIDERWIN Project

Project description: The SIDERWIN project aimed to produce iron by electrowinning iron from its naturally occurring oxides in an aqueous-based electrolyte at low temperatures. The electrolysis process, using renewable energy, transforms any iron oxide into steel plates with a significant reduction in energy use. Broadly, the SIDERWIN project targeted to reduce 31 per cent of direct energy consumption in the manufacturing of steel. The SIDERWIN project demonstrated that the carbon footprint of steelmaking could be reduced by 60-74 per cent, depending on the source of energy[21]. The project, which was pursued from 2017 onwards, was anchored by ArcelorMittal in France.

Funding structure of the SIDERWIN project: The project had a planned tenure of five years. It received a total budget of EUR 6.8 million, wholly funded by the European Union's Horizon 2020 programme. ArcelorMittal is the project coordinator. Twelve partners from seven different European countries covered the entire value chain, from raw materials and energy to metal production.

12.3.2.2. HYBRIT Project

Project description: The HYBRIT project was started by three Swedish companies - Svenskt Stål AB (SSAB), Luossavaara-Kiirunavaara Aktiebolag (LKAB) and Vattenfall. SSAB is a steel manufacturer, LKAB sells iron ore, and Vattenfall is a state-owned electricity producer and retailer. The four components of the project for achieving total decarbonisation of the entire value chain are fossil-free pellet production, direct reduction with fossil-free hydrogen, storage of hydrogen and smelting of sponge iron in an EAF unit. To take care of risks in moving directly from the laboratory scale to testing and production on an industrial scale, the entire project is structured to run for more than ten years – covering three phases: the pre-feasibility and research programme, the pilot phase and the demonstration phase. The HYBRIT demonstration aims to introduce fossil-free steel to the markets by 2026. The plant is being built in Sweden in the pilot stage.

Funding structure of the HYBRIT project: The project has received funding of EUR 143 million from the EU's Innovation Fund.[22] The grant consists of EUR 108 million (Hybrit Development AB) for a demonstration of the hydrogen direct reduction process, including fossil-free hydrogen production in Gällivare, a further EUR 30 million (SSAB) for the demonstration of electric melting of hydrogen-based direct reduced iron in Oxelösund and finally EUR 5 million (LKAB) for the demonstration of fossil-free DR-pellets production for the hydrogen reduction process. Furthermore, since 2016, the HYBRIT initiative has been granted financial support of SEK 599 million (EUR 50.4 million) by the Swedish Energy Agency.[23] As of 2019, the three owner companies had committed to invest SEK 1.1 billion (EUR 92.5 million).[24]

12.3.2.3. Molten Oxide Electrolysis by Boston Metal

Project Description: Boston Metal, a start-up based out of MIT in USA, has developed an MOE process that eliminates the need for coal in steel production. It is a zero-emissions process when renewable electricity is used. In this process, an inert anode is immersed in an electrolyte containing iron ore at 1,600 degrees Celsius and electrified to produce iron from iron ore. MOE converts even low and mid-grade iron ore fines directly into high-purity molten iron. The process eliminates the need for coke production, iron ore processing, blast furnace reduction, and basic oxygen furnace refinement. Boston Metal's MOE cells are modular and can be scaled up to meet production capacity targets from thousands to millions of tons of output. Currently, the project is at the semi-industrial validation stage. The company plans to deploy a demonstration plant by 2025 and targets commercial deployment in the latter half of the 2020s.

Funding structure of Boston Metal: Boston Metal has raised equity funding from strategic and institutional investors. The company closed the latest Series C funding round with a raise of USD 120 million in 2023. In total, it has raised more than USD 200 million in equity funding to date.

12.3.3. Key lessons from the analysis of global RD&D efforts

Following are the three key learnings from the analysis of global RD&D efforts as presented in this section:

Consortia of non-competing entities: Globally, the research projects are driven by multi-stakeholder engagement involving steel manufacturers, academic and research institutes, decarbonisation solution providers, original equipment manufacturers (OEMs), design and engineering firms, funders and government entities. An assessment of data indicated shows that there are at least two or more contributing partners in 58 out of the 75 projects tracked. Hence, adopting a collaborative approach to engagement in RD&D is recommended.

Industry players as project anchors: All projects listed in Figure 12.1, Figure 12.2 and Table 12.1 have steel companies as the main project anchors. It is seen that 29 steel companies have anchored the 75 projects that feature in the research tracker. A further assessment shows that ArcelorMittal, Salzgitter and POSCO are the top steel companies that are either anchoring or involved in 18, 6 and 6 projects, respectively. Therefore, it is important that any research project on the decarbonisation of the steel sector has an industrial player as the anchor point that sets and drives the targets for RD&D. These players not only provide an avenue for the continuous operation of a plant that produces output for the project to generate revenues but also put in a significant share of the project investments.

Financial support from the government: Table 12.1 shows that the investment needed to pursue research in green steel technologies is substantial. Therefore, as evident from the examples of the SIDERWIN project and the HYBRIT projects, active support from various stakeholders along with the government in terms of grants is helpful for the realisation of any RD&D plan. It is also important that such grants are given to industry-led consortia and that the payment be based on multiple interim milestones and deliverables.

12.3.4. Indian scenario

Indian academic and research institutes are pursuing research on technologies for decarbonising the steel sector. This includes research on new-age technologies like alternative fuels, green hydrogen, carbon recycling and CCUS, rotary hearth furnaces (RHF) and electrolytic production of iron. A few research projects also focus on aspects related to the decarbonisation of conventional coal-based technologies through avenues like process improvements, energy efficiency and material efficiency. Research institutes in India are also involved in modelling and plant simulations for green steel technologies. Figure 12.3 provides an overview of the research institutes existing in India, along with the topics pursued at these institutes.

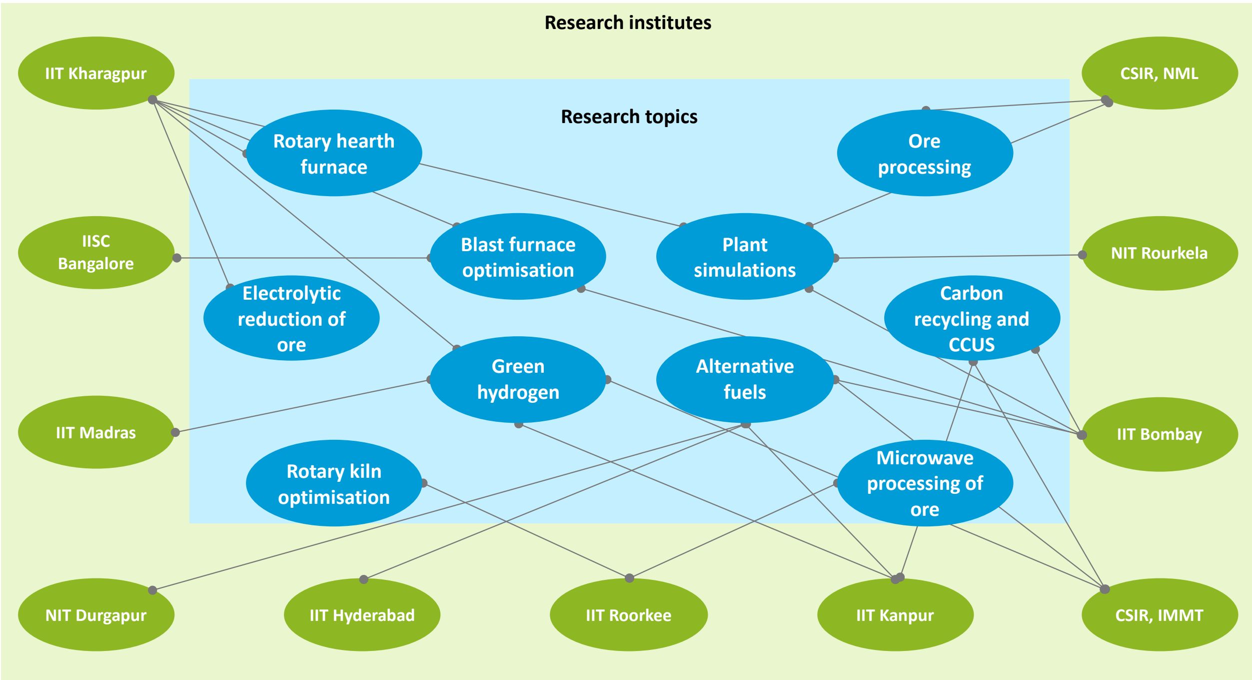


Figure 12.3: Research topics pursued by research institutes in India[25]

The Ministry of Steel has financially supported a few projects in the Indian steel sector in the CCUS domain since 2018-19, which can be found in Table 12.3. For these projects, the government has provided grants totalling INR 5.73 crores (approximately USD 0.7 million) since 2018-19. These grants account for 73 per cent of the project's total budget. Partner industrial players such as SAIL, JSPL, and the academic institutions leading the projects bear the remaining costs. Only one project by IIT Bombay out of these has been concluded successfully, while the others are still in progress as shown in Table 12.3.

Table 12.3: Projects in green steel technologies supported by the Ministry of Steel

Sr. no.	Project	Partner institutes	Project status
1	Conversion of emitted Carbon Dioxide (CO_2) to chemical fuels	IIT Bombay	Completed
2	Simultaneous removal of CO_2, Sulphur Oxides (SOx) & Nitrogen Oxides (NOx) from flue gas and their catalytic conversion into fuels and value-added fertilisers	CSIR, IMMT	In progress
3	Designing a sustainable, low-energy consuming, and modular CO_2 capture and mineralisation technology	CSIR, IMMT	In progress
4	Developing facile electro-catalytic CO_2 to Carbon Monoxide (CO) conversion technology	IIT Bombay	In progress
5	Selective removal of CO_2 from the gas produced from coal/ biomass using suitable media for gas enrichment	CSIR, IMMT	In progress

12.3.5. Challenges

The following are key challenges faced by RD&D initiatives on steel decarbonisation in India, which are centred around the organisational aspects of the RD&D ecosystem as a whole:

- Low R&D expenditure with poor private sector participation: As can be inferred from Figure 12.4, India severely lags behind major economies of the world in R&D expenditure as a proportion of the GDP. While most of the major economies exceed the world average of 1.98 per cent, India's R&D expenditure stands at 0.64 per cent of the GDP as of FY 2020-21.

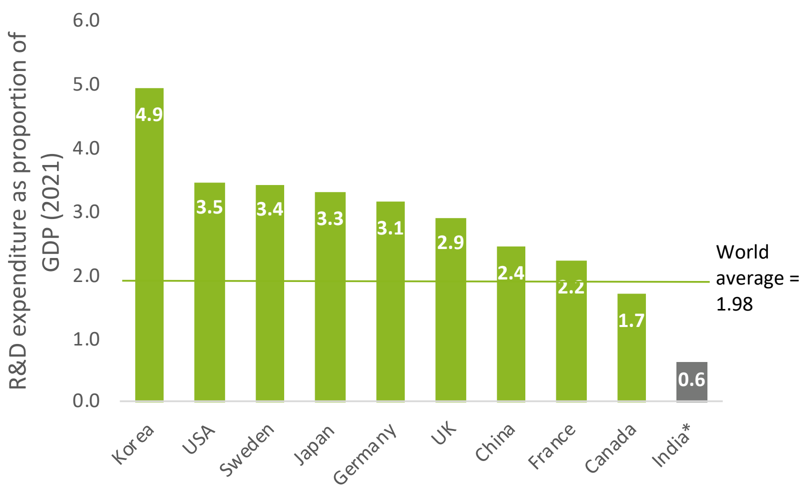


Figure 12.4: R&D expenditure as a percentage of GDP in major economies of the world[26]

Another important feature of R&D expenditure in India is that it is mainly driven by the government sector. The central government, state government and public sector industrial entities cumulatively contribute 54.8 per cent. Higher education institutes contribute 8.8 per cent, and the private sector industry contributes only 36.4% as of FY 2020–21[27]. Figure 12.5 provides a detailed breakdown of the sources of R&D expenditure.

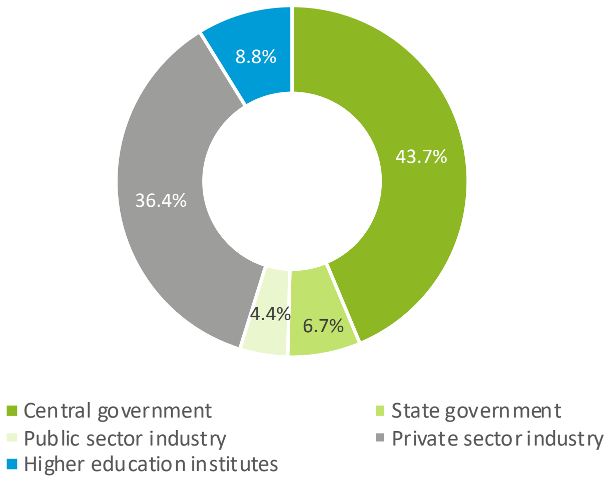


Figure 12.5: *Contribution to R&D expenditure in India by sector (%)*[28]

In comparison to India, the private sector contributes much more to that of the USA, UK, and China. The proportion of private sector contribution stands at 73 per cent in the USA in 2020[29], 59 per cent in the UK in 2021[30], and 74 per cent in China in 2015[31] as depicted in Figure 12.6.

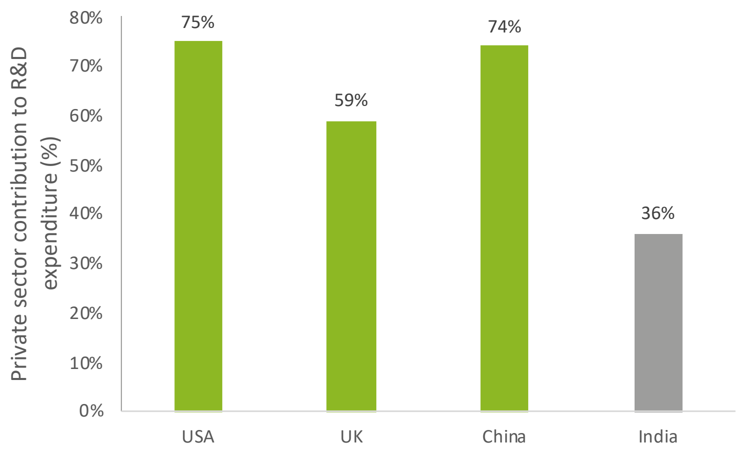


Figure 12.6: *Private sector contribution to R&D expenditure (%)*

- Longer projects with high capital requirements: RD&D activities in green steel technologies require large investments, often exceeding USD 50 million for demonstration projects. Projects need to run over a significant duration, over multiple phases, to develop the technology and then to validate it and conclusively establish the results. Running a small-scale facility for a long duration becomes commercially challenging in the absence of sufficient funding.

- Absence of an umbrella entity to coordinate RD&D as per a roadmap: It is seen that research institutes, industries and OEMs undertake projects in an asynchronous and uncoordinated manner. In the absence of an umbrella entity that defines strategic priorities through a roadmap and grants projects to interested participants, research on steel technologies in India will remain dispersed.

- Lack of experimental facilities in iron and steel making: Any innovative solution requires experimentation and testing. India lacks smaller-scale versions of production units like experimental Blast Furnaces or DRI making units. Any innovative solution – be it a new technology, process modification, or alternative feedstock – requires rigorous experimentation and testing before large-scale implementation. Without dedicated facilities, it's difficult to evaluate the feasibility and effectiveness of these solutions. Testing new approaches in existing commercial blast furnaces or DRI units is also extremely cost-prohibitive due to their massive scale as well as the need to shut down entire operations.

- Reluctance to participate in consortia-based projects: It is seen that the Indian steel companies do not undertake RD&D projects in a collaborative, consortia-based approach, which benefits the entire ecosystem. Consequently, the development of technology is siloed, and knowledge of steel decarbonisation technologies seldom gets shared in the public domain. Globally, large-scale RD&D projects have had a multi-stakeholder consortium structure of non-competing parties with an industrial company as an anchor.

- Lack of Indian OEMs possessing state-of-the-art design and engineering capabilities: India's steel sector is reliant on foreign technology providers with patented intellectual property (IP) rights to drive its innovation efforts. Any start-up in technology development and manufacturing will face significant challenges in competing with foreign OEMs.

- Challenges with sharing of Intellectual property: It becomes challenging to scale up the deployment of decarbonisation technologies beyond the host industry without IP being shared, which further increases the cost of the project.

12.4. RD&D roadmap for the Indian steel sector

12.4.1. Priority RD&D projects, research mode and decarbonisation potential

Factoring in the existing structure of the Indian steel industry, its dependence on conventional technologies like the BF and rotary kiln processes, and its priorities for decarbonisation without deceleration in the foreseeable future, a list of projects has been identified for RD&D in India. To ensure that research projects are delivered on time, the projects are categorised as per four research modes based on clear, quantifiable goals and selection criteria. Table 12.4 shows the framework for determining the research mode of various projects. The four research modes are - Mission mode, Blue-sky research, Collaboration Heavy and Grand Challenge.

Table 12.4: *Framework for determining the research mode of identified researched projects*

Sr. no.	R&D approach	Definition	Aim	Criteria
1	Mission mode	This mode covers goal-oriented and time-bound projects.	The goal of this mode is to enhance the global competitiveness of Indian Steel industries. This mode focuses on sub-parts of the value chain.	• Decarbonisation potential - medium • Ecosystem capability - low • TRL gap between India and other countries - high • Need for collaboration - low • Financial and technical needs - low-medium

Sr. no.	R&D approach	Definition	Aim	Criteria
2	Blue sky research	This mode covers direction-oriented projects for creating new knowledge.	This mode aims to establish global leadership in breakthrough technologies.	• Decarbonisation potential-high • Ecosystem capability-low • TRL gap between India and other countries-low • Need for collaboration-high • Financial and technical needs-high
3	Collaboration Heavy	This mode covers collaboration-heavy projects that involve multiple industries across various domains to support developing the end-to-end supply chain.	This mode aims to develop consortia/ alliances within non-competing members for knowledge sharing, transactions and the development of the complete value chain.	• Decarbonisation potential-high • Ecosystem capability-medium • TRL gap between India and other countries-medium • Need for collaboration-high • Financial and technical needs-medium-high
4	Grand Challenge	This mode covers projects with clear, quantified targets seeking innovation from startups and industries to solve identified problems.	This mode aims to promote competitiveness and de-risk support to first-movers.	• Decarbonisation potential-high • Ecosystem capability-low • TRL gap between India and other countries-high • Need for collaboration-high • Financial and technical needs-high

Table 12.5 encapsulates the RD&D projects along with their decarbonisation potential, research horizon and research mode. In summary, 9 projects belong to the short term, 11 projects to the medium term and 3 projects to a long-term implementation timeline. A brief description of the short, medium and long-term projects is provided below:

- Short-term horizon: Short-term projects will target conclusion within 2-3 years since they are commissioned. The plan identifies projects based on incremental technological improvements over conventional technologies. These include projects belonging to domains such as material efficiency (beneficiation), energy efficiency, a few aspects related to carbon capture, utilisation and storage, and projects that involve the usage of alternative fuels in conventional steelmaking processes.

- Mid-term and long-term projects: Mid-term projects target conclusion between 2026 and 2030, while long-term projects will conclude beyond 2030. These projects require reimagination of conventional steelmaking methods, either through process transitions, deployment of advanced CCUS technologies, or the pursuit of alternative routes of steelmaking.

Table 12.5: List of RD&D projects identified

Sr. no.	Domain	Project title	Research mode
Short-term research horizon			
1	Material efficiency (beneficiation)	Iron ore beneficiation by advanced technology like dense media separation and ultra-high dense media separation	Mission mode
2	CCUS	Conversion of CO_2 and carbon-rich gases to ethanol	Collaboration Heavy
3	CCUS	Conversion of CO_2 and carbon-rich gases to methanol and other usable products	Collaboration Heavy
4	Energy efficiency	Development of energy efficiency measures by using hot coal-based DRI directly into EAF/IF	Blue-sky
5	Energy efficiency	Hydrogen recovery & recycling of coke oven gas in BF for new plants	Mission mode
6	Alternative fuels (H2)	H2 injection in vertical shaft DRI modules as partial replacement of natural gas	Mission mode
7	Miscellaneous	**Miscellaneous pilot projects:** ● Dry scrubbing of off-gases ● CO separation from BOF and top gas (CO and CH_4 recovery from off-gases) ● Waste heat recovery in sintering ● Maximisation of pellets in blast furnace, capacity enhancement in rotary kiln through pellet use	Blue-sky Mission mode
8	Alternative fuels	Injection of CO-rich gases in rotary kiln	Blue-sky
9	Alternative fuels	Injection of alternative fuels (biomass, plastic, MSW) in rotary-kiln furnace	Blue-sky
Mid-term research horizon			
10	CCUS	Carbon recycling by converting CO_2 into CO and utilising the same in the furnace (industrial scale)	Collaboration Heavy
11	CCUS	Carbon capture, co-electrolysis for making syngas for use in a vertical shaft in DRI	Mission mode
12	CCUS	Carbon recycling through dry reforming of CO_2 with the methane obtained from coke oven gas	Mission mode

Sr. no.	Domain	Project title	Research mode
13	Energy efficiency	Briquetting of cold iron to convert fines directly into briquettes	Mission mode
14	Energy efficiency	Use of dry slag process for heat capture and organic Rankine cycle to generate electricity (developing a 20 MW plant)	Mission mode
15	Energy efficiency	Utilisation of waste heat of steelmaking slag	Blue-sky
16	Energy efficiency	Utilisation of waste heat of ironmaking slag	Blue-sky
17	Alternative fuels (H2)	H2 injection in BF through the shaft (blue blast furnace)	Mission mode
18	Alternative fuels (H2)	Hydrogen-based DRI with EAF (1 TPH HYBRIT-scale) (0.008MTPA)	Collaboration Heavy
19	Process transition	Scaling down of shaft furnaces for gas-based DRI production (for smaller units <0.5 million tonnes)	Mission mode
20	Miscellaneous	**Miscellaneous RD&D projects** ● Waste utilisation from steel slag ● Alternate gasification technology ● Development of binders for various iron ores	Blue-sky
21	Miscellaneous	Setting up experimental facility for research on blast furnace	Mission mode
22	Miscellaneous	Setting up experimental facility for research on vertical shaft furnace	Mission mode
23	CCU	CCU through conversion of CO_2 to methane and other utilisation pathways	Mission mode
24	Process transition	Molten oxide electrolysis	Grand Challenge
25	Process transition	Electrowinning	Grand Challenge

12.4.2. Technical and financial requirements

Each project, depending upon the domain, technology readiness level and the capability of the ecosystem, will have different needs to meet the project goals. Consequently, each project will require collaboration among stakeholders in various capacities and will require dedicated financing. Funding sources for financing projects will vary depending on the quantum of financing required, the research mode, the potential of the project to produce output or revenue during the project duration and the risk associated with the project. Table 12.6 provides the technical and financial research needs for each project, along with an overview of the readiness of India's steel sector with respect to technology

Table 12.6: Technical and Indicative investment along with appropriate sources of funding for the list of identified pilot projects

Sr. no.	Project title	Project participants	TRL in India (TRL globally)	Capability of ecosystem	Research needs (technical)	Investment needs (INR crore)	Appropriate sources of funding (excluding capital investment by industries)
1	Iron ore beneficiation by advanced technology like dense media separation and ultra-high dense media separation	Industry - OEM - Academia - Foreign collaboration (South Africa, Australia)	2 to 3 (9)	High	• Modification of existing beneficiation plant or new beneficiation plant • The development of ferrosilicon and or alternate media • Testing capabilities	100-150	• Tax-based and production-linked incentives • Low-carbon steel customers • Carbon-credit customers
2	Conversion of CO_2 and carbon-rich gases to ethanol	Energy supplier - Industry - OEM	Nil (9)	Medium	• Additional land and equipment for the chemical plant • Technical partners to run chemical plants • Research institutes for data modelling • Facilities for a pilot plant	500 - 1,000	• Government grants • Private donors
3	Conversion of CO_2 and carbon-rich gases to methanol and other usable products	Industry - OEM	4 to 5 (8 to 9)	Medium		500 - 1,000	• Government grants • Private donors
4	Development of energy efficiency measures by using hot coal-based DRI directly into EAF/IF	Technology suppliers (Germany)	Nil (7 to 8)	Low	• Modifications to the discharge system of an existing rotary kiln • Provision for inert gas • Concept development in laboratories	50	• Government grants • Tax-based and production-linked incentives • Low-carbon steel customers • Carbon-credit customers

Sr. no.	Project title	Project participants	TRL in India (TRL globally)	Capability of ecosystem	Research needs (technical)	Investment needs (INR crore)	Appropriate sources of funding (excluding capital investment by industries)
5	Hydrogen recovery & recycling of coke oven gas in BF for new plants	Industry - OEM	Nil (9)	Medium	• Gas purification technologies. Proven technologies are costly and run at low efficiencies • Concept development by labs	305	• Tax-based and production-linked incentives • Low-carbon steel customers • Carbon-credit customers
6	H_2 injection in vertical shaft DRI modules as partial replacement of natural gas	Industry - OEM	9 (9)	High	• Green H2 source near the plant with supporting infrastructure • Kinetic and thermodynamic modelling of hydrogen injection	40 - 50	• Tax-based and production-linked incentives • Low-carbon steel customers • Carbon-credit customers
7	**Miscellaneous pilot projects:** • Dry scrubbing of off-gases • CO separation from BOF and top gas (CO and CH_4 recovery from off-gases) • Waste heat recovery in sintering • Maximisation of pellets in blast furnace, capacity enhancement in rotary kiln through pellet use	Multiple stakeholders	2 to 3 (7+)	-	• Modelling studies for enhancing pellet content to understand the effect on kinetics and thermodynamics • For other research projects, basic concepts will have to be developed	1,000	• Government grants • Tax-based and production-linked incentives

Sr. no.	Project title	Project participants	TRL in India (TRL globally)	Capability of ecosystem	Research needs (technical)	Investment needs (INR crore)	Appropriate sources of funding (excluding capital investment by industries)
8	Injection of CO-rich gases in rotary kiln	Academia-Industry	2 (2)	Medium	• Change in process design to use the gaseous fuels of a host plant • A simulation model for simulating kiln performance • Project concept through feeding system design, CFD, and reaction kinetic modelling studies	20-25	• Government grants • Private donors
9	Injection of alternative fuels (biomass, plastic, MSW) in rotary-kiln furnace	Academia-Industry	2 (2)	Medium	• Change in process design to use the gaseous fuels of a host plant • A simulation model for simulating kiln performance • Project concept through feeding system design, CFD, and reaction kinetic modelling studies	5 to 10	• Government grants • Private donors

Sr. no.	Project title	Project participants	TRL in India (TRL globally)	Capability of ecosystem	Research needs (technical)	Investment needs (INR crore)	Appropriate sources of funding (excluding capital investment by industries)
10	Carbon recycling by converting CO_2 into CO and utilising the same in the furnace (industrial scale)	Academia-Industry	5 to 6 (7 to 8)	Low	• CO_2 capture facilities and conversion facilities • Catalyst development • Technologies with low energy requirements	150-200	• Government grants • Private donors
11	Carbon capture, co-electrolysis for making syngas for use in a vertical shaft in DRI	Academia-Industry	2 to 3 (5 to 6)	Low		150-200	• Government grants • Private donors • Insurers and first-loss donors/debtors
12	Carbon recycling through dry reforming of CO_2 with the methane obtained from coke oven gas	Industry - OEM	1 to 2 (8 to 9)	Medium	• Additional land and equipment for the chemical plant • Technical partners to run chemical plants • Research institutes for data modelling • Facilities for a pilot plant	100 - 150	• Government grants • Private donors
13	Briquetting of cold iron to convert fines directly into briquettes	Academia-Industry - Foreign collaboration (Australia - CSIR, Monash & UK)	TRL 1-2 (9 (Vale - Brazil))	High	• A briquetting machine along with an existing beneficiation facility • Alternate binders which can withstand high-temperature in blast furnaces/DRI kilns	100	• Tax-based and production-linked incentives • Low-carbon steel customers • Carbon-credit customers

Sr. no.	Project title	Project participants	TRL in India (TRL globally)	Capability of ecosystem	Research needs (technical)	Investment needs (INR crore)	Appropriate sources of funding (excluding capital investment by industries)
14	Use of dry slag process for heat capture and organic Rankine cycle to generate electricity (developing a 20 MW plant)	Industry - Foreign collaboration (Aus) -Technology supplier (SMS Paulworth, Prime Metal, Ecomaster (Korea), Harsco (Germany))	Nil (2 to 3)	Low	• Host steel plant • Basic concept development	150-200	• Private donors • Insurers and first-loss donors/ debtors
15	Utilisation of waste heat of steelmaking slag	Industry	Nil (3 to 4)	Medium	• Modification to slag dumping pits • Basic concept development	10	• Government grants
16	Utilisation of waste heat of ironmaking slag	Industry	Nil (3 to 4)	Medium		10	• Government grants
17	H_2 injection in BF through the shaft (blue blast furnace)	Industry - OEM	1 to 2 (6 to 7)	Low	• Green H2 source near the plant with supporting infrastructure • Kinetic and thermodynamic modelling of hydrogen injection	300-400	• Tax-based and production-linked incentives • Low-carbon steel customers • Carbon-credit customers
18	Hydrogen-based DRI with EAF (1 TPH HYBRIT-scale) (0.008MTPA)	Industry - OEM - Academia	1 to 2 (6 to 7)	Low		1,500-2,000	• Government grants • Tax-based and production-linked incentives • Low-carbon steel customers • Carbon-credit customers

Sr. no.	Project title	Project participants	TRL in India (TRL globally)	Capability of ecosystem	Research needs (technical)	Investment needs (INR crore)	Appropriate sources of funding (excluding capital investment by industries)
19	Scaling down of shaft furnaces for gas-based DRI production (for smaller units <0.5 MTPA)	Academia - OEM - Industry - Government	Nil (8 to 9)	Low	• Indigenous development of cost-effective vertical shaft furnaces • A commercial technology supplier needs to be hired	350-500	• Tax-based and production-linked incentives • Private equity investors
20	Miscellaneous RD&D projects Waste utilisation from steel slag Alternate gasification technology Development of binders for various iron ores	OEM - Industry - Academia	5 to 6 (8 to 9)	Medium	• Technology that has already been developed at Central Institute of Mining and Fuel Research (CIMFR) and Bharat Heavy Electricals Limited (BHEL), Thermax needs to be scaled up and some commercial projects of reasonable scale need to be installed	600 - 800 (INR 500 to 650 crore will be required just for the project on alternate gasification technology)	• Government grants
21	Setting up experimental facility for research on blast furnace	Industry-OEM-Academia	9	High	• Simulation and modelling setups to augment the experimental facility	400-500	• Industry • Government grants • Private equity investors • Low carbon steel customers
22	Setting up experimental facility for research on vertical shaft furnace	Industry-OEM-Academia	9	High	• Natural gas availability • Overall project concept development	200-300	• Private donors • Insurers and first-loss donors/debtors

Sr. no.	Project title	Project participants	TRL in India (TRL globally)	Capability of ecosystem	Research needs (technical)	Investment needs (INR crore)	Appropriate sources of funding (excluding capital investment by industries)
23	Carbon recycling through CO_2 to methane and other utilisation	Industry-Academia (IITR) - Foreign collaboration with academia (European institutes)	1 to 2 (2 to 3)	Low	• Natural gas availability • Overall project concept development	200-300	• Private donors • Insurers and first-loss donors/ debtors
24	Molten oxide electrolysis	Industry-Academia	Nil (2 to 3)	Low	• Achieving the objectives of this project will require creating a dedicated laboratory. Central Electro Chemical Research Institute (CECRI) or any other related institute can be approached to develop this technology. The project concept needs to be developed from scratch by academic institutes and research laboratories	1,000-1,500	• Government grants • Tax-based and production-linked incentives • Private equity investors • Insurers and first-loss donors/ debtors
25	Electrowinning	Industry-Academia	Nil (2 to 3)	Low		500-1,000	• Government grants • Tax-based and production-linked incentives • Private equity investors • Insurers and first-loss donors/ debtors

12.4.3. Possible sources of funding for the RD&D plan

The involvement of the government, industry, and financial institutions in funding RD&D projects will be necessary to realise the RD&D ambitions. Global experiences suggest that RD&D projects can approach diverse funding sources that offer different funding instruments. Grant funding through government channels or private donors is essential for developing technologies that are at low TRL. Furthermore, capital-intensive projects would need access to low-cost capital through green debt provided by development finance institutions (DFIs) or multilateral banks. Low-cost financing support would be needed to deploy technologies at a commercial scale that would also give some return to investors. A mechanism allowing RD&D project entities to issue carbon credits will be helpful in generating revenues. Furthermore, financial risk mitigation plans with specialised entities must also be implemented to alleviate commercial concerns. An overview of the possible sources of funding for RD&D projects has been provided in Table 12.7.

Table 12.7: *Summary of the possible funding sources for RD&D and relevant funding instruments*

Sr. no.	Category of funding	Type of funder	Description of funding instrument	Examples of relevant Indian entities	Global references
1	Purpose-focused sources of finance	Government entities	Capital grants from a budgeted fund by government entities against the fulfilment of specified criteria as per policy	Ministry of Steel[32]	EU Research Fund for Coal and Steel,[33] ARENA,[34]
		Donors	Capital grants for projects with specific objectives or targets	-	Eurostars[35]
		Sovereign lenders or multi-lateral banks	Green debts as the senior funder or the subordinate concessional funder	-	World Bank,[36] ADB,[37]

Sr. no.	Category of funding	Type of funder	Description of funding instrument	Examples of relevant Indian entities	Global references
2	Incentives	Tax-based incentives by governments	Tax credits issued for low-carbon production	-	US IRA[38]
		Production-linked incentives by governments	Monetary incentives for production and investments in low-carbon products	Ministry of Steel[39]	EU subsidies[40]
3	Traditional sources of finance	Private equity investors	Private equity investments	-	Brookfield,[41] GIC, Altor, AMF Pension,[42] Roc Partners,[43] IFC[44]
		Steel companies	Capital investments by equity holders	Steel companies in India	Thysenkrupp, Salzgitter, ArcelorMittal
4	Sources of revenue	Low-carbon steel customers	Advance purchase agreements or purchase at a green premium	-	BMW, Miele, Ford, Mercedes Benz,[45]
		Customers of carbon credits	Purchase of carbon credits out of the project	-	Gestamp,[46] Ovako[47]
5	De-risking sources	Insurers	Insurance against project risks or revenue risks	Export Credit Guarantee Corporation of India	Euler Hermes, Swedish National Debt Office[48]
		First-loss donors/ debtors	Credit enhancement, where a certain amount of loss or escalation is covered	-	European Investment Bank[49]

12.5. Institutional mechanism for oversight of green steel RD&D in India

An institutional mechanism for promoting RD&D in India in a coordinated manner, aligned with the long-term strategic objectives of the steel sector, is necessary. The overarching objective of such an institutional framework should be to accelerate technological advances in high-risk and priority areas which the industry is unlikely to pursue independently.

The governance of RD&D endeavours will be helmed by an RD&D committee housed within the Ministry of Steel, as depicted in Figure 12.7. The RD&D committee will be a part of the governance framework. Given that RD&D endeavours in the steel sector require the active participation of multiple stakeholders such as academic and research institutions, industries, technology developers, OEMs, energy providers, financiers, and the government, the RD&D committee will have representation of all stakeholders. The RD&D committee will also liaise with the start-up ecosystem in India to provide incubation support and to develop components of breakthrough technologies. Furthermore, the committee will incorporate key learnings from the Anusandhan National Research Foundation (ANRF) and similar global RD&D and innovation models into the governance mechanism and leverage the provisions under the ANRF to enhance the effectiveness and efficiency of RD&D endeavours in India.

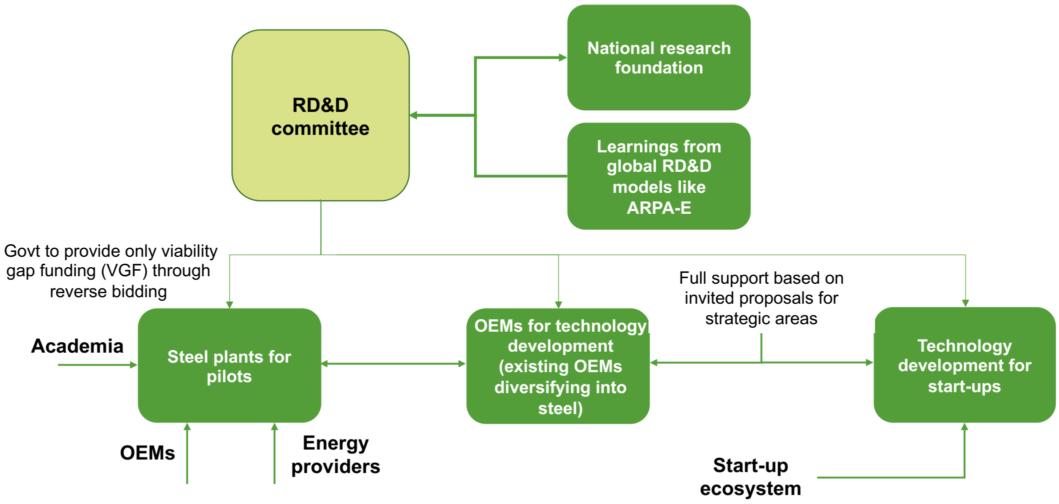


Figure 12.7: Representative structure of the governance mechanism for RD&D in green steel technologies

Key responsibilities of the RD&D committee

a. **Coordinating financial support to RD&D endeavours**

The RD&D committee will oversee the deployment of catalytic financial support that the Government of India will provide to RD&D activities. The government will support the consortia of non-competing entities such as steel producers, academia, OEMs, and energy providers in pursuing strategically important projects through viability gap funding (VGF) support. The VGF will only be a catalytic support, attracting larger investments from the steel-producing companies that will act as project anchors. Steel companies will be provided the rights to IP to protect and incentivise their investments. In addition, start-ups and OEMs who can develop key technologies from scratch in strategically important areas will be fully supported through grants. Incubation support will be facilitated by the RD&D committee at premier academic and research institutes. The scaling up of such technologies will further facilitate the development of a robust domestic manufacturing ecosystem.

b. **Easing administrative requirements for RD&D projects**

The RD&D committee will set and communicate strategic technology development targets with all stakeholders. The RD&D committee will receive and evaluate proposals from interested parties (preferably synergetic consortiums of non-competing partners). Such a mechanism will ensure progress along the core objectives of the sector as a whole. Further, the committee will track the progress of the projects and issue milestone-based payments. The committee will also facilitate all other administrative requirements for the project participants.

c. **Reviewing RD&D expenses**

The committee will develop criteria for reviewing the return on investment of RD&D activities. The holistic assessment criteria will factor in the impact of activities on the decarbonisation of the sector and also factor in externalities such as employment generation, the inflow of foreign and domestic capital to the sector, India's position in the international markets for green steel, and development of Indian OEMs, start-ups and upstream component manufacturers in the sector, etc. The committee will periodically inform the Ministry of Steel and all other stakeholders with a published report on such an assessment.

d. **Facilitating access to knowledge for all stakeholders**

The objectives, scope, principles, criteria and other modalities of the RD&D endeavour will be well-documented and publicly accessible. RD&D committee will actively track global developments in the steel sector. All stakeholders will be periodically informed about the breakthrough developments in technologies and challenges faced in RD&D efforts. Case studies of the projects being pursued in India will be developed and publicised to attract global attention and support. The committee will convene an annual workshop on green steel RD&D in India, and a quarterly newsletter will be published covering major developments on the topic.

12.6. Action plan for RD&D

India recognises the strategic importance of RD&D in decarbonising its steel industry. Existing research in academic and research institutes cover most aspects of decarbonising the steel sector, from existing coal-based technologies to upcoming technologies like green hydrogen. The Ministry of Steel may place emphasis on scaling these RD&D efforts to match the level of ambition for decarbonisation in India's steel sector. The following steps may be pursued for RD&D by the Ministry of Steel:

1. **Setting up an RD&D committee:** An RD&D committee may be set up within the Ministry of Steel, Government of India, to coordinate and regulate RD&D efforts in India.
2. **Coordinating with other government entities:** The committee may liaise with the Anusandhan National Research Foundation (ANRF) and with relevant departments in other ministries to coordinate cross-sectoral research in certain domains.
3. **Releasing RD&D roadmap:** A detailed guideline on the RD&D roadmap for steel decarbonisation in India may be released. The objectives, specifications, eligibility criteria, funding support and project requirements of each project listed under the RD&D roadmap for steel decarbonisation in India may be notified.
4. **Implementation of RD&D Projects:** Efforts may be taken by MoS under the guidance of RD&D committee to implement RD&D projects as per the published roadmap and available budget.
5. **Convening workshops and disseminating information:** The RD&D committee may convene an annual workshop on green steel RD&D activities in India and release a quarterly newsletter covering major developments.

CHAPTER 13

FINANCE

13.1. Introduction

Finance and technology are key factors for achieving the goals of the Paris Agreement and are critical enablers towards a low-carbon transition. Historically, though the financial sector has promoted conventional technology, significant funding has been sourced to emission-intensive assets and sectors. Importantly, such investments need to be urgently redirected and scaled up towards low-carbon development pathways. UNEP's Emission Gap Report[1] stresses the importance of an overall enabling environment to facilitate this transition. The report highlights several enabling factors, which include 'increasing the efficiency of financial markets', 'introducing carbon pricing', 'nudging financial behavior', 'creating markets,' 'mobilizing central banks', 'setting up climate clubs', 'enhanced flow of international finances' and 'increasing cross-border stakeholder collaboration' for technology development.

India announced its Long-Term Low-Carbon Development Strategy (LT-LCDS) in 2022 which sets out a roadmap for economy-wide transitions and emphasis es the importance of adequate international financing for India to be able to meet its decarboniation goals[1]. Particularly, it highlights the need for 'effective and innovative industrialisation' away from emissions with the help of 'multilateral support in the form of technology, capacity, and finance'. To mobilise necessary finance for achieving decarbonisation goals, it identifies three major categories of sources of finance: (1) International public finance (2) Domestic public finance, and (3) International and domestic private finance. This would require addressing technology performance risk, providing certainty of policy and regulations, dovetailing appropriate incentives, removing information and knowledge gaps, creating bankable business models, provisioning for high upfront investment costs, developing requisite supporting infrastructure, improving technical capabilities, inter alia. The LT-LCDS also emphasis es maintaining a healthy balance between the developmental aspirations of the country, trade prospects, and the feasible low-carbon development pathway.

Overall, for the effective assimilation of international public and private finance with domestic public and private finance for rapid transition, India would require a cohesive ecosystem for its industrial sector. The process of deploying and scaling clean technologies, however, cannot be shouldered alone by market forces. Past experience demonstrates the critical role of governments in enabling the low-carbon transition of the sector through policy, public finance, and de-risking. This chapter elaborates on the barriers to accessing finance that the industry faces, including in implementing the various decarbonisation strategies identified in different chapters. Accordingly, an action plan is outlined for enhanced mobilization and access to finance for decarbonisation of the sector.

13.2. Potential pathways for decarbonisation

The iron and steel sector, the highest emitting industrial sector in India, would require financing for a variety of low-carbon technologies at various stages of development. This would include best-available technologies that offer incremental abatement as well as breakthrough technologies that have near zero emissions. Concerted efforts would be required from a range of stakeholders to prevent carbon lock-in from predominantly fossil fuel-based steel capacities envisaged to be added in the coming two decades. Access to suitable financing and financial services would also need to be tailored for both ISP and SSP, as both have distinct needs, technical capabilities and access to emerging technologies.

Decarbonisation of the iron and steel sector has to be based on three key recognitions. First, the transition of existing plants to low-carbon production systems will follow a different pathway than those for the greenfield plants. Accordingly, the financing challenges and solutions for mobilizing and accessing finance will be different. Second, the strategies will need to be further differentiated for ISPs and SSPs. Third, irrespective of the variations in the cost of low-carbon technologies over the long-term time horizon, financing challenge is essentially about the high upfront capital requirements in the sector. Hence, the strategies for mobilizing finance as well as enhancing access will need to, first and foremost, address the concerns related to high cost of capital and high-risk perception. Overall, therefore, the financing strategy will need to be broad and agile to accommodate the diverse challenges faced by the potential decarbonisation pathways.

The discussions in other chapters on technological options for decarbonisation suggest that the potential decarbonisation pathways for the sector will have the following four essential tracks:

1. **Decarbonisation of existing ISPs:** Decarbonisation of existing ISPs, during their plant lifetime, would require a mix of interventions including, inter alia, enhanced integration of renewable energy, etc., followed by incremental process transition including changing fuel mix, energy efficiency and recovery (TRT, PCI, CDQ, PCG, WHR, and others), increasing blending of low carbon fuel (e.g. green hydrogen) and feedstock, material circularity and adoption of CCUS. As the domestic and international carbon markets mature, these plants can also benefit from offsetting emissions. It will be important to map the age of the fleet of the existing steel plants and prepare a phased-wise approach for substituting such capacities, as per their retirement schedule, with the green technologies.

2. **Decarbonisation of existing SSPs, including MSMEs:** Main thrust of decarbonisation would be on increasing adoption of commercially available technologies which have substantial emission mitigation potential but remain underutilised despite favorable economics. These include incorporating RE, energy efficiency and scrap-EAF. Uptake of such technologies in the steel sector would also need enabling policy/ regulatory interventions, for instance, effective implementation of Steel Scrap Recycling Policy etc. On the other hand, emerging technologies which offer near zero emissions would require RD&D efforts as well as regulatory interventions to bridge the mismatch between scale of operation and cost-effectiveness of technological process. Policy and RD&D efforts need to focus on improving techno-economic feasibility of adoption of low-carbon technologies by SSPs. SSPs could also be the net supplier of emissions reduction units and take the benefit of carbon market revenues.

3. **Decarbonisation in new ISPs:** The greenfield projects planned for few years later will be able to take advantage of technological advancements. However, greenfield projects in the immediate future will be the most challenging from the decarbonisation point of view. They will need to build-in flexibilities to adopt new technological options, e.g. those based on green hydrogen, and CCUS to minimise production disruption at the time of adoption. Such projects planned in the near future will need to be thought through carefully as any investments in fossil-fuel oriented technologies are likely to be there for at least another 25 years and will run the risk of becoming a stranded asset few years down the line.

4. **Decarbonisation in new SSPs, including MSMES:** The new SSPs are best to not include coal based DRI process and should focus on integrated EAFs and Rerolling plants operating at a certain minimum scale. A combination of BATs, 100% RE, and maximum scrap utilization would be an ideal decarbonisation pathways for new small-scale plants in the sector.

Each of the four tracks of decarbonisation pathways for the iron and steel sector has their own unique challenges in accessing finance. These are discussed in the next section.

13.3. Barriers to Accessing Finance

There are several challenges to financing the decarbonisation of the sector. These include complexity of production processes and value chains, potentially locked in investments in carbon-intensive assets, unviability of current low carbon technologies, inadequate experience, high capital and operational expenditure[2]. Also, the sector in India is extremely diverse with high degree of variation in the scale of operations. For example, the SSPs are neither as large as integrated steel plants, nor as small as the micro-enterprises of other economic sectors. Rather, their capacities vary greatly in the range of medium and small, which makes homogenous financial servicing to the sector difficult. Other reasons range from lack of enabling policy ecosystem, lack of knowledge about technologies and their financial implications, limited availability of finance, maturity of market for green steel, inter alia. Table 14.1 summarizes potential barriers to flow of finance towards emission reduction in the steel sector.

It is to be noted that inflow of investments in a given sector are dependent upon the risk profile of the sector in addition to the risk profile of a given technology. Thus, in order to attract higher order of investments towards green steel, non-financial barriers also need to be resolved.

Table 13.1: *Barriers to accessing finance for greening the steel sector*

Barriers	Seg-ment	Industry	Domestic Financial System	International Financial System
Knowledge-based Barriers	ISPs	-	• Low Technological Awareness	• Maturity of technologies
	SSPs	• Lack of Awareness, • Documentation Requirements, • No Financial Expertise.	• Low Technological Awareness, • High Perceived Risks • Lack of taxonomy	• Limited Direct Exposure • High Perceived Risks.
Cost of Capital related barriers	ISPs	• Interest rates • Competitiveness • Demand concerns	-	• High risk perception; • Country credit ratings
	SSPs	• High Transaction Cost, • Interest Rates, • Long Payback Periods • Demand concerns	• Low Margin, • High Transaction Cost, • Interest Rates, • Low ticket size	• Restraining Lending Prerequisites, • Due Diligence, • High Transaction Cost, • Low ticket size
Credit-worthi-ness-based barriers	ISPs	-	-	-
	SSPs	• Irregular Cash Flow (SSPs), • Delayed Payments. • Low risk appetite	• Lack of Collateral, • Seasonal Operations Low Credit Score. • Documentation	• Low Credit Score. • Scale of operation • Balance sheets • Documentation

Source: *Adopted from TERI. (2023). Financing Decarbonisation of the Secondary Steel Sector in India: Towards an Enabling Environment. New Delhi, India: The Energy and Resources Institute.*

Prominently, substantial Awareness gaps exist among the sectoral units in addition to technological inefficiencies of the steel sector, particularly the secondary sector. Notably, the sector largely lacks knowledge about the efficiency and the payback periods of low-carbon technologies, as well as the provisions of financial assistance available to them through several initiatives. In case of SSP, the haphazard bookkeeping of financial records, low familiarity with digital platforms, and lack of awareness of documentation requirements to acquire loans has constrained the formal credit sources' risk perception against them. A significant awareness gap also exists on the supply side where the financiers' understanding of mitigation technologies and their maturity status remains limited. Consequently, they find it hard to ascertain the kind of financial instruments and risk structures that can be deployed to support the uptake of clean technologies in the sector.

Communications strategy for the financial institutions along with demonstration projects in these technologies (to begin with the export-oriented units) within the country will be critical to bring commercial financers onboard. Further, awareness campaigns with the steel producers regarding the green technologies will play an important role. As of now, the steel players are more conversant with the business-as-usual technologies and are concerned about multiple aspects as discussed earlier in this chapter. Mitigation measure around all of those aspects, such as, developing a long-term view about the newer technologies, creating incentives for the early movers/adopters of green technologies, improving financial management and corporate governance, creating digital transition, developing standard set of forms for accessing the funds, are some of the suggested interventions that may help in transitioning towards green steel agenda. Capacity building throughout the value chain is also very important to expand the understanding of the emerging technologies and to create financial instruments around it. Involvement of credit rating agencies can further help in reducing the risk perception around newer technologies.

Furthermore, several cost-of-capital-related barriers to financing the decarbonisation of the steel sector in India emerge due to the high upfront investment requirements of decarbonisation technologies as well as the due diligence requirements of the financial structures in place. The long payback periods of technologies in some instances, the low profit margin, and the monitoring requirements of loans, all add to the existing transaction costs for servicing the sector and make non-concessional lending to the sector decisively ineffective in enabling the uptake challenge of clean technologies. Additionally, structured procedures and verification processes to acquire international climate finance, alongside certain prerequisites in some cases, also add up to the cost of capital and disincentivize technological upgradation. Initial adopters of the green technologies need to be incentivised to demonstrate the technologies in Indian context. The cost of servicing the secondary steel sector units, particularly the SME units, is also particularly tricky to resolve for the commercial sector, owing to their low credit scores. Inadequate collateral holdings, irregularity of operations, and poor liquidity due to delays in payments[3] and aid to these units, reflect poorly on their creditworthiness, and hence, make it harder for them to acquire financial support.

Beyond this bird's eye view of barriers to financing decarbonisation of the sector, it is worth separating the barriers that emerge from the side of industry (demand side) from those that emerge from the side of finance sector (supply side).

13.3.1. Demand side concerns

1. **High cost of capital:** The sector needs high upfront capital expenditure irrespective of its green gradient. The landed cost of capital on average is as high as 12%. The combination of high upfront capital requirement and high cost of capital increases overall cost of steel production. There are wide range of estimates suggesting that the additional capital expenditure required for a greenfield green steel project ranges from 30% to 60% depending upon the technological interventions adopted for greening the production process. For existing plants, it ranges upto 20%. At the current lending rate such additional costs are prohibitive from the competitiveness point of view.

2. **Competitiveness concerns:** Cost implication of greening the production process cast shadow on the market size of the product as discussed in the chapter 4 on demand generation. It is not possible to transfer the full additional cost to the end consumers as it will affect the total demand negatively. Thus, the cost disadvantage of producing green steel would directly restrain the industry – ISPs and SSPs both. Additionally, lacking domestic demand for green steel in the absence of necessary regulatory mandates, would increasingly stress the export orientation of the sector – cascading a need to be aligned with cross-border carbon adjustment mechanisms such the EU's CBAM (from 2026 onwards). Thus, for green steel's market competitiveness domestically and internationally, it needs to be supported with regulatory measures around promoting green procurement and production incentives.

3. **Commercial viability:** Economic viability of a project requires that debt maturity is aligned with project gestation period. The capital structure of large investments in ISPs is such that debt-to-equity ratio is 25% to 45%. Additional debt will negatively affect alignment between debt maturity and project gestation period. The potential negative impact on the market demand for green steel can further negatively affect this alignment. For the existing ISPs, the net profits after tax, do not provide them sufficient flexibility to increase equity that can allow them to go beyond piloting green interventions. Steel industry and financial companies should coordinate to establish new business models that have bankable cashflows, achieved through appropriate allocation and effective management of investment risks.

4. **Additional concerns of SSPs:** The SSPs face additional concerns affecting their demand for green finance. In general, the awareness of decarbonisation options is low. Notably, the sector largely lacks knowledge about the efficiency and the payback periods of low-carbon technologies, as well as the provisions of financial assistance available to them through several initiatives. Beyond, the haphazard bookkeeping of financial records, low familiarity with digital platforms, and lack of awareness of documentation requirements to acquire loans, worsen the sector's interaction with formal credit – sharpening the formal credit sources' risk perception against them.[4] More specifically, however, it is the mismatch between the cost of low-carbon technologies and their scale of operation that makes the cost of greening the production process disproportionately high. As discussed in the Chapter 5 on Energy Efficiency, the low penetration of BATs (including among ISPs) is illustrative of low demand for green finance. Moreover, the cost of technical services to identify applicable green technological options, use of digital platforms, and identifying options to access the available low-cost financing solutions, through developing appropriate DPR documents, prohibits the SSPs to undertake these initiation expenses. In addition, inadequate collateral holdings with SSPs (particularly MSMEs) leads to an increased credit risk perception. As banks consistently insist on the requirement of collateral for loans, MSMEs largely prefer to stick to loan options that do not require collateral.

5. **Limited financial support to SSPs:** While previously undertaken programmatic partnerships and technical grants have supported the uptake of energy efficiency in the secondary steel sector clusters, their scale has been grossly inadequate.[5] Importantly, loans, concessional or non-concessional, cannot provide redressal for the pressing technological backwardness of the sector (See Table 14.2). The aforementioned programmatic partnerships for energy efficiency in secondary steel sector clusters illustrate the usage of financial instruments in combination, at a micro scale. For instance, the GEF-UNDP-MOS Programme for Energy Efficiency in Steel-Rolling Mills (Phase-1 – 2004-2013) combined concessional financing with technical grants for handholding support to improve energy efficiency and technological upgradation steel re-rolling clusters. Thus, financial instruments need to be deployed in combinations to cover diverse challenges hampering the low-carbon transition of the sector since no single financial instrument would be capable of addressing the technical, as well

as the cost of capital-related barriers faced by the sector. To maximize the financial servicing to the sector, a mix of instruments needs to be devised in a manner that adheres to the suitability of risk/ return dynamics and the mitigation requirements of the sectoral sub-segments.

6. **Lack of data, regulations, and compliance among MSMEs:** Given the unorganized nature of MSMEs, there is an acute data scarcity, particularly with respect to emissions data. This corresponds to difficulty in planning and executing long-term sustainable development within the MSMEs. This deficiency in data also results in an absence of reporting and monitoring frameworks for MSMEs. Additionally, there is no mandate or cap in place for emissions in MSMEs. The sector's drive towards low-carbon technologies (LCTs) is predominantly based on incentives and voluntary involvement. Larger industrial sectors have these checks and balances in place in the form of regulations and standards and failing to meet them would result in penalties. Similarly, successfully driving industries and perceptions within the MSME stakeholder towards a LCT, will require both incentives as well as regulations in order to influence the shift to RE and EE technologies. However, the unorganised nature, scepticism about green alternatives and the low level of awareness and capacity in MSMEs make it a difficult affair to implement regulatory and reporting frameworks and implement compliance-based targets. The large number of actors in the sector also makes it difficult to enforce regulations unless the actors are willing participants. This collectively leads to low demand for green finance.

Above factors lead to a high-risk perception about the commercial viability of undertaking green investments in the steel sector. Overall, demand-side concerns are more pronounced among MSME SSPs because of the factors discussed above (lack of awareness, relatively low technological and managerial capacity, lack of credit history, small balance sheets, inadequate collateral holdings etc.) Therefore, larger players and ISPs, especially the export-oriented units and the ones committed towards net zero emission targets, might be better placed to be early adopters of technologies, and thus helping in proving bankability and creating track records to scale up financing for these technologies.

Table 13.2: *Suitability of financial instruments in addressing barriers to accessing finance by MSMEs*

Bottlenecks/ Challenges Covered	Financial Instruments & Examples							
	Aset-based Finance	Securiti-zation	Leasing	Guar-antee Funds	Tech-nical Grants	Hybrid Financ-ing	Risk-Sharing Funds/ Facility	Re-volving Funds
Lengthy Documentation Procedures & Processing Time								
Inadequate Collateral Holdings								
High Rate of Interest on Commercial Loans								

Bottlenecks/ Challenges Covered	Financial Instruments & Examples							
	Aset-based Finance	Securiti-zation	Leasing	Guar-antee Funds	Tech-nical Grants	Hybrid Financ-ing	Risk-Sharing Funds/ Facility	Re-volving Funds
Low Credit Scores								
High Transaction Costs								
Technical/ Financial Capacity Building								
Investor Risk Protection								
High Technological Upgradation/ Capital Costs								
Large-scale Coverage								

Legend

Highly efficient Moderately efficient Less efficient

Source: *TERI. (2023). Financing Decarbonisation of the Secondary Steel Sector in India: Towards an Enabling Environment. New Delhi, India: The Energy and Resources Institute.*

13.3.2. Supply side concerns

On the supply side, high-risk perception regarding returns on investment make the equity investors as well as debt financiers hesitant. While the growth in the green portfolio of the banking sector in recent years has been impressive, it is heavily inclined towards renewable energy projects. Moreover, the overall size of their green portfolio is not sufficient to meet the needs of the iron and steel sector. There are a number of factors that contribute to the high-risk perception among the investors:

1. **Lack of green taxonomy:** Policy incentives provided to the sector in accordance with the green taxonomy, such as tax holidays or viability gap funding, is an important consideration for determining terms of credit for projects. While the financial sector is opening up to green investment, it is in a state of uncertainty in terms of developing appropriate financial products specifically designed to provide low-cost capital at scale. This uncertainty emanates from the lack of a standardized green taxonomy.
2. **Lack of awareness about economic viability of low-carbon technologies:** A significant awareness gap also exists on the supply side where the financiers' understanding of mitigation technologies and

their maturity status remains meager. Consequently, they find it hard to ascertain the kind of financial instruments and risk structures that can be deployed to support the uptake of clean technologies in the sector. Overall, the financial sector lacks capacity to reasonably assess expected returns from the green investments in the sector.

3. **Transaction costs:** The due diligence requirements for ascertaining commercial viability of investments, relatively longer payback periods of technologies, the low profit margin, and the monitoring requirements of loans, all add to the existing transaction costs for servicing the sector and make non-concessional lending to the sector decisively expensive in enabling the uptake of clean technologies. Additionally, structured procedures and verification processes to acquire international climate finance, alongside certain prerequisites in some cases, also add up to the cost of capital and disincentivize technological upgradation.

4. **Cost of capital:** The institutional investors (banks, mutual funds, pension funds, etc.) mobilize their capital from retail investors. Their ability to mobilize capital is sensitive to the market expectations on returns, which are usually timebound and risk averse. To manage the market expectations and low risk appetite of the retail investors, the institutional investors also adopt a risk averse behavior. Risk aversion among the institutional sources of credit lead them to either minimis e their exposure to green investment or adopt a stricter due diligence (including collateral requirements) and higher expectations of return on capital. FIs would be unwilling to take on risks for technologies which are not yet commercially viable. Overall, it increases transaction cost for both industry and financial institutions, pushing the overall cost of capital upwards.

5. **Limited capacity of the domestic financial market:** India's domestic financial market is still evolving. A comparatively lower capital base of banking and non-banking financial institutions limits their ability to extend credit beyond a certain scale. India's annual gross savings rate has been declining, albeit marginally, for over a decade and was estimated to be 30.2% for 2022[6], limiting overall investment potential at national scale. While the growth in GDP has to a great extent compensated for the decline in savings rate, it is imperative to make efforts to increase the overall savings volume. This has been also impacting the access to financing by the steel sector especially in the newer technologies that are not yet demonstrated in Indian context.

6. **Lower levels of international and domestic green finance in India:** Globally, recent years have seen substantial growth in international green finance flows. However, it is predominantly concentrated in OECD countries. India has not received international green finance at scale. In fact, India's achievement of its initial NDC targets is primarily financed through domestic sources.[7] Further, India's experience with green bonds so far indicates less than 1% participation of international institutional investors. [8]Primary reason for lack of interest in India's financial market for international investors is the low credit rating of the country (Fitch: "BBB-"). Domestic green finance is also in nascent stages and expanding gradually, constraining the accelerated expansion of such funds to newer technologies especially in hard-to-abate sectors, such as, steel.

7. **Lack of creditworthiness of SSPs:** The cost of servicing the secondary steel sector units, particularly the SME units, is also particularly tricky to resolve for the commercial sector, owing to their low credit scores. Inadequate collateral holdings, irregularity of operations, and poor cash flows and aid to these units, reflect poorly on their creditworthiness, and hence, make it harder for them to acquire financial support.[9] Lastly, in instances where the servicing cost has been covered by ESCOs and facilitative organizations such as the BEE, the maximum funding ceilings have remained inadequate in comparison with overall requirements.[10] Conspicuously, a high-risk perception prevails within the secondary steel sector as well as among the financiers, albeit due to different reasons. Risk mitigation

instruments / credit enhancement instruments can play a critical role in allowing access of financing to MSMEs. One such example is where SIDBI is providing partial risk sharing facility (through the World Bank) to the MSMEs for adoption of energy efficient interventions.

8. **Knowledge gap:** The sector associates low-carbon technologies with risks, while the financiers are apprehensive towards both, the creditworthiness of the sector, as well as the reliability of decarbonisation technologies. Notably, none of these risk concerns are valid in the case of BATs, yet the knowledge gap has stunted their adoption. Thus, the uptake of clean technologies by the SSPs, needs the engineering of policy and financial initiatives that offer handholding support to the sector for acquiring financial support, as well as cover technological demonstration and capacity-building needs of the sector, in order to operationalize these technologies.

9. **Limited innovation and funds for extensive R&D and pilot projects:** Availability of finance at competitive terms is significantly informed by the trust in technologies deployed in a project. Sufficient number of commercially viable projects enhance financial sectors willingness to extend credit at competitive rates. As discussed in Chapter 12 on Research and Development there is limited demonstration effect for decarbonisation in the sector, accentuated by limited R&D to make technologies suitable to scale. The Ministry of Steel may take few pilot cases, small/medium/large units, geography wise, so as to step in either to bear part of capex for pilot and demonstration plant for the corporates & MSMEs or needs to come up with specific scheme (related to our country specific parameters) to support such projects. Such pilot demonstrations in collaboration with international expertise, will be very important and helpful in greening the sector in India in a timely manner.

13.4. Action plan

The international experience of financing low carbon transition of industrial and energy sectors has demonstrated the application of diverse financial instruments, often in combinations as well. Energy Efficiency Revolving Funds (EERF) for specific sectors, for instance, have been utilized across the globe, with the backing of international finance from the World Bank or the Global Environment Facility (GEF). These EERFs have been utilized to provide guarantees (in Bulgaria, Hungary, and Slovenia), to enable credit lines for mobilizing private investments (in Thailand), or to finance projects around renewable energy and energy efficiency. In India EERFs have been availed to support urban infrastructure sprawl in Tamil Nadu[11]. Similarly, the effective implementation of credit guarantees in parts of Africa has alleviated market distortion challenges to a great extent[12] and helped resolve the bottleneck of payment delays to MSMEs in Chile[13].

As discussed earlier, the unique nature of the steel sector in India poses twin requirements for financial coverage – the upfront investment for low-carbon technologies, and the cost of covering technical support and handholding for the sectoral units to enable these technologies. While previously undertaken programmatic partnerships and technical grants have supported the uptake of energy efficiency in the secondary steel sector clusters, their scale has limited.[14] The technologies for decarbonizing the iron and steel sector are at various TRLs and there also exist knowledge gaps and the sector therefore would require a host of different mechanisms to support them. Financial instruments may be deployed in combinations to cover diverse challenges hampering the low-carbon transition of the sector. The programmatic partnerships for energy efficiency in secondary steel sector clusters illustrate the usage of financial instruments in combination, at a micro scale. For instance, the GEF-UNDP-MOS Programme for Energy Efficiency in Steel-Rolling Mills as mentioned earlier.[15]

Strategic approach for financing decarbonisation of the iron and steel sector may have three inter-related components-mobilization of low-cost finance at scale, strategies to address the demand side barriers and strategies to address the supply side barriers. These strategies together respond to the needs of the four parallel tracks of decarbonisation pathways discussed in section 6 as well as take guidance from the overall financing strategy for implementing India's LT-LCDS which emphasizes on integrating domestic public funds, international public funds and private finance along with mainstreaming resources for climate action through monetary and fiscal policy measures.

Its critical to recognize that newer technologies always face constraints in accessing commercial financing during the initial years, till the time technology is demonstrated and proven in given circumstances. This is similar to the case of Solar in 2009/2010 when installed solar capacity was only 39 MW, whereas it stands at more than 82,600 MW as of April 30, 2024. The success is due to multiple interventions on policy and regulatory side to bring higher levels of commercial financing to this technology. Such facilitation involves careful crafting of realistic targets for the installed capacities that are green, prioritizing the projects to have a clear visibility on the tender calendar (at least for one year), arranging for long tenor capital from multilateral banks (to absorb first mover risks), demonstrating technology through initial investments (to improve risk perception), incentivising early investors in a new technology, continuous alignment of the policy and regulatory interventions to signal the market to move towards adoption of green technologies (for instance, renewable power purchase obligations were introduced for power distribution companies with a clear upward trajectory), creating awareness amongst financial institutions, and bringing credit rating agencies to adequately peg the risk profiles (both technological as well as environmental and social) of the proposed projects are some of the interventions that may collectively enable unlocking of commercial investments in the sector to promote its decarbonisation.

13.4.1. Mobilization of finance

Assessing the financial needs for decarbonisation of the iron and steel sector in India is a difficult task. Estimates vary based on the scope of scenarios, assumptions about demand and supply, and costs. For example, various estimates to achieve India's overall target of net-zero emissions by 2070 place the requirement in excess of USD 10 trillion (~INR 83000 crores) till 2050.[16] In contrast, the global estimates for making the sector net-zero range from USD 5.2 and USD 6.1 trillion, including options such as green hydrogen and CCUS (Carbon Capture Utilization and Storage).[17] The existing steel plants in India alone would require USD 283 billion investment to become green.[18] Another estimate suggests that the technology cost of adoption of BATs in the existing SSPs alone is estimated to be more than USD 13 billion and cost of process transition is an additional USD 150 billion.[19] Irrespective of the estimates, the financial requirements are significant.

For any financing to be accessible, the risks associated with a given technology needs to be addressed so that the risk profiling of the investments can be adequately measured. This requires thorough understanding of the associated risks and implementation of linked mitigation measures. Starting from engaging multilateral development banks to absorb early mover risks and demonstration of technology to innovation challenge funds (to bring international investments to a sector in a competitive manner) to Environmental, Social and Governance (ESG)/sustainability linked financing, all need active policy signals. Some of such policy actions include, gradual emphasis on green public procurement, penalizing fossil-fuel based technologies, introducing next generation financial instruments for the sector (such as green bonds), etc. Once the risks are clearly identified and adequate measures are taken, investments will start to come to a sector. This is in addition to availability/access to a variety of financial instruments to address residual risks.

10. **Domestic public finance**

Public finance plays a critical role in unlocking the potential of financial markets in economic growth. Over the last decade budgetary outlays for clean energy and infrastructure have been growing significantly. The 2023-24 budget, for example, announced a plan of INR 350 billion (~USD 4.3 billion) for clean energy infrastructure development including transmission of renewable energy and development of green hydrogen. The Sovereign Green Bonds issued at the beginning of 2023 have mobilized ~USD 2 billion. The government, given the critical role it may play in the transition, may adopt a clear strategy specific to mobilizing and making available public finance for decarbonisation of the iron and steel sector to include, but not be limited to:

a. **ESG linked financing:** The Securities and Exchange Board of India (SEBI), in July 2023, introduced several complementary regulatory guidelines on ESG ratings, disclosures, and funds, which are expected to significantly improve the allocation and monitoring of green finance instruments and funds in India. One important intervention is the introduction of a comprehensive regulatory framework for ESG rating providers, who are now required to register with SEBI and disclose their rating methodologies. SEBI also introduced more stringent ESG disclosure requirements for the largest listed firms as well as external validation requirements. Such measures are paving the way forward for increasing confidence in ESG funding and channeling it towards the eligible projects.

   i. **Sovereign green bonds (SGB):** This instrument can be used to raise debt financing for transition activities – adoption of best available and commercially viable technologies while investing in the demonstration and scaling up of breakthrough technologies until they become competitive. The instrument is usually targeted for technologies which are at TRL levels of 8-10. The issuance of green bonds to promote adoption of green technologies can also cater to the development of allied sectors such as hydrogen production, and renewable energy scale up. Consequently, the development of allied sectors may lead to a significant lowering of operational and production costs for green steel, and offer better market competitiveness.

   ii. **Sustainability linked Bonds:** Such financing instruments are focused on advancing sustainable practices in a company. Unlike green bonds, their funding proceeds are not linked to a specific project. Such funds are available at corporate level. SLB are linked to Sustainability Performance Targets (SPT) and Key Performance Indicators (KPI). To ensure credibility of such SLBs, international organizations such as, Climate Bonds Initiative have come up with sector specific standards. Such standards exist for Steel sector also.[20] One variant of such funding is Sustainability Linked Loans where interest rates adjust as per the achievement of the targets.

b. **Strategic expansion of a functional carbon market under the Carbon Credit Trading Scheme (CCTS) and Carbon Contracts for Difference (CCfD).** Breakthrough technologies, which are at TRL levels of 6-9, have incremental production costs relative to conventional technologies due to higher CAPEX, OPEX or both. This is a significant barrier for adoption in addition to market uncertainties, financing structure and financing costs. Carbon revenues obtained for trading credits in carbon markets can be an important cash inflow to a low carbon project. The recent amendment to Energy Conservation Act (2001) introduces an offset mechanism to the existent compliance structure by allowing voluntary participation of non-obligated entities to register projects in specific sectors for tradable carbon credit certificates (CCCs), enables a greater pricing of emissions through CCCs' trading. Carbon pricing is expected to play a critical role in reducing the gap between grey and green technologies.

The option of CCfD, a bilateral contract between the government (or its entity) and a low carbon project, structured around an agreed carbon price required to make a project viable, denominated as the strike price and price of carbon in the market, can act as a hedging mechanism[21]. CCfDs are being introduced in Europe, however a lot of ground needs to be covered to introduce them to the Indian context. Success of CCfD rests on setting the strike price at the right levels to incentivize the green technologies. It also depends on creation of the pool of funds – identification of the right authority to manage the fund, source of seed financing for this fund and how to make it a revolving facility.

c. **Technical Assistance Facility and Development Equity Fund.** Early-stage projects, with TRL levels of 4-7 (even sometimes higher TRLs also if not yet scaled up sufficiently enough to attract commercial investments), lack commercial viability and a successful track record which limits their ability to raise capital. Risk capital and requisite technical assistance, in form of grants/ concessional financing, at this early stage would help create a project pipeline and boost investor confidence. A dedicated technical assistance facility along with a development equity fund can provide necessary support in enhancing understanding of the project and improving quality of information available to investors. The support can include technical feasibility studies, market assessments, impact assessments, legal advisory services, permitting costs inter alia.

2. **International public finance**

The Government of India needs to adopt a comprehensive strategy to build on the potential international public finance availability, including but not limited to:

a. **Multilateral/bilateral banks:** The sources of international public finance include multilateral financial institutions like the Green Climate Fund and Global Environmental Facility; Multilateral Development Banks (MDB) like the World Bank, Asian Development Bank, and New Development Bank; Multilateral Development Agencies like the UNDP and UNIDO; and bilateral finance through partnerships with other countries such as the Green Hydrogen Partnership with Germany, and credit lines, etc. Such funding is generally long tenor and can be instrumental in development and deepening of the markets. These institutions can provide financial and non-financial assistance to stakeholders, including advisory for formulation of policies and enabling environment at the government level; development of low-carbon pathways at the sectoral level; transition plans, setting up demonstration projects, capacity building and institutional strengthening, knowledge exchange at the corporate level through technical assistance, and use of direct financing and risk mitigation instruments[22]. Depending on the needs of the sector/technology, the instruments from such institutions can be leveraged. For instance, the World Bank, in 2023, approved a USD 1.5 billion development policy operation titled "The First Low-Carbon Energy Programmatic Development Policy Operation[23]" – the first in a series of two envisaged operations – to support India in developing green hydrogen, renewable energy and carbon financing through variety of policy and regulatory interventions. Such measures were critical to advance the ecosystem for providing clear signals to the market to attract investments. In addition, many multilateral financial institutions have pledged to significantly increase their green investment portfolio. Under the UNFCCC process, negotiations on the New Collective Quantified Goal on Climate Finance (NCQG) are scheduled to conclude in 2024. Direct investment in the projects through such bodies helps in absorbing the early risks associated with the sector, demonstrating a technology, increasing confidence of the other commercial financiers, and eventual deepening of the market.

b. **Concessional Funding:** The Green Climate Fund (GCF) has more than USD 13 billion to be disbursed in developing countries of which 50% is for Decarbonisation projects. Another example of market development is to deploy some of such concessional funds/grants to introduce risk mitigation instruments. For instance, the World Bank deployed GEF to activate a partial risk sharing facility for the MSME sector to advance energy efficiency adoption in India.

c. **Blended Debt Fund.** A Blended Debt Fund that blends funding from various sources of available international public finance (including concessional finance). Such financing can be facilitated by commercial institutions (generally, development finance institutions) or MDB (such as, World Bank)/Bilateral financing institutions (such as KfW, JICA inter alia) depending on the requirements and depth of the financial markets. Such funds aim to deepen the markets and mobilise private sector resources for a referenced technology. Such funds can provide lower cost and longer-term investment in projects deemed too risky by traditional commercial banks. These funds aim at utilizing public capital for de-risking the projects by providing partial funding that demands lower returns and takes on higher risk, such that requisite (and indispensable) private capital can be mobilised. Necessary Technical Assistance and additional risk capital (in form of a first-loss tranche) can be further built in to increase the fund's risk capabilities. The blending of funds can also be incorporated through a local financial institution (FI such as IREDA, SIDBI, REC, SBI inter alia), such that international public finance lending institutions provide credit lines of concessional finance which is then blended with FI's own funds. It might be noteworthy that sources of concessional finance are limited, and they should therefore be deployed in the most catalytic manner[24].

d. **Partial Credit Guarantee Mechanism.** A partial credit guarantee mechanism operates on similar principles as a Blended Debt Fund where a pool of capital is underwritten and capitalised by domestic and/or international funders and covers identified risk(s), such as, of payment default on the guaranteed portion of debt offered by a traditional FI. This improves the risk-taking ability of traditional FI who then can evaluate and onboard projects that otherwise would have been deemed too risky. Risk sharing between a local financial institution and a guarantor improves risk perception, reduces information asymmetry and may also improve lending terms. The mechanism may be instituted as a fund managed by a fund manager and open to participation from commercial lenders who could then apply for partial risk coverage.

e. **Utilization of the cooperative approaches as well as market-based approaches under the Article 6 of the Paris Agreement.** The Paris Agreement provides an international architecture, enabling voluntary cooperation between a developed country and a developing country for implementation of NDC through various Market Based Mechanisms (MBM) and Non-Market Approaches (NMA). The developed country, based on the provisions of Article 6, can provide low-cost financing and technical assistance to a developing country for deployment of decarbonisation projects. The developing country in lieu of the financing and assistance would defer claims of mitigation outcomes (from the project) to the developed country. The cooperation agreement between countries may also include sharing of potential financial returns on investments. Article 6 targets the establishment of mutually beneficial agreements where the developing countries are supported in terms of low-cost finance, access to technological solutions and requisite institutional support for implementing and operating projects. The developed countries on the other hand get access to mitigation outcomes which would have otherwise been relatively more expensive if the decarbonisation project was being developed there. MBM of Article 6, like its predecessor (Clean Development Mechanism) have attracted criticism in relation to calculation of accurate baseline, additionality, double counting, and carbon leakage[25]. The UNEP[26] reports that as of 1 May 2024, 82 Bilateral Agreements between 10 different buyers and 46 different countries have been signed.

The strategy for leveraging international public financing needs to be aligned with the strategy for effective utilization of domestic public finance.

3. **Domestic private finance**

Decarbonisation of the ironand steel sector has attracted investments globally. Based on analysis undertaken by CPI, as of November 2023, a cumulative investment of USD 41.7 billion had either been made or announced for low-carbon steel projects. These investments have been centred around Hydrogen-DRI (H-DRI), carbon capture utilization and storage (CCUS) and scrap EAF. It is however important to note that the share of private sources of funding for green steel projects was 84%, which makes private finance indispensable for the sectors' decarbonisation. Private sector, however, is risk averse and its participation increases as the technology reaches maturity, is bankable, has a proven track record and is ready to be deployed at scale. At earlier stages of technology development, the state's role becomes catalytic through creation of an enabling environment and deploying high risk funding to initially crowd in private capital and subsequently spur deployment of private investments at scale. This enabling environment for the steel sector in India would require:

a. Formulation of a sectoral transition pathway through due consultation with industry associations.

b. Setting of clear and realistic targets for installed green capacities with at least one-year calendar for tenders. Units that are export-oriented and/or have net-zero emissions (NZE) targets can be prioritized.

c. Innovative PPP models to create common infrastructure such as a common DRI plant or coal gasification plant for the cluster, common slurry pipeline, infrastructure for transportation and storage of green hydrogen and CO_2, supporting steel specific R&D with due participation of government, industry and academic institutions; and, public funding of demonstration projects which may be deemed risky for private sector.

d. Consulting with off takers to create a demand for low carbon steel through green procurement policies (gradual with an upward trajectory).

e. A combination of regulatory push and fiscal incentives (such as tax holidays) during initial years to encourage equity investment by companies; to reduce CAPEX costs, and hence contributing towards lowering the gap between grey and green steel.

f. A facilitative monetary policy to increase allocation of commercial credit to the decarbonisation projects in the iron and steel sector such as priority sector lending.

g. Targeted infusion of capital in the banking system to enhance favourable credit for decarbonisation projects in the sector (including through international credit lines)

h. **Provision of Viability Gap Funding (VGF)** for adoption of BATs in SSPs or for even newer technologies across the iron and steel sector.

i. **Venture Funds and Innovation Challenge.** Such initiatives promote start-ups and newer ideas that are generally home-grown and can contribute towards inward-looking policies of the government. A collaboration with the Department of Science and Technology (DST) and other concerned ministries along with venture capitalists can help promote greener solutions in the steel sector.

j. **Credit Ratings for utilities (specifically for MSME) can improve the risk perception:** Projects of Secondary Steel Producers (SSP) deploying BATs and early-stage projects of Integrated steel plants (ISP) deploying breakthrough technologies face reluctance from risk averse commercial lenders in form of high perceived credit risk. The former may have low credit ratings or an unproven business model while the latter may lack a proven track record for the proposed technology. It is important that the credit rating agencies are involved to devise a credit rating methodology (technical, environmental, and social) for such segments to channel funds flow to them.

k. Refinancing of the existing loans to circulate the funds in the sector is another possibility. Such projects are generally low on risks and are promising candidates for this option.

l. **Multi-layered risk sharing mechanism and introducing risk mitigation instruments:** A number of public, private, domestic and international financial institutions are involved in financing sectoral investment needs. Each of them has its own risk perception. To mitigate this layered risk perception, a comprehensive multi-layered risk reduction mechanism providing guarantees will build confidence of different financial actors (See Figure 14.1). Such a risk-guarantee mechanism can also be combined with multiple credit lines from MDBs and bilateral sources.

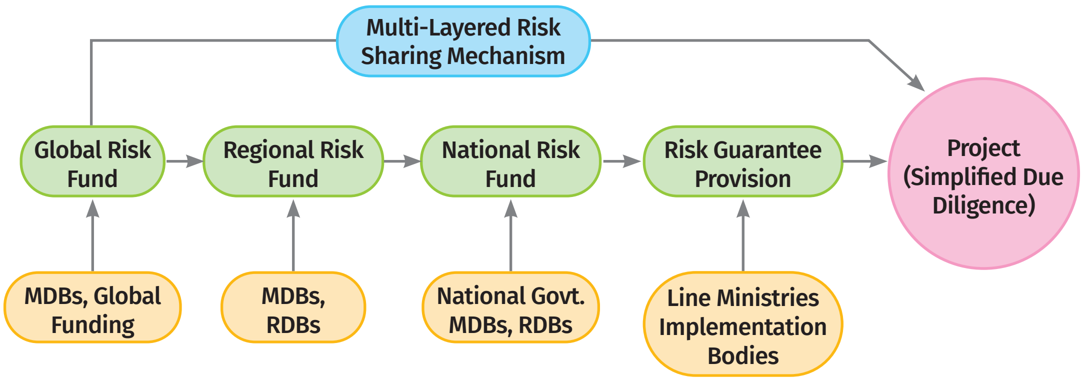


Figure 13.1: *Multi-layered Risk Sharing Mechanism*[27]

4. **International private finance**

Similar to domestic private finance, the key balancing issue remains handling the higher cost of capital and de-risking investments. International private finance flows are informed by comparative risk perceptions and investment climate. To reduce the risk perception of international investors, nationally appropriate policy measures are to be implemented. These will include:

a. Innovative blending of domestic and international public finance in designing debt instruments such as green bonds.

b. Asset based securitization of debt instruments.

c. Development of currency hedge funds to mitigate the impact of currency risk for international investors and domestic borrowers.

d. Attracting international funds through global players in a sector can also contribute towards the end goals of a sector.

Some of such institutions that could play a critical role during the initial phases of introducing newer technologies in a sector are International Finance Corporation, CDPQE (Caisse de dépôt et placement du Québec), amongst others. Recently, international philanthropic organizations have also shown eagerness to support decarbonisation efforts in developing countries. A facilitative mechanism needs to be developed to efficiently utilize such resources.

Regular engagements between policymakers, regulators, financial institutions and industry/corporate world and international fund houses, would help in the formation of more effective strategy for industry, which can drive faster adoption of Green Steel.

13.4.2. Addressing demand side barriers

Following steps may be undertaken to enhance the demand for green finance in the sector:

a. **Green taxonomy and public procurement:** Government of India may adopt a public procurement target in line with the action plan discussed in Chapter 4 on Demand Generation and Chapter 2 on Green Taxonomy. A public procurement target aligned with the well-defined green taxonomy would play an important role in giving strong direction as well as signal to investments and technological choices in the industry.

b. **Consumer support:** As long as the producers are able to transfer a part of their additional cost to consumers, or consumers find it competitive to buy green steel, the industry outlook towards green transition will be positive. The Government of India may consider incentivising the private end consumers for using green steel through instruments such as lower GST rates on green steel in combination with issuing quotas such as minimum % of green steel in large construction projects.

c. **Time bound regulatory targets:** The Ministry of Steel may consider establishing time bound targets for manufacturers to achieve different levels of greenness (emission reduction) as per the definition of green taxonomy for steel. This will allow the plants to find least cost options according to their scale of operation. An innovative adoption of the 'top-runner' model for energy efficiency in Japan may be adopted for the sector. Given the high heterogeneity in the sector, time-bound targets should be based on intensive consultations and buy-in from manufacturers, and should be combined with tradeable "greenness" (emission reduction) certificates to allow plants to make progress in an economically efficient way. Thus, one could take elements from the Top Runner model (dynamic targets) and combine them with elements of the PAT scheme (market-based mechanism). Further, earmarking a share of funds under the Steel Development Fund for green R&D and investment could also be considered.

d. **Viability gap funding and innovative business models:** The Ministry of Steel may consider providing viability gap funding through innovative business models for the adoption of BATs. The focus will be on developing technology specific business models such as to scale up adoption of waste heat recovery interventions. The business models need to be reworked and aimed at addressing the challenges of knowledge gaps as well as poor cash-flow especially of the SSPs.

e. **Technology upgradation funds (TUF):** It is important to learn from transitions in other sectors. India has successful experience with technology upgradation funds scheme in the textile sector where in 5% of interest payments were reimbursed. The Ministry of Steel may consider setting up a Technology Upgradation Fund Scheme (TUFS)with an aim to reduce cost of capital for adoption of BATs. The fund may operate in coordination with the mechanisms for viability gap funding.

f. **Market based mechanism:** The Ministry of Environment, Forest and Climate Change may consider to include specific provisions in the Domestic Carbon Market as well as the Green Credit Scheme for encouraging the participation of SSPs. Additional sources of revenue through the carbon market will encourage the SSPs to adopt BATs.

g. **Reducing upfront capital requirement:** The Ministry of Steel in coordination with relevant line ministries may consider to develop a policy package to reduce the upfront capital requirement for setting up green industry. The policy package may include provisions such as easy and cost-effective access to land, renewable energy, supporting infrastructure, etc.,

h. **Long-term low-cost financing:** The Ministry of Finance may consider developing a policy framework to ensure long-term low-cost credit availability to support green interventions. Lower interest rates will be an essential component of such a framework .

   i. **Fiscal Incentives:** The Ministry of Finance may consider to introduce a host of fiscal support instruments such as interest subventions, directed subsidies, accelerated depreciation, tax holidays, export subsidies etc. to encourage industry for investing in green technologies.

   ii. **Pilot financing facility:** For the steel sector, specifically in the context of emerging technologies, companies can adopt measures that either reduce risks across the board or transfer specific risks to those best suited to handle them. Deconsolidated financial structuring (project financing) and co-financing of projects by multiple sponsors (steel and energy companies, technology providers, etc.) allow for ring-fencing and sharing of risks among parties, improving the overall risk profiles of investments. To reduce the risk perception regarding technologies, the Ministry of Steel may consider to set-up a pilot financing facility to demonstrate that technological interventions are economically attractive. These, however, will need to be supported by feasibility studies.

13.4.3. Addressing supply side barriers

1. **Targeted Capital Infusion in the banking sector:** The Ministry of Finance may consider to provide for additional operating capital to the select public and private sector banks to enhance their credit supply. This additional capital infusion can be exclusively targeted to promote affordable credit for decarbonisation of the iron and steel sector.
2. **Export oriented priority sector lending:** The RBI may consider issuing guidelines for priority sector lending (PSL) towards green steel. In particular, the focus can be on supporting the new capacity addition as well as the existing plants exporting steel. These guidelines need to be aligned towards offsetting the impacts of the market access barriers like the CBAM. The scope of priority sector lending may be further enhanced to cover decarbonisation projects in the sector and equipment being supplied to such projects up to a pre-determined limit. Further, RBI may also consider lowering the risk weight (RW) for lending to decarbonisation projects to make it more attractive for banks.
3. **Support for sector specific green bonds:** The Ministry of Steel may consider to support the sector specific green bonds issued by commercial banks and industry through instruments like sovereign guarantees, rebates on certification fees. In addition, considering that the green bonds market in India

is still emerging and the ratings do not attract international institutional investors, risk guarantees from multilateral agencies like the World Bank and the Asian Development Bank, can be negotiated towards issuing high investment grade sector specific green bonds.

4. **Enhanced access to international finance:** Risk guarantees are proven instruments for encouraging investors to overcome their hesitation in investing in certain technologies where risk perception is high. In the context of international finance flows, technology risks are further added by the risk perceptions embedded in country ratings and the disproportionate cost of due diligence compared to the ticket size. For the industry, in addition to high cost of capital, the exchange rate fluctuation induced risks are also a deterrent for accessing international green finance. The Ministry of Steel may consider introducing a host of risk reduction measures to address different types of risks. For example:

   c. **Partnerships with multi-lateral development banks** as well as bi-lateral partnerships for:

      i. extending financing to demonstration projects and

      ii. providing guarantees to reduce the risk premium, effectively reducing the lending rate

   d. **Simplified due diligence procedures** with risk guarantees to access institutional international finance

   e. **Underwriting of loan documents for small units:** There are several medium and small size steel units including mini–blast furnace, sponge iron units, induction furnace units and rolling mills. These units usually struggle with understanding existing policies and processes for the emerging technology (of Low Carbon emission) and may not understand what roles and controls are required to manage the risk of implementation. Most emerging technologies require significant effort in acquiring new knowledge to understand how the application is relevant to the enterprise. Because emerging technologies often demand new skills, knowledge and capabilities, many organizations rely on external parties for aspects of the technology or its use, leading to increased third-party risk. For example, manufacturers look to technology enterprises to implement new technology for reducing carbon emissions. But this presents a new level of risk since it is not always clear who is ultimately responsible for the breakdown in trust if the technology is compromised. It takes time and effort to understand roles and include them in contracts/Loan financing Documents. While underwriting loans, the MoS may coordinate with top Legal Firms to include appropriate clauses related to technology risks, including for the third-party providers who are providing new technologies as well as new units who are adopting new technologies in the process of decarbonisation of the sector, which will safeguard bank finance as well the other stakeholders' interest as well.

5. **Cooperative approaches under Article 6 of the Paris Agreement:** The Ministry of Steel in collaboration with the Ministry of Environment, Forest, and Climate Change, may consider exploring using the cooperative approaches provided under the Article 6 of the Paris Agreement. Partnerships with other countries under Article 6 will allow India to mobilize international finance for green steel capacity expansion at an effective lower lending rate for long-term loans. Since the steel sector is not explicitly part of India's NDC, this option may be innovatively used as a transition instrument.

6. **Partnership with the Glasgow Financial Alliance for Net-Zero:** The Glasgow Financial Alliance for Net Zero (GFANZ), a group formed during the COP26 climate conference in Glasgow, is a global coalition of leading financial institutions committed to accelerating the decarbonisation of the economy. The Ministry of Steel in collaboration with the Ministry of Environment, Forest, and Climate Change may consider a partnership with GFANZ and similar initiatives for increased availability of affordable finance for greening of the steel sector in India.

7. **Capacity Building of the Financial Institutions:** Capacity building in the financial sector to help evaluate and invest in technologies in the sector is also equally important. One model could be similar to green investment banks in industrialized countries (e.g. Australia's CEFC, Germany's KfW, the UK's GIB), which are often staffed not only with bankers, but also technology specialists and in-house engineers, and thus (i) are in a better position to assess risks and evaluate new technologies, (ii) help create standardised de-risking approaches, financing structure and contracts to help make projects bankable, and (iii) play a role in educating the wider financial sector by co-investing, providing advisory services and training.

8. **Pooled finance for SSPs:** To address the issues of pooling of risks of SSPs, a financial platform should be established under the administrative control of the Ministry of Steel. This financial platform may involve international and domestic FIs and other external agencies/ professionals with experience in asset management. The international and domestic FIs can extend lines of credit to establish a Hybrid Pool, which can then provide, on a case to case basis, long-term finance to SSPs in accordance with an established framework. A Hybrid/ blended finance model under this framework can ensure that concessional loans from climate funds also reachSSPs.

13.4.4. Enabling institutional initiatives

With a view to provide a long-term stable ecosystem for mobilising and disbursing affordable finance for green projects in the iron and steel sector, the Ministry of Steel in collaboration with relevant line ministries and technical institutions may consider to set-up following institutional initiatives:

1. **National Investment and Infrastructure Fund (NIIF)**

A dedicated fund to support decarbonisation of the hard-to-abate sector, particularly the iron and steel sector, may be established. This fund will be aimed at blending mobilization of finance through domestic and international sources public as well as private finance. The initial capital will have 50% contribution from the government of India and the rest will be mobilized from multilateral financial institutions (the World Bank, ADB, GCF, etc.), domestic and international institutional investors such as pension funds, private equity investors, and contributions from philanthropies. Over the years the Fund will aim to raise capital from the international financial market to the effect of reducing government contribution to 25%. The Fund will have to provide integrated technical assistance and financial solutions for decarbonisation of the sector to reduce the cost of capital and risk perception. Initial government contribution will be INR 4000 crores. The Fund can be housed with an existing public sector financial institution with sufficient financial and technical capability and will work in collaboration with other financial institutions, including NBFCs and venture capital funds.

2. **A revolving fund with comprehensive financial package for SSPs**

The Ministry of Steel may consider establishing a comprehensive financial package for SSPs which will blend various financial instruments such as grants, concessional loans, commercial loans, risk guarantees, equity, technology specific innovative business models, etc. This package can be implemented through a revolving fund housed in SIDBI.[28] The fund will have an initial operating capital of minimum INR 4000 crores.

3. **A multi-stakeholder facilitative (technical assistance) platform**

To address the knowledge gaps within the industry and financial institutions regarding low-carbon technologies for green steel, as well as to facilitate development of innovative financial instruments, the Ministry of steel may consider establishing a multi-stakeholder technical assistance platform. It may be modeled along the UK's Green Finance Institute, backed by the Government and staffed by technical experts, bankers, industry, and technology providers. The Platform will proactively work with industry, particularly the SSPs, to help them identify appropriate technological options for decarbonisation as well as low-cost capital structure. In parallel, the Platform will have to work with a consortium of financial institutions to identify innovative policy ideas and instruments blending financial sources suitable to the needs of industry as well as financial institutions. It will also serve as a repository of knowledge on latest technological development through interactions with technology developers. After an initial seed funding of INR 50 crores from the Ministry of Steel, the Platform may be envisaged to be self-sustaining through nominal fee from industry, financial institutions, and technology developers. It can be housed with a consortium of institutions with necessary technical expertise. The Platform is illustrated in Figure 14.2.

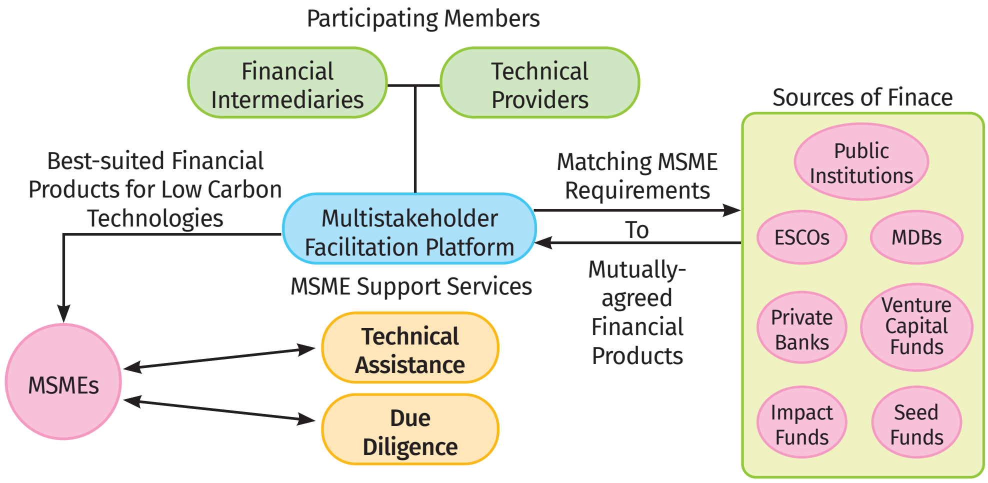


***Figure 13.2:** Multistakeholder Facilitative Platform (Adapted from TERI (2023))*

4. **Supply chain linked market-based decarbonisation model**

The concern for competitiveness resulting from higher cost of production is a major deterrent for industry. In the evolving context of decarbonisation requirements across sectors, it will allow a great deal of flexibility to industries if they are allowed to meet their obligatory or voluntary emission reduction targets through investing in their supply chain. Since steel is an important input to many other sectors, they should be allowed to invest in steel sector decarbonisation in return for eligible emission reductions. While they can do so, using the carbon market route too, such flexibility may reduce their transaction costs as well as make it easy for the steel industry to mobilize finance. This will certainly help the SSPs and MSMEs in the steel sector. The Model is illustrated in figure 14.3.

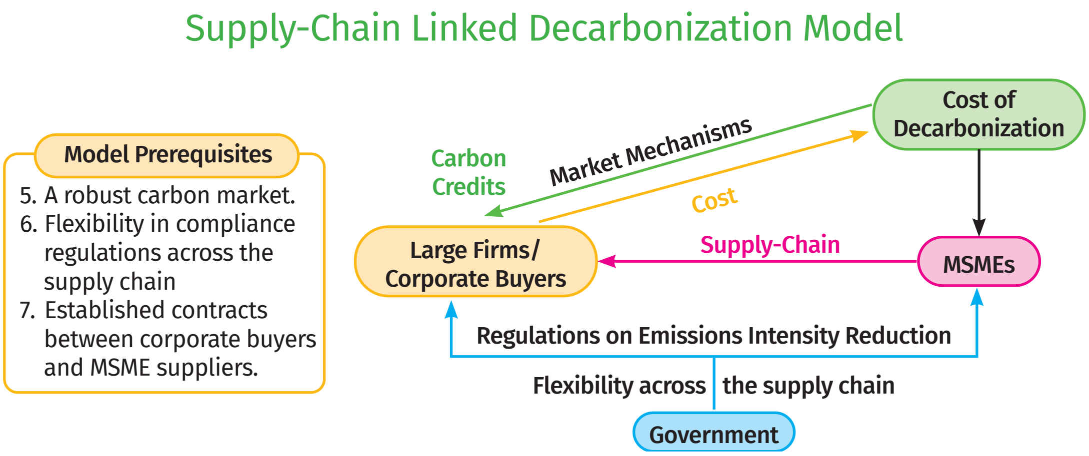


***Figure 13.3:** Supply-chain linked market-based decarbonisation model*

8. **An enabling policy framework**

The Ministry of Steel may consider establishing an enabling policy framework with a view to provide necessary guidelines for industry as well as financial institutions so as to operate within a stable policy environment. The framework needs to have elements such as:

i. **Green certification:** An appropriate institutional mechanism be set-up for certification of green steel. It will enable the financial institutions to come-up with dedicated financial instruments.

ii. **Sustainable STEEL Principles (SSP):** In addition to high investment costs, operational-cost, and complex technological uncertainties, companies face challenges emerging from limited amounts of accessible equity capital, partially defined regulatory requirements, and high-risk profiles, especially in early technology stages. The role of financiers in greening steel is at a critical juncture. With the high cost of transition towards green steel initiatives beyond most steel producers' internal resources, more finance is needed to accelerate this transition. The Sustainable STEEL Principles (SSP) enable banks to measure the climate alignment of their steel lending portfolios by providing insight into their clients' emissions intensity, compared to NetZero pathways. Consequently, the Principles help empower financial institutions in providing clients with the tools necessary for decarbonisation .

iii. **Exclusion from Large Exposure Framework (LEF):** Under the Large exposure Framework, an exposure to a counterparty constitutes both on and off-balance sheet exposures included in either the banking or trading book and instruments with counterparty credit risk. The LEF was introduced to address inadequacies of market infrastructure such as reporting, trading and exchange platforms, disclosure insufficiencies, and subdued corporate bond market etc. In the last one-decade, Indian markets have developed significantly, considering the reporting mechanism, bond market evolvement, Green Deposit Framework, and Draft Disclosure framework (2024) in pipeline. The sovereign green bonds issued by India in Jan-2023 reflects the growing policy focus to scale up domestic financing capacity on climate mitigation and adaptation. Hence, excluding green financing for the Iron & Steel industry from the LEF norms may be considered.

iv. **ESG linked finance:** In light of the increasing emphasis on ESG reporting, including the recent guidelines issued by the SEBI on BRSR, an institutional framework promoting ESG linked financing will be instrumental in building forward looking engagement between the industry and finance sector. It may also be worth exploring whether graded concessions on interest rates based on incremental ESG performance targets would be attractive to industry as well as the financial sector.

v. **Dedicated platform to list projects that need financing:** The banking units in International Financial Service Center (IFSC), GIFT CITY, are mandated to lend 5% of their incremental lending towards sustainable projects. Apart from banks and the bond market, more climate funds are scheduled to be launched in GIFT City. Taking these initiatives forward, a dedicated platform may be created listing projects that need financing. These projects then can be financed from the IFSC-Banking Units (IBUs).

vi. **Grant Infrastructure Status to Iron & Steel industries implementing green technology:** Several initiatives proposed by the government in the housing, infrastructure and automotive sector, are supporting the growth of the steel industry. These focused efforts have invited domestic stakeholders to invest in the industry. India is also working towards becoming a major steel exporter and this has proved to be an added stimulus to investors. In view of this, steel industries implementing green technology under the infrastructure sector, which will boost investments and faster greening of steel industries/units should be deemed to be eligible for incentives and support provided to infrastructure projects.

vii. **Best global practices:** Success stories are often replicated with institutional push. It is important that we learn from the experiences of success stories, abroad as well as at home, and adopt them in the diverse context of sectoral decarbonisation. (for example, Sweden-a pioneer in Green steel production)

viii. **Monitoring mechanism:** An institutional mechanism may be framed to track the transition from conventional to green steel making in existing plants will create certainty about the transition requirement for industry.

ix. **International sustainability exchange:** A platform may be created to provide information to different stakeholders, facilitate dialogue between them with regard to progress and prospects of green steel in India. This may help alleviate risk perception among the international investors as well as make the industry and domestic financial actors more aware and confident about investing in green steel. A Centre of Excellence (CoE) may also be a part of such a platform which will facilitate adoption of best practices linked to green finance for the steel sector.

13.4.5. Proposed studies

- A study to assess the aggregate impact of different combinations of policy interventions and financial instruments on reducing the cost of capital and mobilisation of private and international finance.

- A study to develop an assessment tool to evaluate the economic viability of different technologies for the benefit of industry as well as financial institutions.

- A study to identify appropriate business models, including public-private partnerships, for decarbonisation of the sector, particularly for SSPs.

CHAPTER 14

INTERNATIONAL FOCUS

14.1 Introduction

Global demand for steel is projected to increase by more than a third by 2050. Even technologies driving the energy transition require a substantial amount of steel. India is the second largest producer of steel in the world. The Government of India's Long Term Low Emission Development Strategies, submitted to UNFCCC in 2022, identifies the promotion of economy-wide decoupling of growth from emissions and development of an efficient, innovative, low-emission industrial system as a lever to fulfill domestic needs while achieving decarbonisation in the steel industry.

Achieving the world's climate goals agreed upon in Paris necessitates forceful and urgent global action. High-income countries cannot do it alone because of the large share of emissions and projected growth in middle-and low-income countries. Herein, the role of international focus assumes significant importance for heavy industries, like steel, as it is often highly traded, serves global markets, and its Net-zero transition involves the massive deployment of emerging technologies and finance.

Today, India is poised to work through existing global forums and position the heterogeneity of current steel industries through facilitated discussions on the open and free trade of low-emissions steel. Regarding supply, standards make it possible to evaluate whether a given innovative technology or interim emissions-reduction measure deserves financial support andat what level. Increasing international collaboration between major steel producers will be an important part of setting common standards and further collaboration through sharing of knowledge, technologies and best practices can drastically increase the spread of clean technology.

The chapter captures the State of Play of steel decarbonisation in major countries and provides key lessons for India and Indian Steel Players.

14.2 State of Play: Steel Sector Decarbonisation in Major Countries

In addition to India, major countries where steel is produced include China, Japan, the Republic of Korea, Brazil, Turkey, Germany, South Africa, Sweden and the USA. In 2023, India ranked second in terms of global crude steel production. Several countries have developed national policies and commenced research to identify steel production methods using decarbonisation technologies. The following section explores the experiences of the major steel-producing countries in their efforts to decarbonize the steel sector. The section highlights key initiatives of countries on:

1. Explicit articulation of net-zero target for the steel sector
2. Development of a technology roadmap for decarbonisation of the steel sector
3. Key technological routes being pursued for decarbonisation of the steel sector
4. Key policy levers adopted to drive decarbonisation of the steel sector
5. Key national institutions/organisations who are developing new technologies and undertaking Research & Development on steel sector decarbonisation

14.2.1 Explicit articulation of net-zero target for the steel sector

It is observed that many countries have adopted net-zero-emission targets. Countries accounting for over two-thirds of 2020 GHG emissions have committed to NZE in 2050 or 2060, while some have made earlier or later commitments (for example, India 2070). Also, countries are adopting sectoral approaches to mitigation, typically policies covering power, industry, transport, buildings, and agriculture and forestry. The net-zero target of the steel sectors in major steel-producing countries are enumerated below.

Name of Country	Net-zero target for steel sector within climate commitments
China[1]	China has a declared commitment to achieve carbon neutrality by 2060. China to achieve net-zero carbon dioxide emissions by 2050, and reduce all greenhouse gases by 90% on the basis of 2020 emissions, so as to achieve the carbon neutrality goal by 2060.
Japan[2]	Japan declared that it aims to achieve carbon neutrality by 2050. This is a goal for the country as a whole, regardless of sector.
Republic of Korea[3]	Korean government announced net-zero by 2050 in the year 2020. In the year 2021, as their enhanced NDC, the Korean government announced that industrial emissions to be reduced by 14% by 2030 below the 2018 level
Brazil	Brazil has not yet set a net-zero target for the steel sector. While the Brazilian government has made commitments to reduce greenhouse gas emissions, these commitments do not specifically target the steel sector.
Turkey[4]	Turkey announced to reach net-zero target by 2053 in its NDCs[5]
Germany[6]	Net-zero target by 2045 for Germany
European Union[7]	Net-zero target by 2050 for European Union
South Africa[8]	To meet global energy and climate goals, emissions from the steel industry must fall by at least 50% by 2050, South Africa needs to reduce its emissions to below 348 $MtCO_2$ e by 2030 and to below 224 $MtCO_2$ e by 2050 to be within a 1.5°C 'fair-share' pathway. The Steel Master Plan proposes that the industry agrees to a target for the industry to reach carbon neutrality by 2050.
Sweden[9]	By 2045, Sweden is to have zero net emission fossil free steel.
USA[10]	USA does not have a steel sector specific net-zero target. However, on a broader scale, the US Government has announced to become net-zero emitter by 2050, and several steel companies have started working to meet this target.

14.2.2 Countries specific technology roadmaps for decarbonisation of the steel sector

Industry transition roadmaps can be analytical tools for understanding, framing, and shaping complex transition processes. They offer an opportunity to set out the timing and sequencing of policy, investment, and innovation in such a way that reduces the risk of industries being locked into higher emission trajectories due to the long lifespans of industrial assets.

Name of Country	Key elements of technology roadmap for deep decarbonisation of the steel sector
China[11]	• In 2022, the Low Carbon Work Promotion Committee of China Iron and Steel Association officially released the Carbon Neutrality Vision and Low Carbon Technology Roadmap of the Iron and Steel Industry. • The roadmap clarifies the "dual carbon" technology path for China's steel industry - improving system energy efficiency, resource recycling, process optimisation and innovation, breakthroughs in smelting processes, product iteration and upgrading, and capture and storage utilisation. • The "Roadmap" divides the implementation of the "dual carbon" **project into four stages according to time nodes:** ***actively promoting and steadily achieving a carbon peak before 2030; From 2030 to 2040, innovation-driven deep decarbonisation will be achieved; From 2040 to 2050, achieve significant breakthroughs in sprinting to the limit of carbon reduction; From 2050 to 2060, integrated development will help carbon neutrality.*** • From the perspective of **key tasks, the Roadmap proposes five points:** ***first,*** to deepen supply-side structural reform; ***second,*** to continue optimising process structure; ***third,*** to innovate and develop low-carbon technologies; ***fourth,*** to create a green and low-carbon industrial chain; and ***fifth,*** to strengthen global low-carbon industry innovation cooperation. • **The main policy to support the decarbonisation of Chinese steel will be to support the expansion of zero-carbon renewable energy and nuclear power generation.** In the zero-carbon scenario by 2050, the production of electric furnace short-process steel will reach 333 million tons, bringing about a zero-carbon electricity demand of 0.16 trillion kilowatt hours. • It is crucial to support the development of waste recycling systems through policy support and appropriate market design. Many studies predict that **by 2050, China will have an annual supply of 300 to 400 million tons of scrap steel, sufficient to meet the demand for short process steel.**
Japan[12]	The technological pathways to decarbonisation of the iron and steel sector include: • Low-Carbon and Decarbonisation Technologies for Carbon Neutrality • Technology Roadmap for Iron and Steel • Scientific Basis/Alignment with the Paris Agreement. It is focused on achieving 2050 carbon neutrality by steady low-carbonization and implementing innovative technologies whilst sustaining and enhancing the Japanese iron and steel industry. • COURSE50 (CO_2 Ultimate Reduction System for Cool Earth 50)

Name of Country	Key elements of technology roadmap for deep decarbonisation of the steel sector
Republic of Korea[13]	• On February 16, 2023, the Ministry of Trade, Industry and Energy (MOTIE) released the Steel Industry Development Strategy for Transition to Low-Carbon Steel Production. • The strategy was announced through the 'Steel Industry Development Roundtable', a public-private council involving the MOTIE, seven steel companies (POSCO, Hyundai Steel, Dongkuk Steel, SeAH Steel, KG Steel, Korea Steel, and Aju Steel), the Korea Iron & Steel Association, and the Korea Steel Scrap Industry Association. • While including both facility retrofit and facility conversion allocations, the current strategy provides significantly less support for facility conversion and lacks the specificity of a plan to close all 11 blast furnaces and replace them with 14 HyREX facilities during 2040-2050.
Brazil[14]	• Brazil has a technological roadmap for the deep decarbonisation of the steel sector. In 2020, the study "Technological Roadmap for the Decarbonisation of the Brazilian Steel Sector" was launched, which was coordinated by the Brazilian Association of Metallurgy, Materials and Mining (ABM) and funded by the Energy Research Company (EPE) and the Ministry of Mines and Energy (MME).
Turkey[15]	• The "2021 Iron and Steel Sector Report" was published in 2022 by the General Directorate of Industry under the Ministry of Industry and Technology of the Republic of Turkey. Turkey has promised to abide by the European Green Deal. Accordingly, a consensus on zero-carbon emission steel by 2030 has been reached, yet it has not been specified which methods or technologies will be used.
Germany[16]	• In July 2020, the Federal German Government, together with its industry outlined Germany´s Steel Action Concept, which builds on its Industrial Strategy 2030, the Climate Action Plan 2050, the Climate Action Programme 2030 and the European Green Deal. • The concept includes a comprehensive package of actions and measures to support the industry and accompany its conversion to climate-neutral production financially and with suitable instruments. • Germany´s steel industry is working on the introduction of low-carbon, carbon-neutral and zero-carbon processes, for example, using hydrogen rather than carbon to reduce iron ore (carbon direct avoidance, CDA) and, to some extent, on ways of making further use of carbon within the industrial value network (carbon capture and utilisation, CCU). • The scrap-based production of steel via the Electric arc furnace route already offers a lower-GHG process for around 30% of the crude steel produced. This share, however, can be increased, but only to a certain extent due to the limited availability of steel scrap. Moreover, due to varying alloy metal contents for certain higher-quality steel products, the suitability of the process is limited. • The National Hydrogen Strategy is implemented by the German Federal Government. At an early stage, major centres of the steel industry and other energy-intensive industries can offer a large, reliable and predictable demand-side market for green, thus making an important contribution to the market ramp-up of hydrogen in Germany.

Name of Country	Key elements of technology roadmap for deep decarbonisation of the steel sector
South Africa	● To meet global energy and climate goals, emissions from the steel industry must fall by at least 50% by 2050, South Africa needs to reduce its emissions to below 348 $MtCO_2$ e by 2030 and to below 224 $MtCO_2$ e by 2050 to be within a 1.5°C 'fair-share' pathway.
Sweden[17]	● The development of a brand-new process technique which uses hydrogen to reduce iron ore to iron. With this technique, the carbon dioxide emissions are eliminated from the reduction process, and instead, the by-product would be water. This technological leap involves numerous challenges, but a successful outcome would allow blast furnaces to be phased out. Potentially, the new technique could also be spread globally. The technique means an increased need for about 15 TWh of electricity at the current production level. ● The development of biocoke for the reduction of iron ore for powder production and for scrap melting processes. This requires a suitable source of carbon, processes for coke production and access to biomass for biocoke at a cost equal to that of fossil coke. At the current level of production, at least 1-1.5 TWh is required. ● The use of bio-based gas as a substitute for the fossil fuels used in heating and heat-treatment processes where electrification is not an alternative. This requires access to a gas of the same quality as natural gas and liquefied petroleum gas. The cost of bio-based gas has to be competitive in relation to international energy costs. The estimated need is at least 2-3 TWh at the current level of production
USA[18]	Under the near-zero GHG emissions scenario, the US steel industry GHG emissions can go down to almost zero in 2050 while steel production increases by 12%. The proposed roadmap focuses on the following aspects: ● More than two-thirds of GHG emissions reduction comes from improvement in energy efficiency and switching to low- and no-carbon fuels and electrification. ● Aggressive RD&D and procurement for transformative technologies, such as hydrogen-based steel production, iron ore electrolysis, and CCUS. ● Molten Oxide Electrolysis (MOE) for Steelmaking by Boston Metals[19] uses renewable electricity to convert all iron ore grades to high-quality liquid metal. This direct approach eliminates several steps in the steelmaking process and does not require any preparation of feedstock and any chemical as a reducing agent. ● Significant increase in demand for clean hydrogen and low-carbon electricity use in steelmaking by 2050. RD&D efforts to improve the efficiency of electrolysers. ● Transition to low-and no-carbon fuels and expand industrial electrification. ● Pilot demonstrations for transformative technologies such as hydrogen-steel production, electrolysis of iron ore, and carbon capture and utilisation storage (CCUS). ● Improve materials efficiency and increase materials circularity.

14.2.3 Key technological routes that countries are pursuing for decarbonisation

Different countries have adopted different technological routes for deep decarbonisation. Hydrogen and CCUS are the dominant technological routes that countries are pursuing for deep decarbonisation of the steel sector. In August 2021, SSAB produced the world's first fossil-free steel, using HYBRIT technology. Some countries like China, Sweden, and Germany, have existing plants based on hydrogen at their country's steelworks, while CCUS routes are still in the early stage of development.

Name of Country	Key technological routes that countries are pursuing for deep decarbonisation
China[20]	• According to the Environmental Planning Institute of the Ministry of Ecology and Environment, to achieve the 2^{0}C temperature target of the Paris Agreement by 2060, China's CCUS needs to reach a production capacity level of at least 500 million tons per year. At present, the total production capacity of CCUS technology in China is about 2 million tons, mainly consisting of integrated capture and oil displacement demonstration projects independently invested and developed by large energy state-owned enterprises. The main source of carbon dioxide is captive or nearby coal chemical and power generation enterprises. • There are currently about 40 CCUS demonstration projects in operation and construction in China, distributed in 19 provinces, involving pure capture projects such as power plants and cement plants, as well as diversified storage and utilisation projects such as CO_2-EOR, CO_2-ECBM, in-situ leaching of uranium, reforming to synthesis gas, microalgae fixation, and saline water layer storage. • In addition, the China National Building Materials (Hefei) new energy project, which was recently put into operation, is the world's first demonstration project for carbon dioxide capture and purification in a glass furnace. • The technology of carbon dioxide capture and production of baking soda has been applied in industrial enterprises such as Zhangjiakou City in Hebei Province, Zigong City in Sichuan Province, and Laibin City in Guangxi Province. This technology is still in the early stage of industrialization development, hence the promotion proportion is currently low.
Republic of Korea[21]	• Recently, POSCO has started developing HyREX technology, which is a unique hydrogen reduction iron and steel technology for a carbon-neutral era. • HyREX is an innovative hydrogen reduction ironmaking technology that produces molten iron using powdered iron ore and hydrogen. It is based on POSCO's FINEX fluidised reduction reactor technology. The reduction and melting reaction occur separately in the reduction and electric furnace. • About 25% of hydrogen generated during combustion of coal is used to reduce iron ore in POSCO's FINEX technology. POSCO is currently working with the government and domestic steelmakers to develop HyREX technology.

Name of Country	Key technological routes that countries are pursuing for deep decarbonisation
Brazil[22]	• Brazil is pursuing several technological sectors for deep decarbonisation, including renewable energy, electric vehicles, biofuels, hydrogen, and CCUS. • Hydrogen can be produced from natural gas with CCUS, resulting in low-carbon hydrogen. This can be used in fuel cells to generate electricity or as a feedstock for chemical production. • In addition to hydrogen and CCUS, there are other technological routes being pursued to address climate change and reduce greenhouse gas emissions. One such route is renewable energy, which includes solar, wind, and hydroelectric power. Another route is energy efficiency, which involves reducing energy consumption using more efficient technologies and practices. Additionally, bioenergy and nuclear power are also being explored as potential sources of low-carbon energy.
Germany[23]	Hydrogen plays a central role in decarbonising Germany´s steel sector. Germany wants to replace blast furnace technology with direct reduction processes using green hydrogen, whereby 97 % of the CO_2 emissions in steel production can be saved. A large number of installations would face major reinvestments in traditional blast furnace technology up to 2030, approximately EUR 30 billion upto 2050, of which Euro 10 billion needs to be spent in the years to 2030. • In the SALCOS project, a hydrogen-capable direct reduction plant, an electric arc furnace for the production of 1.9 million tons of crude steel and a 100 MW electrolyser at the Salzgitter Steel Group site are intended to ensure that the company step into the hydrogen-based direct reduction process for steel production, which can replace part of the conventional blast furnace route. • In the “EVAGMH” decarbonisation project of Georgsmarienhütte GmbH (GMH) in Lower Saxony, a plant is being built that converts the heat treatment of steel from natural gas to the direct use of green electricity. • Steel manufacturer GMH is setting up an inductive individual bar tempering plant to treatand to operate bar steel in mid-2023. • H2 Stahl, Thyssenkrupp Steel Europe AG and AIR LIQUIDE Deutschland GmbH are working on a project at the Duisburg steel site and the VDEh - Betriebsforschungsinstitut GmbH to test how hydrogen can replace coal as a reducing agent in the production of pig iron in the blast furnace.
South Africa	• The Steel Master Plan identifies a set of technology routes for the steel industry to reach carbon neutrality by 2050. This will include the increased use of renewable power, gas replacing coal power, the development of the hydrogen economy, water recycling and the more efficient use of water and waste reduction and recycling (the circular economy). Major gas pipelines are proposed, making lower-emission gas available for power. • South Africa is well endowed with available land, wind, and solar resources to provide the energy sources for green hydrogen production and has the makings of suitable distribution infrastructure. Existing South African infrastructure will allow for the production of blue, grey, black, and brown hydrogen, with the possibility of pink hydrogen arising in light of existing plans for nuclear power projects.

Name of Country	Key technological routes that countries are pursuing for deep decarbonisation
Sweden[24]	● In 2016, SSAB, LKAB and Vattenfall launched the HYBRIT (Hydrogen Breakthrough Ironmaking Technology) initiative to create an entirely fossil-free value chain from mine to finished steel. ● In August 2020, the pilot facility to produce fossil-free sponge iron in Luleå, Sweden, was commissioned. ● In March 2021, Gällivare in Sweden was chosen as the site of the HYBRIT Demonstration project, which includes the construction of a greenfield, full-scale plant to directly reduce iron ore using fossil-free hydrogen. The hydrogen will be produced via a 500 MW water electrolysis plant in Gällivare, using renewable electricity. Commissioning is scheduled for 2026. ● In May 2021, the construction of a pilot rock cavern storage facility for hydrogen gas began, adjacent to HYBRIT's pilot facility for direct reduction in Luleå. The underground storage facility commenced operation in late summer 2022, storing hydrogen produced by water electrolysis using fossil-free electricity. The pilot plant has a storage capacity of 100 m3. At a later stage, a full-scale hydrogen gas storage facility measuring 100,000–120,000 m3 may be required, enabling it to store up to 100 GWh of electricity converted into hydrogen gas, which is sufficient to supply a full-sized sponge iron factory for three to four days. ● In August 2021, SSAB produced the world's first fossil-free steel, using HYBRIT technology, reduced by 100% fossil-free hydrogen instead of coal and coke. ● Another Swedish company, H2 Green Steel is planning the construction of a fossil fuel-free plant in the north of Sweden. Attached to that effort will be a sustainable hydrogen facility. The production phase of the H2 plant is expected to be 2024. To implement the 2045: Fossil-free steel roadmap, the industry is working on: ● Transitioning to reducing ore using hydrogen. ● Using bio-coal for some reduction and as an alloying element. ● Electrifying furnaces and using bio-based gas or hydrogen as fuel. The Swedish Steel Producers' Association, Jerkontoret, is coordinating the follow-up of the roadmap and has launched the climate research project Samforsk klimat.
USA[25]	The key technological sectors pursued by the US for deep decarbonisation are: ● Energy Efficiency: Energy efficiency is a foundational, crosscutting decarbonisation strategy and is the most cost-effective option for GHG emission reductions in the near term. ● Industrial Electrification: Leveraging advancements in low-carbon electricity from both grid and onsite renewable generation sources will be critical to decarbonisation efforts. ● Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES): Substituting low-and no-carbon fuel and feedstocks reduces combustion associated emissions for industrial processes. ● Carbon Capture, Utilisation, and Storage (CCUS): CCUS refers to the multi-component strategy of capturing generated CO_2 from a point source and using the captured CO_2 to make value added products or storing it long-term to avoid release.

14.2.4 Key policy levers for decarbonisation of the steel sector

Coherent policy moves to support the steel transition can ensure long-term competitiveness and secure jobs throughout the industrial value chain. A variety of policy levers are evident across countries. These policy levers draw synergistic relations with country-specific technology roadmaps aligned with the Paris Agreement commitments, while engaging cross-ministerial national policies.

Name of Country	Key policy levers driving the steel sector deep decarbonisation
China[26]	• In 2019, the Ministry of Ecology and Environment, the National Development and Reform Commission (NDRC), and other five ministries jointly issued the "Opinions on Promoting the Implementation of Ultra Low Emissions in the Steel Industry", promoting the industry to strive to complete the transformation of over 80% of production capacity. • In March 2021, China's 14th Five Year Plan and the Outline of 2035 Long term Goals formulated an action plan to reach the peak of carbon emissions by 2030, and anchored efforts to achieve carbon neutrality by 2060. • In March 2022, the Environmental Development Center of the Ministry of Ecology and Environment issued a notice on publicly soliciting opinions on the "Catalogue of National Key Promoted Low Carbon Technologies (Draft for Soliciting Opinions)", which includes 36 low-carbon technologies. In June 2022, nine Ministries including Ministry of Science and Technology, the NDRC, the Ministry of Industry and Information Technology and etc. issued the Implementation Plan for Science and Technology to Support Carbon Peak carbon neutrality (2022-2030), proposed scientific and technological innovation actions and safeguard measures to support the goal of achieving carbon peak by 2030, and made technology R&D reserves for achieving carbon neutrality by 2060. • In January 2021, the "Guiding Opinions on Coordinating and Strengthening the Response to Climate Change and Ecological Environment Protection" encouraged the development of carbon peaking special plans in key areas such as energy, industry, transportation, and construction, and promoted the formulation of clear peaking goals and action plans for key industries such as steel, building materials, ferrous and non-ferrous metals, chemical, petrochemical, power, and coal. • China published a decarbonisation plan for the steel industry in 2022 with an aim to peak emissions by 2030, in alignment with the national target. The guideline states the country will "upgrade over 80% of steel production capacity" to slash carbon emissions and aim to push down overall energy consumption per ton of steel by over 2 percent per annum. The policy encourages research and demonstration of Oxfire Steel Furnace, hydrogen direct reduced iron and scrapped steel regeneration through electric furnace. It also encourages developing carbon capture technologies. • In January 2021, the "Management Measures for Carbon Emission Trading (Implementation)" stipulated the national carbon emission trading and related activities, including carbon emission quota allocation and payment, carbon emission rating, trading, settlement, greenhouse gas emission reporting and verification.

Name of Country	Key policy levers driving the steel sector deep decarbonisation
Japan[27]	The Technology Roadmap aligns with the Paris Agreement and Japanese policies aimed at achieving carbon neutrality. It is focused on achieving 2050 carbon neutrality by steady low-carbonisation and implementing innovative technologies while sustaining and enhancing the Japanese iron and steel industry. ● The technology roadmap synergies with key Japanese national policies, namely: ● Green Growth Strategy Through Achieving Carbon Neutrality in 2050 (Carbon recycling, materials) ● R&D and Social Implementation Plan about "Hydrogen utilisation in iron and steelmaking processes" project ● Environment Innovation Strategy ● Strategic Energy Plan ● The Plan for Global Warming Countermeasures ● Roadmap for Carbon Recycling Technologies
Republic of Korea[28]	● In September 2021, the Republic of Korea enacted the Framework Act on Carbon Neutrality and Green Growth for Climate Crisis Response (or "the Carbon Neutrality Act"), enshrining the minimum level of a mid-term national GHG emission reduction target as well as a robust implementation mechanism in law to ensure a faithful implementation of its NDC ● In May 2021, the Republic of Korea launched the 2050 Carbon Neutrality Commission, the key governance to support its carbon-neutrality transition. The Commission is co-chaired by the Prime Minister and a representative from the private sector, and its membership is broad from cabinet members to businesses, experts, the youth and civil society from the private sector. ● The Republic of Korea has been developing sectoral strategies, such as the Basic Plan for Carbon Neutrality and Green Growth, to achieve its NDC and the 2050 goal. ● The Republic of Korea plans to reduce GHG emissions efficiently based on the market mechanism by utilising K-ETS. ● The Republic of Korea will continue to financially support the transition to carbon-neutrality. A total of KRW 61 trillion (approximately USD 51.7 billion) is planned to be invested under the Korean Green New Deal.
Brazil	Several key policy levers that play a role in driving the deep decarbonisation of the steel sector. Some of the key factors that contribute to the decarbonisation efforts: ● **Renewable Energy Policies:** Brazil has been focusing on promoting renewable energy sources, such as wind, solar, and hydropower. These policies support the transition to cleaner energy for steel production, reducing the carbon intensity of the sector. ● **Carbon Pricing and Emissions Trading**: Implementing carbon pricing mechanisms or emissions trading systems can incentivise steel producers to reduce carbon emissions by putting a price on carbon. By internalising the cost of emissions, it encourages companies to adopt cleaner technologies and practices.

Name of Country	Key policy levers driving the steel sector deep decarbonisation
	• **Research and Development Support:** Government initiatives that support research and development (R&D) in low-carbon technologies for the steel sector can drive innovation and the adoption of cleaner processes. This can include funding research projects, establishing partnerships with industry stakeholders, and supporting pilot projects. • **Industry Standards and Efficiency Regulations:** Setting energy efficiency standards and regulations can encourage steel producers to invest in energy-efficient technologies and practices. This can lead to a reduction in energy consumption and associated carbon emissions. • **Circular Economy and Recycling Policies:** Encouraging the use of recycled steel and promoting circular economy practices can help reduce the demand for primary steel production, which typically has higher carbon emissions. Policies that support recycling and incentivise the use of recycled steel can contribute to decarbonisation efforts. • **International Cooperation and Agreements**: Brazil's participation in international agreements and collaborations, such as the Paris Agreement and partnerships with other countries, can shape its policies and commitments for decarbonising the steel sector. This includes knowledge sharing, technology transfer, and access to funding opportunities.
Turkey	• Zero carbon policies are subject to 5 contracts/protocols in total by the Climate Change Presidency, s under the Ministry of Environment, Urbanization and Climate Change, in addition to the EGD mentioned above. These contracts/protocols consist of "UN Framework Convention on Climate Change", "Paris Agreement", "Kyoto Protocol", "Vienna Convention" and "Montreal Protocol".
Germany[29]	• **Creating a level playing field in the global steel market.** Germany will call for more resolute efforts in the EU and similarly affected third countries to tackle market-distorting measures such as non-WTO-compliant subsidies or dumping prices and protectionist trade policies, particularly to reduce related global overcapacities. To this end, the Federal Government supports the work of the Global Forum on Steel Excess Capacity (GFSEC) to attain the goals defined in the G20 process. The only way to keep exerting influence on the countries that are the chief contributors to the current over-capacities on the world market is via the G20. In addition, the Federal Government will also work to ensure a rigorous application of EU trade safeguards and improve them where necessary. • The EU already deploys a market-based instrument to reduce greenhouse gas emissions. The free-of-charge allocation of emission allowances within the EU Emissions Trading System (EU ETS) is an effective instrument that should be continued as necessary in order to avert the risk of carbon leakage. Just like the Innovation Fund of the EU ETS, the free-of-charge allocation of allowances is to be designed to create incentives for technological innovation and support the long-term transformation of industry. • In addition to free-of-charge allocation as compensation for direct carbon costs, it is also important to consider adequate options for offsetting carbon-related increases in electricity prices for industrial installations. And to ascertain whether a border tax or alternative approaches can be designed in a legally robustly to ensure the same degree of protection against carbon leakage. Given the unresolved issues pertaining, among other things, to compatibility with WTO law, it is not possible today to predict whether a border adjustment tax will be able to replace the existing anti-carbon-leakage system in the long term and what kind of introductory and transitional periods the new system might require.

Name of Country	Key policy levers driving the steel sector deep decarbonisation
	• **Working together to make progress on the transformation.** Germany wants to create lead markets for low-carbon technologies by setting incentives and if necessary, by drawing up rules for steel processors to deploy steel which is produced on a low-carbon (and by 2050, definitely on a carbon-neutral, preferably carbon-free) basis and to make good use of the potential offered by the circular economy. • The implementation of carbon contracts for difference is another way to incentivise companies to invest in and operate green technology. • A state guarantee of a carbon price for companies investing in climate change mitigation would increase the financial incentive to reduce carbon emissions. It would reduce the uncertainty surrounding the development of the carbon price and make it easier for companies to plan their investment decisions. Moreover, it can add to the cost-effectiveness of such measures. • By financing, in full or in part, the differential between the current carbon price and a contractually defined carbon price oriented to emissions avoidance costs, companies could be given the necessary security to invest in forward-looking technologies in line with the goal of greenhouse gas neutrality. • Such guarantees can be granted based on individual projects, on a demand basis, or by public tender to avoid over-funding. Over-funding is also prevented by securing the actual differential costs. In addition to carbon contracts for difference, the introduction of moderate and gradually rising quotas for producing and using climate-friendly basic materials may also be assessed. • **Germany supports the development of a market for hydrogen technologies.** The Federal Government considers only hydrogen that has been produced using renewable energy (green hydrogen) to be sustainable in the long term. It therefore seeks to use green hydrogen, promote its rapid market rollout and establish the necessary value chains. • Apart from that, it believes that a global and a European hydrogen market will emerge in the coming ten years and that carbon-neutral (for example blue or turquoise) hydrogen will also be traded on this market. Given Germany's close integration in the European energy supply infrastructure, carbon-neutral hydrogen will also be relevant for Germany and, if available, will be used on a transitional basis. • Germany wants to achieve a situation in which the use of coking coal to make steel can gradually be shifted to hydrogen. This requires that new steel production facilities are designed from the outset topermit the use of both natural gas and hydrogen. This applies to "first of its kind" projects and the entire conversion process. • A new budget item entitled Use of Hydrogen in Industrial Production worth EUR15 million for 2020 and commitment appropriations worth EUR430 million up to 2024. • The National Decarbonisation Programme of approximately EUR1 billion up to 2023. • The programme Carbon Avoidance in the Basic Materials Industry with funding of EUR370 million up to 2023.

Name of Country	Key policy levers driving the steel sector deep decarbonisation
South Africa	• The steel producers have adopted the World Steel Organisation's climate change policy. The South African steel sector is part of a global supply chain, and many of the inputs, such as iron ore and coal, are sourced from other countries. Decarbonising the steel sector will require coordination and collaboration across the supply chain to ensure these inputs are produced with a low carbon footprint.
Sweden[30]	• Sweden leads with the hydrogen Policy. One of the main policies is to use fossil-free electricity to produce hydrogen, which can replace coal in the manufacturing process. The gas, which can be produced by electrolysis with oxygen as the only emission, can then be used in what are known as direct reduction plants, as a replacement for today's coal-based blast furnace technology. • In 2016, SSAB, Vattenfall and LKAB launched the joint initiative Hybrit. Four years later, the world's first pilot plant for producing fossil-free steel was opened outside Luleå, and in August 2021 the plant presented its first fossil-free steel produced using hydrogen. In the same year, the company H2 Green Steel announced that it had begun constructing a plant for large-scale production of 'green steel' outside Boden. The goal is to be able to reduce carbon emissions by 95 percent. Hybrit has already supplied green steel to Volvo. • Hybrit Policy: Under the HYBRIT joint venture, the Swedish firms SSAB, Vattenfall and LKAB are collaborating to develop a fossil-free hydrogen-based steelmaking process as an alternative to coal-based steelmaking by 2035. While the main objective is to reduce the environmental impact of steelmaking, the economic impacts are also important. With this new method of producing steel, CO_2 emissions generated from the steel industry could be eliminated, thus contributing to Sweden's goal of Net-zero emissions by 2045. Construction of a pilot plant began in 2018, with EUR 52 million of assistance from the Swedish Energy Agency. The pilot phase should last until 2024, with a subsequent demonstration phase from 2025 to 2035.
USA	There are multiple policies targeting steel sector deep decarbonisation. The prominent ones are: • **Federal-State Buy Clean Partnership[31]:** The Congress recently made available a USD 6 billion in industrial decarbonisation grants via the Department of Energy to decarbonize heavy industrial facilities, including retrofitting or replacing blast furnaces with low-carbon primary steelmaking technology. • **The Inflation Reduction Act of 2022 (IRA)[32]:** It includes the Advanced Industrial Facilities Deployment Program, which will leverage nearly USD 12b in federal and private capital to cut emissions at energy-intensive industrial facilities, including steel plants. In addition to direct funding, the IRA includes tax credits that will incentivise further private capital investment in decarbonisation technologies. • **Advanced Energy Manufacturing and Recycling Grants[33]:** The Advanced Energy Manufacturing and Recycling Grant Program is designed to provide grants to small- and medium-sized manufacturers to enable them to build new or retrofit existing manufacturing and industrial facilities to produce or recycle advanced energy products in communities where coal mines or coal power plants have closed.

Name of Country	Key policy levers driving the steel sector deep decarbonisation
	• **The Regional Clean Hydrogen Hubs program**[34]**:** It provides up to USD 7 billion to establish six to ten regional clean hydrogen hubs across America. Clean hydrogen hubs will create networks of hydrogen producers, consumers, and local connective infrastructure to accelerate the use of hydrogen as a clean energy carrier that can deliver or store tremendous amounts of energy. • **U.S. Climate Alliance**[35]**:** The U.S. Climate Alliance is a bipartisan coalition of 24 governors working together to achieve the goals of the Paris Agreement and keep temperature increases below 1.5 degrees Celsius.

14.2.5 Engaging national institutions/organisations for steel decarbonisation technologies

It is observed that national governments are engaging with different institutions and organisations for undertaking steel sector specific research and technology development. Such institutions and organisations are collaborating with industries and other Technical Organisations to serve as a platform for new technology development and deployment. The key national institutions are listed below.

Name of Country	Key national institutions/organisations who are developing new technologies and undertaking Research & Development
China	• Development Research Center of the State Council • National Climate Change Expert Committee • China Academy of Engineering • Zero-Carbon Technology Research Institute • Tsinghua University's Global Research Center • Carbon Neutrality Committee of China Energy Conservation Association
Japan	• New Energy and Industrial Technology Development Organisation, NEDO
Republic of Korea	• There is no national organisation in Korea. However, companies like POSCO have own research institute. For example, POSCO Research Institute
Brazil	• **National Steel Technology Center (CTNBio):** CTNBio promotes research and technological development in the steel sector. It works towards enhancing the competitiveness and sustainability of the Brazilian steel industry through R&D projects, technology transfer, and innovation. • **National Steel Research Institute (INSTITUTO AÇO BRASIL):** IAB is one of the most important organisations in Brazil's steel sector. It was established in 2005 as a non-profit organisation to promote technological development, competitiveness, and sustainability in the steel industry. It conducts research and development projects, provides technical assistance and training, and promotes cooperation between companies, research institutions, and universities. Its work focuses on improving the quality of steel products, reducing production costs, and minimizing the environmental impact of the industry.

Name of Country	Key national institutions/organisations who are developing new technologies and undertaking Research & Development
	• **Center for Metallurgical and Materials Technologies (CETEM):** CETEM is a research institution under the Ministry of Science, Technology, and Innovation of Brazil, conducts research and development projects in various areas related to metallurgy and materials science, including the steel industry. Its work aims to promote technological innovation, improve the efficiency and sustainability of industrial processes, and develop new products and materials. • **National Association of Metallurgy, Materials, and Mining (ABM):** ABM is an organisation that promotes knowledge exchange, research, and development in the fields of metallurgy, materials science, and mining. It brings together professionals, researchers, and industry experts, facilitating collaboration and innovation in the steel sector. • **EMBRAPII (Brazilian Company for Industrial Research and Innovation)**: EMBRAPII supports industrial research and innovation across various sectors, including steel. It collaborates with companies and research institutions to fund and facilitate R&D projects focused on technological advancements in the steel industry. • **Brazilian Association of Technical Standards (ABNT):** ABNT is a non-profit organisation that develops and publishes technical standards for various industries, including the steel sector. ABNT works to ensure the quality, safety, and reliability of products and services in Brazil by establishing standards and guidelines for their design, production, and testing. • These are some of the key national institutions and organisations involved in research, development, and technology in the steel sector in Brazil. Collaboration between these entities, industry players, and academics is significant in driving innovation and advancements in the Brazilian steel industry.
Germany	• Centre of Excellence for Climate Action in Energy-Intensive Industries (KEI), Cottbus[36] • Federal Environment Agency[37] • Max-Planck-Institut für Eisenforschung GmbH[38], now Institute of Sustainable Materials • Fraunhofer-Society[39]
South Africa	• Department of Trade, Industry, and Competition (DTIC) in South Africa • The Department of Forestry, Fisheries and the Environment • The Industrial Development Corporation (IDC)
Sweden	• The metals research institute Swerim is a leading industrial research institute within mining engineering, process metallurgy, materials, manufacturing engineering and applications. Swerim is part of the Green Steel for Europe (GREENSTEEL) consortium that supports research and innovation in creating low-carbon emissions steel production.
USA	• **National Institute of Standards and Technology (NIST):** NIST supports R&D in various industries, including the steel sector. They provide measurement standards, technical guidance, and research collaboration opportunities that contribute to developing low-carbon steelmaking processes and materials.

Name of Country	Key national institutions/organisations who are developing new technologies and undertaking Research & Development
	• **United States Steel Corporation (U.S. Steel):** U.S. Steel is one of the largest steel producers in the United States, has committed to reducing greenhouse gas emissions and advancing low-carbon steelmaking technologies. They invest in R&D to develop and implement innovative processes such as direct reduced iron (DRI) and carbon capture, utilisation, and storage (CCUS) technologies. • **American Iron and Steel Institute (AISI):** AISI is a trade association that represents the North American steel industry. They collaborate with industry stakeholders, government agencies, and research institutions to promote research and development initiatives for sustainable steel production and decarbonisation. • **White House Office of Science and Technology Policy:** This office coordinates to equitably advance innovation across the entire sector. • **Department of Energy (DOE):** The DOE is involved in energy-related R&D, focusing on renewable energy, nuclear energy, energy efficiency, and environmental management. • **National Renewable Energy Laboratory (NREL):** NREL is the primary national laboratory for renewable energy research and development, focusing on technologies such as solar power, wind energy, biofuels, and energy-efficient buildings. • The Council on Environmental Quality and White House Office of Domestic Climate Policy are establishing the first-ever Buy Clean Task Force, which will harness the federal government's massive purchasing power to support low-carbon materials made in American factories.
Australia	• The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is Australia's national science agency and innovation catalyst. Combining research, industry, government, and communities to help Australia's hardest-to-abate sectors – including steel, sustainable aviation fuel, and agriculture – halve their emissions by 2035. The Towards Net-zero mission of CSIRO is building Australia's national capability to support the transition to Net-zero emissions by enabling Australia to prosper and grow in a global low emissions world through new economic, societal and environmental value.

14.3 Global platforms for collaboration: Steel Sector Decarbonisation

Countries and firms are increasingly collaborating through coalitions to accelerate the development and adoption of specific technologies or policies. Notable international cooperation efforts that have emerged esspecially focused on steel sector decarbonisation,complement the Paris Agreement by raising ambition, highlighting key policy issues, accelerating technological development, and diffusing knowledge on mitigation policies. India is leading a few international cooperation efforts and has actively participated in some.

International Cooperation Efforts	Leaders	Brief Description
Leadership Group for Industry Transitions (LeadIT)	India and Sweden	LeadIT brings together countries, companies and industry experts to achieve net-zero emissions from heavy industries by 2050

Industry Deep Decarbonisation Initiative (IDDI)	India and UK	The Clean Energy Ministerial Industrial Deep Decarbonisation Initiative (IDDI) is a global coalition of public and private organisations who are working to stimulate demand for low-carbon industrial materials.
First Movers Coalition	Hosted by World Economic Forum	Global initiative aimed at decarbonising the heavy industry and long-distance transport sectors responsible for 30 percent of global emissions.
Mission Innovation	India is host	Global initiative catalysing a decade of action and investment in research, development and demonstration to make clean energy affordable, attractive and accessible for all.
OECD Clean Energy Finance and Investment Mobilization	OECD led	Programme aims to strengthen domestic enabling conditions to attract finance and investment in renewable energy, energy efficiency and decarbonisation of industry ("clean energy") in emerging economies.
Mission Possible Platform	Industry led	Movement of climate leaders and companies driving industrial decarbonisation across the entire value chain of the world's highest-emitting heavy industry and transport sectors. Indian industries supporting MPP are Tata Steel
Steel Zero	Industry led	Global initiative that brings together leading organisations to speed up the transition to a Net-zero steel industry
International Energy Agency	Inter-governmental; India is an association country	The IEA family is made up of 31 member countries, 13 association countries, and 5 accession countries. IEA works with countries around the world to shape energy policies for a secure and sustainable future.

14.4 Indian Steel Players with Global Partnerships

Indian Steel Players have an array of partnerships with global technology suppliers and partners to advance their decarbonisation targets. These include:

Type of Partner	Indian Steel Player	Brief Description
Technology Partner	Tata Steel	M/s Primetals for Hydrogen injection in blast furnaces
	Tata Steel	M/s Paul Wurth for Coke Oven Gas injection in blast furnaces
	Tata Steel	M/s Tennova for DRI feasibility and CO_2 emission reduction strategy roadmap
	JSW Steel	Shell India Markets Private Limited to jointly evaluate short and long-term options for improving energy efficiency, optimising demand for carbon-intensive products and services, adopting decarbonisation technologies, and leveraging digital solutions

Technology Partner	JSW Steel	SMS Group to explore and evaluate cutting-edge technologies and their potential applications in accelerating climate action
	JSW Steel	Smartex to explore and evaluate cutting-edge technologies and their potential applications in accelerating climate action
Consultants	Tata Steel	M/s Xynteo, UK - Creation of hydrogen strategy roadmap for 2030
Suppliers	Tata Steel	M/s BHP, Australia - for use of biomass / biochar
	Tata Steel	M/s SHELL - Decarbonisation roadmap modelling
Academia	Tata Steel	Ohio state university for hydrogen production using Chemical Looping Combustion technology

14.5 Challenges on international collaboration by Indian Steel Producers for decarbonising the steel sector

The challenges identified for Indian Steel Producers for international collaboration are as follows:

1. **Technology Readiness Level (TRL):** Some of the technology identified may be an excellent source to reduce the carbon intensity of the industry , but may have an extended timeline with regards to commericalization. Indian Steel Producers need to evaluate or may need to support such technologies to get the maximum benefit of out them. Aligning technological capabilities and ensuring compatibility with potential partners' systems requires careful assessment and investment in research and development.
2. **Legal and Regulatory Compliance:** Indian Steel Producers must navigate the complexities of various legal and regulatory frameworks in different countries, ensuring compliance with local laws while aligning with their organisational policies and standards.
3. **Intellectual Property Protection:** Collaboration may involve sharing sensitive information, intellectual property, and trade secrets. Organisations need to establish robust mechanisms to protect their intellectual property rights and ensure confidentiality in collaborative endeavors.
4. **Financial Considerations:** International collaboration often involves financial implications, such as funding joint research projects or navigating currency exchange rates. Organisations need to carefully plan and manage financial aspects to ensure equitable contributions and sustainable collaboration. Recent experience illustrates that financial support received by Arcelor Mittal and Tata Steel to overcome challenges in their decarbonisation journey.

Overcoming these challenges requires a strategic approach, including cultural sensitivity, legal expertise, market research, proactive risk management, and adaptability to foster successful international collaborations for Indian Steel Producers.

14.6 Strategic areas for international collaboration

Some of the specific areas of international cooperation on research and development requirements identified as part of the business strategy of Indian Steel Producers are:

1. **Commercially feasible Carbon capture and utilisation technologies:** Carbon capture and utilisation (CCU) technologies are vital for reducing CO_2 emissions and combating climate change by capturing and repurposing CO_2 from industrial processes. They enable the transition to a low-carbon economy, enhance energy efficiency, and contribute to negative emissions and resource optimisation, bridging the gap to decarbonisation. CCU plays a critical role in mitigating climate change and promoting sustainable development.
2. **Development of hydrogen hub:** A robust hydrogen pipeline or hub is vital for reducing emissions in the steel industry. It enables the reliable supply of low-carbon hydrogen sourced from renewables for steelmaking processes. Additionally, it promotes collaboration and efficiency among stakeholders, accelerating the transition to a greener and more sustainable steel sector.
3. **Need for Research on Biochar:** Research is needed to utilise biomass in the form of biochar usage possibility, which can replace coal with renewable energy.
4. **Material Efficiency and Recycling:** Research focused on enhancing material efficiency, promoting recycling technologies, and exploring circular economy principles can reduce the need for virgin raw materials, minimizing energy-intensive extraction processes and associated emissions, for example sustainable use of tailings generated from Iron ore beneficiation.
5. **Life Cycle Assessment and Environmental Footprinting:** Conducting and sharing comprehensive life cycle assessments and environmental footprint studies, which can provide valuable insights into emissions hotspots, enabling targeted emission reduction strategies throughout the steel value chain.
6. **Alternate Disruptive Technologies:** Collaboration with international partners to leverage alternate technologies such as the Molten Oxide Electrolysis (MOE) for Steelmaking can bring in disruption in the Indian industry.
7. **New Product Development:** International cooperation on R&D to continuously expand product portfolio to meet evolving market demands, such as high-strength steels, speciality alloys, and value-added products catering to specific industry sectors.
8. **Supply Chain Optimisation:** Enhancing the efficiency and reliability of the supply chain is critical for the operations of Indian steel players. International cooperation in R&D to enhance the efficiency and reliability of the supply chain through the facilitation of the development of advanced logistics and supply chain management systems, including inventory optimisation, predictive analytics, and real-time tracking technologies.

Global Experience: The European Commission supports ArcelorMittal decarbonisation

European Commission approves EUR 850 million in French measures to support ArcelorMittal's decarbonisation of its steel production.

The European Commission has approved, under EU State aid rules, a EUR 850 million French measure to support ArcelorMittal France ('ArcelorMittal') in partially decarbonising its steel production processes. The measure will contribute to achieving the EU Hydrogen

Global Experience: The UK Government supports Tata Steel's decarbonisation

Tata Steel and the UK government announced a joint agreement on a proposal to invest in state-of-the-art Electric Arc Furnace steelmaking at the Port Talbot site with a capital cost of GBP 1.25 billion inclusive of a grant from the UK Government of up to GBP 500 million, subject to relevant regulatory approvals, information, and consultation processes, and finalisation of detailed terms & conditions.

Strategy, the European Green Deal and the Green Deal Industrial Plan targets while helping to end dependence on Russian fossil fuels and fast-forward the green transition in line with the REPowerEU Plan.

The French notified to the Commission a EUR 850 million measure to support ArcelorMittal's project aimed to partially decarbonise its steel production in Dunkirk, where it operates three blast furnaces producing liquid hot metal from a mixture of iron ore, pellets, coke, coal and preheated air. It also operates three basic oxygen furnaces that convert liquid hot metal into liquid steel.

The aid will support the construction of a direct reduction plant ('DRP') and two electric arc furnaces ('EAF'). The combined DRP/EAF installation will substitute two of the three existing blast furnaces and two of the three basic oxygen furnaces.

Under the scheme, the aid will take the form of a direct grant paid out in four instalments during the construction period of the DRP/EAF installation planned between 2023 and 2026. The combined DRP/EAF installation is envisioned to start operating in 2026 and it is expected to produce 4 million tons of low-carbon liquid steel per year. ArcelorMittal has committed to actively sharing the experience and technical know-how gained through the project with industry and academia.

The proposed project would ensure the continuity of steelmaking in Port Talbot after the transition and transform Tata Steel UK into a sustainable, capital-efficient and profitable business. With UK Government support, the project has a robust investment case.

Tata Steel UK will soon commence consultation on the proposal and the transition period, including potential deep restructuring for the carbon-intensive, unsustainable iron and steelmaking facilities at Port Talbot, where many of the existing 'heavy end' assets — such as blast furnaces and coke ovens—are reaching the end of their operational life.

Further to the investment proposal, as part of Tata Steel's commitment to advance global research and innovation in materials science for a sustainable future, the Company announced its intention to invest approximately GBP 20 million **over 4 years to set up two additional Centers of Innovation & Technology in the UK at the Henry Royce Institute at Manchester (for advanced materials research) and at Imperial College London (for research in Sustainable Design & Manufacturing).**

14.7 Key Lessons for India and Areas of Intervention

Key Lesson 1:

The Government of India should provide financial support for domestic steel players.

The global experience illustrates that steel sector decarbonisation calls for higher outlays in public infrastructure, public research, stimulus for private R&D, and possible deployment subsidies. Ministry of Steel may support domestic steel players in decarbonising their operations, by creating technology demonstration projects. For the domestic steel players, the Ministry of Steel may consult and coordinate with other Ministries and decide son pending on green public infrastructure, public support for innovation, and possibly support for the deployment of existing low-carbon technologies where commercial viability is not proven.

Global Experience (Germany): The Federal German Government, together with its industry, outlined ***Germany´s Steel Action Concept,*** which builds on its Industrial Strategy 2030, the Climate Action Plan 2050, the Climate Action Programme 2030 and the European Green Deal. The concept includes a comprehensive package of actions and measures to support the industry and accompany its conversion to climate-neutral production financially and with suitable instruments.

- In April 2023, the Federal German Economic Affairs and Climate Action Ministry, together with the State Government of Lower Saxony, presented the Salzgitter Group with a ***grant of almost one billion euros for the SALCOS project.*** This investment of more than two billion euros in new systems, which will save a total of around 46 million tons of CO_2 over the individual terms (by 2041 at the latest).
- In November 2022, the Federal Ministry of Economics and Climate Action issued a ***grant notice of around 880,000 euros to the "EVAGMH" decarbonisation project*** of Georgsmarienhütte GmbH

Key Lesson 2:

Government of India create innovation fund for steel decarbonisation

Technologies identified may be an excellent source to reduce the carbon intensity of the industry but may have an extended timeline for commercialisation. Indian domestic steel players will need to support such technologies to get the maximum benefit. This can be done through creation of innovation fund, as seen through global experience.

Global Experience:

- **(Sweden)** The Swedish government has invested **USD 23 million in the HYBRIT project**. The HYBRIT initiative driven by SSAB, LKAB, and Vattenfall, has now officially received support from the European Union, as one of seven innovative projects under the Innovation Fund. The project receives in total EUR 143 million for an industrial and commercial-scale demonstration of a complete value chain for hydrogen-based iron- and steelmaking, from mine to fossil-free steel.
- **(EU)** The European Union is investing more than **EUR 1.1 billion in total in seven projects** that cover a wide range of relevant sectors to decarbonise the European industry and energy sectors, such as chemicals, steel, cement, refineries, and power and heat.
- **(USA)** The Federal-State Buy Clean Partnership of the USA Congress recently made available **USD 6 billion in industrial decarbonisation grants** via the Department of Energy to decarbonise heavy industrial facilities, including retrofitting or replacing blast furnaces with low-carbon primary steelmaking technology.

Key Lesson 3:

Develop a consortium approach for decarbonisation projects supported by R&D activities.

Ministry of Steel may support the steel industry to develop indeginous decarbonisation technologies in India. The most efficient way of doing this would be a consortium approach, wherein MoS can act as an anchor for this project, and steel players, academic institutions, and research agencies can participate in the project to focus efforts on establishing the technology in India.

Global Experience:

- **(Korea)** Ministry of Trade, Industry and Energy (MOTIE) has constituted **a public-private council** involving MOTIE, and seven steel companies (POSCO, Hyundai Steel, Donkuk Steel, SeAH Steel, KG Steel, Korea Steel and Aju Steel), the Korea Iron & Steel Association, and the Korea Steel Scrap Industry Association.

- **(China)** In November 2021, Baowu Steel in China unveiled a **Global Low-Carbon Metallurgical Innovation Alliance** and a fund that will put USD 5.5 million annually toward low-carbon metallurgy research, including hydrogen. The alliance consists of 60 members from 15 countries, including steel companies such as ArcelorMittal and Shougang Group, as well as mining companies such as BHP Group and Rio Tinto Group.

- **(Brazil)** In 2020, **"Technological Roadmap for the Decarbonisation of the Brazilian Steel Sector**" was launched, which was coordinated by the Brazilian Association of Metallurgy, Materials and Mining (ABM) and funded by the Energy Research Company (EPE) and the Ministry of Mines and Energy (MME). The study presents a comprehensive overview of the challenges and opportunities for the decarbonisation of the steel sector in Brazil and sets out a series of milestones and targets to achieve deep decarbonisation by 2050.

Key Lesson 4:

The Government of India may develop a Green Public Procurement Policy after stakeholder consultations

To generate demand for green steel, the Ministry of Steel, Government of India, needs policy-level support. The Ministry of Steel may define a broad policy vision. Policy support needs to establish an appropriate green premium to justify the huge capex investment required for technology change.

The Industrial Deep Decarbonisation Initiative is a global coalition of governments and private sector organisations led by India and the United Kingdom. Canada, Germany, Japan, Saudi Arabia, Sweden, the United Arab Emirates, the United States and Brazil are members. At its most ambitious level, the Green Public Procurement Pledge (GPP) commits governments to start requiring that steel, cement and concrete used in all public construction projects are low-emission – and that 'signature projects' use near-zero emission materials.

- **Level One:** Starting no later than 2025, requires disclosure of the embodied carbon in cement/concrete and steel procured for public construction projects.
- **Level Two (in addition to Level 1):** Starting no later than 2030, conduct whole project life cycle assessments for all public construction projects and, by 2050, achieve Net-zero emissions in all public construction projects.
- **Level Three (in addition to Levels 1 and 2):** Starting no later than 2030, the procurement of low-emission cement/concrete and steel in public construction projects is required, applying the highest ambition possible under national circumstances.
- **Level Four (in addition to Levels 1, 2 and 3):** Starting in 2030, procuring a share of cement and/or crude steel from near-zero emission material production for signature projects is required.

By 2025, IDDI hopes to have enabled a minimum of ten governments to have committed to the GPP Pledge. Different countries have committed to different levels as exhibited in the Box below.

Global Experience:

- **The Government of Canada** has held GPP Pledge discussions with internal government stakeholders, including environmental policymakers, procurement policymakers, technical experts and procurement practitioners; including industry and supplier stakeholder groups, such as steel, cement and concrete producers. ***GPP Levels 1 to 3 are now enshrined as policy commitments.*** Level 4 is being considered.
- **The Government of Germany** identified green public procurement as a goal in its coalition agreement. The Federal Ministry for Economic Affairs and Climate Action is carrying out a stakeholder process on the definitions, measurements methods, and demand signals for green steel and cement. The process actively engages industry, science, and civil society to develop a set of reliable rules that will help us implement the needed measures to incentivise demand for the new materials.
- **The Government of the United States of America** continues to adopt green procurement practices within the country. It launched a Federal Buy Clean Initiative in 2022 to prioritize lower-carbon construction materials in Federal procurement and federally funded infrastructure projects. Buy Clean promotes purchasing lower-embodied carbon steel, concrete, asphalt and flat glass, accounting for whole life-cycle emissions as reported through Environmental Product Declarations.
- **The Government of the United Kingdo**m included all four levels of the GPP Pledge in a wider public consultation on decarbonisation.

14.8 Action plan

Action Plan 1

Avail multilateral funding for new energy-efficient technologies

Financial transfers from high-income to low and lower-middle-income countries may be part of an international side agreement on decarbonisation. In 2009, high-income countries pledged to mobilise USD 100 billion a year from 2020 for mitigation and adaptation in developing economies, both from private and public sources. Estimates suggest that flows have only recently reached this level (OECD 2023). The Ministry of Steel may explore multilateral financial transfers that aim to compensate developing countries for the abatement costs under an international agreement on decarbonisation. (refer to Annex 14-1 for existing multilateral funds for new energy-efficient technologies).

New capital invested in support of deploying energy transition technologies hit a record USD 1.11 trillion globally in 2022. Renewables, which include wind, solar, biofuels and other sources of power, narrowly retained its position as the largest sector, with a record USD 495 billion in new project investments. Together, electrified heat, sustainable materials, energy storage, carbon capture and storage (CCS) and hydrogen added another USD 149 billion in 2022. Ministry of Steel may consider engaging with companies and financial institutions to leverage public markets to raise lending to promote environmental or social improvement. Sustainability-linked loans and sustainability-linked bonds may be used to raise money, where the debt is tied to a sustainability target for the issuer, for example, a greenhouse gas emission reduction goal. (Refer to Annex 14-2 for Global Investment in energy transition by sector).

Action Plan 2.

Establish a global advisory council for India's Steel Sector Decarbonisation

The proposed Global Advisory Council may enable access to a network of frontrunners for industry transitions, including countries, companies, international organisations, and financial institutions. The Council will perform the following 3 key functions:

1. **Global exchanges for Finance and Demand Creation for Steel Decarbonisation, through:**
    i. Obtaining endorsements from international finance institutions, facilitating setting up the mechanism for matchmaking, encouraging donor commitments
    ii. Leverage collaborative global platforms to enhance the demand for green steel in India

2. **Stimulate technology transfer through:**
    i. Create global collaborations for R&D, Pilot/Demonstration and Innovation for the Indian steel sector on hydrogen, material circularity, carbon capture, usage and sequestration (CCUS) and other key infrastructures needed
    ii. Site visits to leading international companies

3. **Inform national strategies on steel decarbonisation, through**
    i. Engaging with industries and governments to develop or update India's steel sector decarbonisation roadmaps
    ii. Create or update India's steel sector decarbonisation implementation plans, including credible interim targets

Proposed Composition: global advisory forum for India's Steel Sector Decarbonisation

Convenors	**Hon'ble Minister of Steel, Government of India** **Secretary, Ministry of Steel, Government of India**
Members	**World Bank, EU, OECD** **Global Technology Providers:** Midrex, Primetals Technologies, Tenova etc. **Global Coalitions:** IDDI, LeadIT

Action Plan 3

Establish India's National Green Steel Think Tank

Global experiences exhibit that national institutions and organisations have been key to implementing the national vision of the steel sector decarbonisation. The Ministry of Steel may consider to establishing India's National Green Steel Think Tank, which may network and collaborate with key national institutions/ organisations that are developing new technologies and undertaking Research & Development in other geographies.

The Think Tank may enable:

1. Identification of technology demonstrations in close coordination with Indian Steel players.
2. Capacity building of operators of Indian steel players through exposure visits to other geographies.
3. Coordinate with other Ministries for policy developments for renewable energy, green hydrogen, financing, standard setting and IPR protection/technology transfer.
4. Document use-cases and publish an annual report of best practices on steel sector decarbonisation.
5. Fulcrum for monitoring global best practices in technology, policy, financing.
6. International cooperation on R&D facilitates the exchange of knowledge and expertise in areas such as energy efficiency, waste management, emission control, and renewable energy integration.

The existing **Steel Research & Technology Mission of India (SRTMI) may be leveraged to establish India's National Green Steel Think Tank.**

CHAPTER 15

SKILL DEVELOPMENT

15.1 Introduction

Skill development in the steel sector is a critical driver of growth, innovation, and sustainability, directly impacting employment generation and economic stability. With a rapid sensitivity to quality assurance and environmental sustainability, the Indian iron and steel industry aspires to unfold various technologies, demanding a seamless transition of its workforce (approximately, 2.8 million). Advanced manufacturing technologies such as automation, artificial intelligence (AI), and the Internet of Things (IoT) are revolutionizing production processes, necessitating a workforce adept in these areas. Apart from the steel majors, there are approximately 2000 small/medium-sized iron and steel manufacturers and steel processing units (with current contribution of roughly 40% to the country's total crude steel production) in India, which require reskilling and upskilling of their existing workforce. Therefore, continuous learning and skill enhancement are essential for maintaining competitive advantage and igniting creative sparks.

The greening of the steel sector will involve a range of new technologies, viz., the use of hydrogen, industry 4.0 and automation of processes requiring skill competency. The implications of skill development in the steel sector are multifaceted. It significantly enhances operational efficiency and productivity. Skill development also drives employment generation. As the steel industry evolves, new roles emerge, requiring specialized skills. The sector can create numerous job opportunities by investing in training programs, apprenticeships, and industry-specific certifications. These initiatives will address the skill gaps and promote economic growth by providing stable employment. Furthermore, focus on upskilling and reskilling enhances workplace safety, as well-trained employees are better equipped to handle advanced machinery and adhere to safety protocols, reducing the risk of accidents.

Collaboration with educational institutions and ongoing professional development are pivotal in skill development in the sector. The steel sector can ensure sustainable growth and innovation by building a resilient workforce capable of adapting to technological changes and market dynamics. Robust skill development initiatives are thus essential for the industry's future, driving competitiveness, environmental responsibility, and economic prosperity.

15.2 Global Scenario

Annually, the total value added contribution of the steel industry is USD 8.2 trillion, or about 11% of the global GDP. The industry directly employs an estimated 6 million people. Estimates suggest that for every job in the steel sector, about 7 more jobs are supported indirectly and about 35 jobs are created in the customer and supply sector—meaning that, in total, an additional 253 million jobs are supported by the sector (World Steel Association, 2020). There are wide variations in labour productivity (330-2200 tons crude steel/man/year) worldwide. Several G20 countries have provided their steel workforces with occupation-based and technology-based skills training. The steel sector in European countries struggles to attract skilled workers and engineers required for technological transformation. The European Steel Skills Agenda (ESSA) aims to provide a strategy for meeting current and future skill demands.

15.3 Indian Scenario

The total employment in the Indian steel sector during the FY22 is as under:

***Table 15.1** Employment potential of the Indian steel sector FY 22*

Type of Producer	Total employment (in million)		
	Permanent	Contractual / Ancillary	Total
Major ISPs	0.1	0.9	1.0
Others	0.3	1.5	1.8
Total	0.4	2.4	2.8

***Source:** JPC*

Technically skilled personnel from various disciplines in engineering (e.g. Metallurgy, Mechanical, Electrical, IT & CSE, Chemical) and basic sciences (Physics, Chemistry, Mathematics), are required by the industry. Specialisation profile of engineers in the large steel plants during the year 2015 was as under:

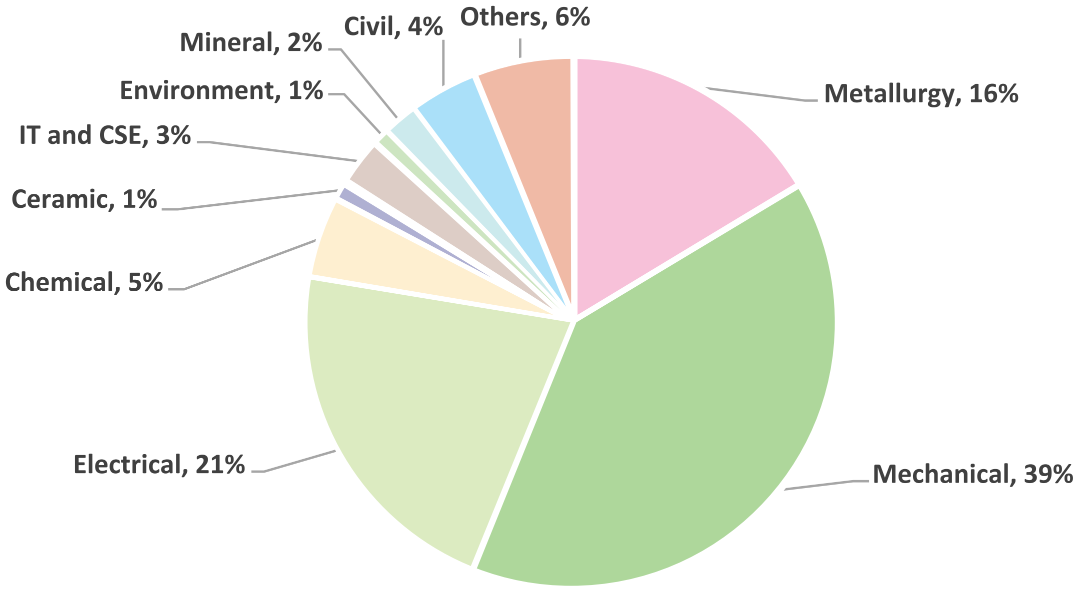


***Figure 15.1:** Specialisation profile of engineers in ISPs* ***Source:** IIT Kanpur report (2015)*

A lower inclination for a career in the steel industry has been observed among engineering graduates compared to other sectors (e.g. financial services, IT). For evolving the features of decarbonisation practices, a large number of researchers, scientists, and environmental specialists are needed to contribute in areas such as hydrogen-based DRI, CCU/S, alternative iron production methods (like molten oxide electrolysis etc), monitoring environmental impact, conducting life cycle assessments and ensuring adherence to sustainability standards.

Although workforce productivity in this sector has improved considerably over the years, these efforts pale into insignificance in terms of wide inter-plant variations. Small and medium-sized companies largely remain unstructured in their approach to train their employees.

15.4 Mapping green jobs and greening of jobs in value chain

15.4.1 Defining green jobs and greening of jobs

Decarbonisation of the iron and steel industry will lead to the creation of green jobs and the greening of jobs. Green jobs are the new jobs likely to be created with the advent of progressive technologies in the steel sector. Greening of jobs, on the other hand, involves integrating eco-friendly practices into existing processes and business strategies to minimize the environmental impact.

15.4.2 Assessment of green jobs and greening of jobs in value chain

Green jobs are likely to be created in the following areas:

Renewable energy: The increasing demand for energy from renewable sources like solar, hydro and wind will create many new jobs. Large-scale adoption of renewable energy will generate additional jobs in the value chain of installation and maintenance services. A mapping of green jobs in this area is presented in Annexure-1.

Environmental management and compliance: These professionals will be responsible for monitoring and ensuring compliance with environmental regulations, conducting environmental impact assessments, managing carbon reduction initiatives and so on. A mapping of green jobs in the environmental services sector is summarised in Annexure-2.

R&D & sustainable supply chain management: This area offers employment opportunities for scientists, engineers, and researchers concerned with energy-efficient technologies and identifies opportunities for energy conservation. Sustainable supply chain management is focused on sustainable procurement, circular economy practices, and managing environmental impacts across the supply chain.

A mapping of greening of jobs that would require new skills and knowledge upgradation in the iron and steel sector is available in Annexure-3.

15.5 Skill requirements in Indian Iron and Steel sector

15.5.1 Direct and indirect employment in iron and steel sector in India

Human resource requirement and their skilling in Indian iron and steel sector in transition to green steel must take a holistic view of including direct and indirect employment in steel producers (all routes of production), the upstream segments (raw materials, DRI, ferro alloys) and in downstream segments (rerolling, foundries).

Table 15.2 shows the route wise employment of technical workforce in the Indian iron and steel industry.

Table 15.2 *Technical workforce in iron and steel sector (route wise): FY2023*

Process Route	Technical workforce/Million TCS	Annual Capacity (Million T)	Total Workforce
BF BOF	3,500	67.3	235,550
DRI	700	54.8	38,360
EAF	400	36.6	14,640
IF	2,000	57.4	114,800
Rerolling	3,000	93.4	280,200
Total			683,550

Source: *JPC, National Institute of Secondary Steel Technology (NISST), FY2023*

Here is a list of proposed job roles to be taken up for making contents and curriculum to facilitate training in both short-term and RPL (Recognition of Prior Learning). It is also imperative to develop suitable trainers and assessors for undertaking training and assessment to enable candidates with an engineering background to implement the decarbonisation strategies in their plants successfully. The list is illustrative and not exhaustive.

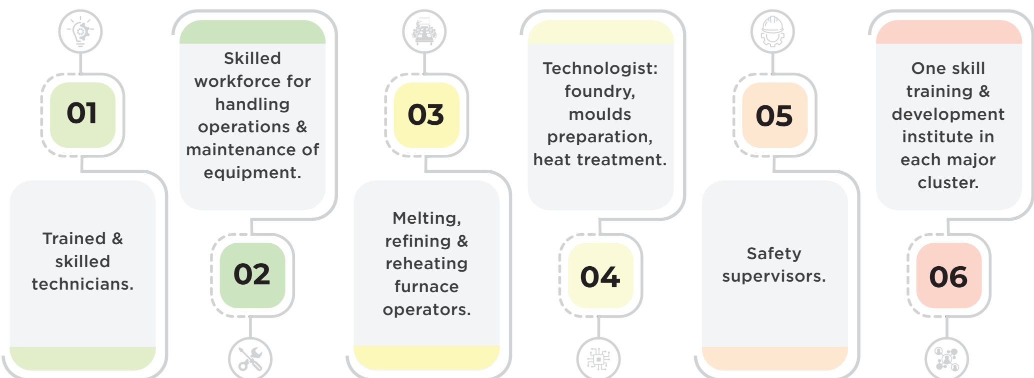
1. Lab Technician (Pollution Control Lab)
2. Controller-Steel plant wastes, E-Waste recycling technician
3. Technician-Water Purification Plant
4. Tuyere Platform Operator: BF for non-fossil fuel injection
5. Metallurgist: Direct Rolling
6. Electrician; Solar Panel Maintenance
7. Windmill Technician
8. Robotics Operator-Sensor Technician
9. Technician: Syn Gas/ Hydrogen Gas based DRI
10. Technologist- C-Neutral & CCUS System
11. Operator: Coal Gasification Plant
12. Engineer: Electrolyser (Operation and Maintenance) for Green Hydrogen production
13. Safety Supervisor (handling of Grey/Blue/Green H2)
14. Industrial IoT
15. Data Analyst

Training on transversal skills, which include analytical and creative thinking, digital, and technological literacy, curiosity and lifelong learning, communication, motivation and self-awareness, leadership, and social influence, should also form an essential component of skill training relating to new technology interventions.

15.5.2 Skills for green jobs in the secondary steel sector

The secondary steel sector constitutes 33-35 percent of India's crude steel capacity. The sector includes DRI units (over 300), EAF/EIF units (over 1000), re-rolling units (over 1100), foundry units (over 4000), ferroalloy units (over 70) and others (including steel fabricators, refractories and so on) spread across the country

The secondary sector needs the following enablers:



15.6 Skill Infrastructure

15.6.1 Skill related institutional structure in the Indian iron and steel sector

16. Research studies showed that a huge demand-supply gap, especially for major branches like Metallurgy. While there are a good number of engineering colleges and institutes offering graduate degrees, only 30 engineering colleges offer graduate-level courses in Metallurgical engineering in India. ITIs and polytechnics impart vocational skills and knowledge.
17. Industry, especially ISPs, has made efforts to develop the skilled workforce required in the iron and steel industry. SAIL, TATA Steel, AMNS, JSW, JSPL and others have set up training institutes to impart training to their employees on contemporary topics and training in special areas by suppliers of specialised equipment.
18. Institutes like the National Institute of Secondary Steel Technology (NISST) and the National Institute of Advanced Manufacturing Technology (formerly National Institute of Foundry and Forge Technology, NIIFFT) offer skills training to the workforce engaged in the secondary sector. The restructured Biju Patnaik National Steel Institute (BPNSI), constituted by the Ministry of Steel, would focus on the secondary steel sector through training, R&D and consultancy.

15.6.2 Skill Programmes in the Indian iron and steel sector

The Government of India, under various ministries, runs various schemes for skill development that are relevant to the iron and steel sector. Some of these are:

Pradhan Mantri Kaushal Vikas Yojana (PMKVY) is a scheme of the Ministry of Skill Development and Entrepreneurship (MSDE) implemented by the National Skill Development Corporation (NSDC). Under the scheme, training is provided for various job roles such as Electrician, Machinist, Fitter, Welder, Crane Operator and so on. Individuals with prior experience are also assessed and certified under Recognition of Prior Learning (RPL).

Deen Dayal Upadhyaya Grameen Kaushalya Yojana (DDU-GKY) is a scheme by the Ministry of Rural Development. It caters to the occupational aspirations of rural youth and enhances their skills for wage employment. The objective of this scheme is to enhance the skills of stakeholders and functionaries for the effective implementation of placement linked skills programs, benefiting the rural youth in India.

The Ministry of MSME is also running various programmes relevant to the iron and steel sector under its entrepreneurship and skill development program and through tool rooms.

The 15,000 ITIs and 4,500 plus polytechnics also provide occupational-based training. Few institutes, such as the National Institute for Solar Energy (NISE) and the National Institute for Wind Energy (NIWE), provide technology-based training in skills for green technologies.

The Institute for Steel Development and Growth (INSDAG) also provides comprehensive training to professionals and teaching faculty on structural steel design methods and technologies. It organises seminars, conferences, training, and knowledge dissemination programmes. Additionally, it runs various refresher courses and short-term training programs, ensuring a wide range of learning opportunities.

15.6.3 Initiatives for standardisation of course curriculum

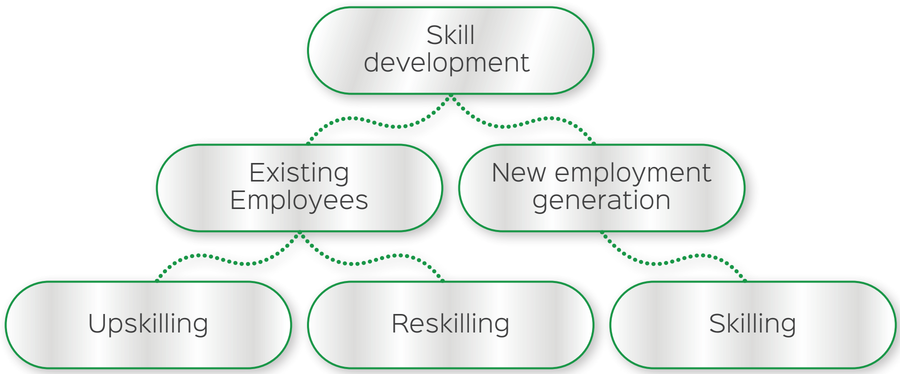
1. The National Policy on Skill Development (NPSD) was formulated by the Ministry of Labour and Employment in 2009 to empower the workforce with the required skills, knowledge, and qualifications to make the Indian workforce globally competent.

2. NSQF (National Skills Qualifications Framework) was set up for competency mapping and standardising the academic delivery across training institutions, and providing career pathways and employment-oriented courses.

3. Several Sector Skill Councils (SSCs)were set up (38 SSCs are operational) as autonomous industry-led bodies by National Skills Development Corporation (NSDC). The IISSSC for the Iron and Steel sector was mandated to create occupational mapping-based Qualification Packages (QP) and National Occupational Standards (NOS) for various job roles related to iron and steel and related industries, aligned with NSQF levels, conduct train-the-trainer programs, conduct skill gap studies, and assess and certify trainees on the contents and curricula (30% theory and 70% hands-on training) developed by them. IISSSC has already created 34 job roles (Electrician, Machinist, Fitter, Welder, Crane Operator, Bearing Maintenance, Process control Engineer-BOF/EAF/IF/DRI, Safety supervisor, Metal Fabricator etc) and has already trained more than 650 trainers and 400 assessors for quality training and assessment.

15.7 Projections for skilling/reskilling/upskilling requirements in iron and steel sector

1. Currently, the Indian iron and steel industry employs a workforce of 11.89 lakh with approximately 500,000 in foundry and 6,250 in ferro alloys, (excluding overseas demand of 1.5 lakh). It is projected that around 50% of this workforce will require upskilling and reskilling, leading to a skill upgradation requirement of 5.95 lakh skilled workers from FY23 to FY34. The skill upgradation requirement attributed to decarbonisation and digitalisation will be 80%, (i.e. 4.8 lakh) of the total skill upgradation requirement in next ten years.



2. It is imperative that workforce requirements in the Indian iron and steel industry based on incremental capacity addition (details in Annexure-4) would come down with the introduction of digitalisation and automation in different areas. It has been assumed that the BF-BOF route would need a workforce of 1,500 numbers per million tonnes of crude steel, EAF at 300, IF at 1,400, DRI at 500 and the rerolling sector at 2,500 numbers per million tonnes of crude steel by FY2034. Substantial efforts need to be made for skilling/re-skilling/up-skilling of new and existing workforce. The total incremental direct and indirect workforce requiring skilling and certifications in the steel industry (including Rerolling, DRI, Foundry and overseas) is estimated to be 1.06 million by FY 2034. This includes an incremental workforce of 0.4 million for steel production and rerolling, 0.66 million for the balance for related industries like ferroalloys production (about 13000), foundry (0.5 million) as well as catering to overseas markets (0.15 million). Assuming that around 80% of the total capacity augmentation plans implemented by various public and

private units, would involve decarbonisation-related jobs, including that of digital transformation, the following table (Table 15.3) captures the incremental workforce volume that would need relevant skill training of short-term duration.

Table 15.3: *Incremental workforce requirement due to Decarbonisation efforts [by FY2034]*

Areas	Incremental Workforce requirement
BF BOF/EAF	1.14 lakh (primarily large players)
IF/DRI/Rerolling	2.04 lakh (primarily secondary sector)
Foundry/Ferro Alloys	4.10 lakh (secondary Sector)
Overseas demand	1.2 lakh
Total	8.48 lakh

3. Annexure-4 & 5 summarise the incremental workforce requirement by steel producers (all routes) and Rerollers. As per NSP 2017, it is assumed that the incremental capacity addition to 300 MT would comprise 60% BF-BOF, 15% EAF and 25% IF route. The various decarbonisation strategies and measures coupled with new-age technology under Industry 4.0 (AI, Machine Learning, Cloud computing, IoT, Renewable Power, etc.) would lead to a lower workforce per tonne of crude steel, as discussed in the previous paragraph.

   The future workforce requirement for skill development on account of decarbonisation has been estimated up to FY2034 only. As the technology and measures beyond FY2034 and the industry preparedness to absorb these technologies for process change in the plant are not yet known, the skill set required to facilitate these changes would take some more time to develop.

   The iron and steel industry has an employment multiplier factor of 6.8X. As the steel industry is projected to grow rapidly in the next decade, employment (both direct and indirect) is poised to grow in the sector. It is estimated that there will be a fresh employment requirement of 1.06 million people in the next decade. Apart from the iron and steel sector, there will be fresh requirements in the material, energy and consumption sectors as well. As per an estimate there will be creation of around 7.2 million indirect employment opportunities due to the steel sector in the next decade.

4. Annexures 4 & 5 tabulate the fresh training required for skill development relating to decarbonisation for about 1.061 million people for steel production, rerolling, DRI, Foundry, Ferro Alloys and overseas placement. As per estimates made by TERI, around 5600 fresh candidates would also be required in the operation and maintenance of solar, wind turbine and hydro projects to supply renewable energy for the iron and steel plants in the country.

5. The basis of the projected workforce required on account of decarbonisation strategies and practices in the steel plants and the related industries are the following assumptions: -

   a. In the last five years (FY2018 to FY2023), Indian steel capacity has had a CAGR growth of 4%, affected by the COVID pandemic years of FY2020 and FY2021. Based on the current trend of steel consumption and the prospects, an annual growth rate of 6% in capacity build-up has been assumed, which would take 160 MT steel capacities in FY2023 to achieve 300 MT (NSP 2017) of capacity augmentation in FY2034. The entire incremental workforce requirement has been worked to fulfil the target capacity expansion of 300 MT by 10 years, hence, from FY2024.

   b. The route-wise capacity build-up is based on the NSP 2017 document, which specifies, BF-BOF 60%, EAF 15%, and IF 25%. It is acknowledged that due to concerns about CO_2 reduction, the DRI-EAF route with more scrap use may be a preferred option, which may result in minor changes in the projected number.

c. The revised workforce requirement per tonne of crude steel as adopted in the skill gap analysis completed recently by NISST for IISSSC, has been utilised to calculate the data.

d. It is assumed that 50% of the incremental workforce required to cope with capacity augmentation efforts by FY2034 would need reskilling and upskilling, and 80% would be linked with decarbonisation and digitalisation endeavours.

6. The total requirement of reskilling and upskilling of graduate engineers, diploma engineers and ITI certificate holders in the Indian steel industry for its decarbonisation journey (based on a study by IIT Kanpur, 2015) by TERI up to 2034, 2047 and 2070 is estimated as per the table 15.4. This is based on estimated production of crude steel at 197 MT by 2030, 374 MT by 2050 and 540MT by 2070. These figures have been estimated for technical workforce only. This estimation does not consider the semiskilled, unskilled, non-technical workforce and people engaged in the ancillary steel industry. The estimates are based on the technical workforce intensity in Indian steel plants as per the IIT Kanpur study (It compares Indian steel plants with Japanese steel plants, which are mature in technology and workforce productivity).

Table 15.4: *Estimated reskilling and upskilling requirement of core technical workforce (graduate engineers, diploma engineers and skilled) employed in Indian steel industry including secondary sector*

	Type of training requirement	Graduate engineers	Diploma engineers	ITI certificate holders
Upto 2033-34	Upskilling	31,700 (15,400)	33,900 (15,100)	36,000 (6,900)
	Reskilling	19,000 (9,300)	20,300 (9,100)	21,600 (4,100)
	Total	**50,700 (24,700)**	**54,200 (24,200)**	**57,600 (11,000)**
2034-47	Upskilling	55,400 (24,000)	60,000 (23,500)	48,900 (10,700)
	Reskilling	33,200 (14,400)	36,000 (14,100)	29,400 (6,400)
	Total	**88,600 (38,400)**	**95,900 (37,600)**	**78,300 (17,100)**
2048-70	Upskilling	55,300 (23,100)	52,100 (18,800)	39,400 (6,800)
	Reskilling	33,200 (13,800)	31,200 (11,300)	23,600 (4,100)
	Total	**88,500 (36,900)**	**83,300 (30,100)**	**63,000 (10,900)**

(TERI analysis)*. The figures in brackets are the requirements for the secondary sector*

7. The reskilling and upskilling requirement in the secondary sector is given in Table 15.5 (figures in brackets). These figures have been estimated for the technical workforce only. The effect of automation in the secondary sector is considered to come in later stages than in ISPs. It is assumed that the impact of newer technologies and automation will affect employment opportunities at the ITI level more than those at engineering and diploma holders level in the future.

8. It is imperative that skilling needs and drawing up plans for skill development for areas related to decarbonisation need to be separate for large players and the secondary sector in the iron and steel industry. While large players can draw up strategies for skill development in each job role, the multi-skill approach is found to be suitable for the secondary sector.

9. Medium and large companies in the secondary sector should set up facilities for skilling of unskilled people. Small steel producers can use this facility. This would have two benefits: one, regarding a skilled workforce and two, increased ancillarisation and enhancement in the productivity of the secondary sector.

10. The cost of reskilling and upskilling the technical workforce in the secondary sector in the next ten years is estimated at INR 267 crores at the rate of INR 7,000 per candidate when batch size is 25 and infrastructure, and curricula being already available and INR 382 crores at the rate of INR 10,000 per candidate if infrastructure and curricula have to be developed.

11. As most large enterprises reskill and upskill their people in their own capacity and operate through the BF-BOF route, it is considered that going forward, major players will bear the cost of reskilling and upskilling their staff. The cost estimation for reskilling and upskilling is given in Table 15.5.

Table 15.5: *Cost of reskilling and upskilling of workforce in secondary steel sector from FY2024-FY2034*

Sub Sector	Number of Candidates	Total Cost (In Crore INR)	
		@INR 7,000 per candidate	@INR 10,000 per candidate
DRI/IF/Rerolling	1,79,000	125	179
Foundry, Forging	2,00,000	140	200
Ferro Alloys	2,500	2	3
Total Cost of Reskilling and Upskilling	**-**	**267***	**382****

Source : *IISSSC*

12. The cost of setting up a skill training centre to run 10-12 courses is estimated around INR 45 lakh. The indicative lab setup cost is given in annexure 6.

15.8 Challenges for skill development in the iron and steel sector

There are challenges and barriers for decarbonisation of the Indian iron and steel sector with respect to skilled workforce availability and these are outlined below:

1. **Lack of specialised skills:** The shortage of professionals with specialised skills in areas like RE, EE, CCUS, etc., can hinder the effective implementation of decarbonisation strategies.
2. **Rapid technological advancement:** Skilled workforce needs to stay updated on the latest developments and trends to effectively adopt and implement new solutions. This requires continuous training and education, which can be a challenge to provide on a large scale.

3. **Interdisciplinary knowledge:** Decarbonisation involves a mix of technical, economic, environmental, and policy-related aspects. Professionals must have interdisciplinary knowledge to address the complex challenges associated with transitioning to a low-carbon economy.

4. **Limited training infrastructure:** Establishing robust training programs and institutions to build a skilled workforce can be a challenge that slows down progress in decarbonisation.

5. **Competition with other sectors:** Skilled professionals in fields like engineering, data science, and policy analysis are in high demand across various industries, which could make it difficult for the industry to attract and retain talent for the sector decarbonisation, especially in the public sector or non-profit organisations.

6. **Transitioning existing workforce:** Many professionals in industries with high carbon emissions may need to transition their skills to align with decarbonisation goals. This requires retraining and reskilling programs, which can be challenging to implement effectively.

7. **Issues specific to the secondary sector:** The secondary sector is not spending on skill development and is dependent on contractual unskilled workforce hired on low wages. For the deployment of specific technologies, a skilled workforce at attractive wages with regular skill upgradation will be required.

Addressing the above challenges requires a multi-pronged approach involving governments, educational institutions, industries, and communities. Investments in education, training programs, policy clarity, and public awareness campaigns can contribute to building a skilled workforce that accelerates the transition to a low-carbon economy.

15.9 Framework for skilling/reskilling/upskilling pathways

There is a need for an integrated nationally agreed framework for skilling/reskilling/upskilling with a defined vision for inclusive, accessible, adaptable and flexible skilling/upskilling /reskilling pathways. The framework needs to be an integral part of the decarbonisation strategy, and co-created by industry, employer and workers associations, and education and training institutions, and facilitated by public policy. It would provide key information on sector and employment, career pathways, occupations/job roles, as well as existing and emerging skills required for the occupations/job roles and a list of training programmes for skills upgrading.

The target group for the framework would include workforce members, employers, training institutions, awarding and assessment agencies, government unions, and professional bodies.

The key stakeholders for the skills framework would include individuals who desire to be part of the journey are:

1. Individuals who are able to assess their career interests, identify training programmes to upgrade their skills and prepare for jobs

2. Employers recognise the skills and invest in training their employees for career development and skills upgrading

3. Education and training providers who can gain insights on sector trends, existing and emerging skills that are in demand, and design programmes to address the sector needs accordingly; and

4. Government, unions and professional bodies are able to analyse skills gaps and future initiatives to upgrade the workforce capability and professionalise the sector.

15.10 Action Plan

The action plan for skill development includes the identification of the needs of the iron and steel sector with a focus on the secondary steel sector. A skilled workforce will play a key role in the Indian steel sector decarbonisation, of which digitalisation will be integral. Apart from fresh training for recruits, the existing workforce will also need upskilling or reskilling to keep themselves relevant in the industry transformation. There will be a requirement for skill infrastructure, for which both existing and new facilities will be needed along with competent and efficient trainers. A mechanism of lifelong learning will also be required for the transient industry because the decarbonization journey of the Indian iron and steel sector will be long- and one-time reskilling or upskilling may not be sufficient for an individual throughout their career.

The detailed strategies for practical skill development to cater to the iron and steel industry have been discussed further in this section. These strategies are:

15.10.1 Planning for Reskilling/Upskilling Pathways

The Ministry of Steel may conduct a specific study to estimate the skill requirement (technical and non-technical) of the secondary sector as it constitutes a large part of the sector and is in greater need of a skilled workforce in its journey towards decarbonisation. This may be done in collaboration with IISSSC and relevant institutes and colleges. An officer from the Ministry well versed with the skilling pathways in the steel sector may be a part of the national climate change action plan committee. This would ensure the development of a plan to not only skill/reskill/upskill the existing workforce to meet requirements of the greening of jobs but also new emerging green jobs.

15.10.2 Strengthening Training Infrastructure including capacity building for Training Need assessment

1. Strengthening existing steel training institutes to align with new technologies is crucial for the advancement of the sector. Therefore, the Ministry may request these institutes to prioritise updating their curriculum to include courses on emerging technologies such as automation, robotics, energy efficiency, renewable energy, green hydrogen, CCU/S, and so on.
2. Collaborations with industry experts and technology providers may facilitate access to state-of-the-art equipment and hands-on training opportunities. A one-year certificate course or two-year course leading to a degree on topics related to decarbonisation with placement prospects in the industry could be an effective tool to promote awareness of new technology and its application.
3. The Ministry of Steel may establish partnerships with research institutions that would participate in joint research projects to ensure that the training institutes stay at the forefront of technological advancements.
4. The iron and steel industry should upgrade the present infrastructure available with them to impart technology-based training for a skilled and semi-skilled workforce, including engineers and technicians, to operate and maintain the new equipment through the adoption of decarbonisation-related technologies. Further, the industry's existing employees may be trained through RPL programmes.
5. Various industry-oriented online skill development courses may be introduced along with certification so that both freshers and existing employees can use them to upgrade their skills. The Ministry may involve various stakeholders like IITs, SIRTMI, BPNSI, and Ministry of Skill Development and Entrepreneurship (with support from IISSSC) for developing the courses and certification mechanism.

15.10.3 Training of trainers and assessors in iron and steel sector

In the iron and steel sector, the training of trainers and assessors is a crucial component for ensuring both the efficiency and sustainability of operations. In the steel industry, major players have established programs like TOTO (Training of Training Officers) to enhance the skills of their trainers who work with employees for skill improvement. However, such mechanisms are notably absent in the secondary sector. This gap highlights the urgent need to train and develop trainers and assessors engaged in the secondary steel sector. The steel training institutes may prepare a blueprint for this.

15.10.4 Promoting industry-academia collaboration

Collaboration between industry and academia is the cornerstone for effective technological development and adoption. The collaboration between IITs/NITs and various large iron and steel industries is a point in the case. The Ministry of Steel, along with the Ministry of HRD, may sensitise the academic institution to:

1. Attract high talent in the industry
2. Share research priorities and
3. Develop demand-based courses to reduce the demand-supply gap

Besides, the Ministry may also review the implementation status of relevant industry-academia related programmes (e.g., UGC's guidelines for 'Engaging Professor of Practice in University and Colleges', Adult education) jointly with the MoE.

15.10.5 Addressing secondary skill requirements

This will be based on the findings of the Study to be conducted by the MoS (as explained in 15.10.1). To make the country globally competitive, all crucial issues, ranging from the basic education level to navigating the path of lifelong learning by the secondary steelworkers, would be addressed.

The regulator, NCVET, has been doing due diligence to ensure that the level of education commensurate with the competencies required for the job roles.

15.10.6 Development of skill gap identification, Training Need Assessments, skill matching/mapping and course revision mechanism

This may be a regular practice. The Ministry of Steel may earmark institutions to do training needs assessments at industry and individual levels to enable timely revision of curriculum.

1. The mechanism to identify skill gaps and address the requirement with change in curriculum at all technical and non-technical levels may be developed along with the Ministry of Skill Development and Entrepreneurship and the Ministry of Education. Tata Steel, in its pilot projects on climate-friendly methods of production, is adopting a mechanism for identifying skill gaps and moulding training interventions accordingly.

Tata Steel training strategy: identification of gaps and learning interventions

Tata Steel has successfully completed some pilot projects on a climate-friendly method of production that reduces energy use and cut carbon dioxide emissions substantially compared to the conventional blast furnace route. This change in process and technology for production has implications both for existing workforce skills at all levels and also new entrants to the company.

To address the availability of a skilled workforce, the current training strategy at Tata Steel focuses on developing role-based functional competencies for white and blue-collar members of the workforce. The interventions are competency-wise learning, self-assessment by an officer on competencies mapped to the role, and validation by a superior. In the case of blue collared jobs there is pre-assessment on a questionnaire based mapping in Talent Pro, and training is on the required skill sets for a job role. There is provision for training re-delivery, if required.

Source: *Tata Steel*

2. A portal on skill matchmaking may be developed, especially for the secondary steel industry, where people may register their skills, credible users, including academia and industry, may verify the same. The industry can identify the people with the required skills for both temporary and permanent positions. Regular competency mapping of the workers' skills would help determine the skill gap and cater for it as a priority. The portal may provide real-time data on special jobs for the steel sector and bridge the gap between potential employees and employers. This may be done in consultation with the MSDE.

15.10.7. Increasing Digitalisation to focus on Transversal skills

Against the backdrop of decarbonisation, coupled with increased mechanisation, the steel industry is likely to witness the application of different technologies in automation, data science and information technology with upcoming intelligent sensors, Internet of Things (IoT), artificial intelligence, machine learning, robotics, cloud computing, big data, cyber-security, additive manufacturing, augmented reality, virtual reality, etc. for smart networking of machines and industrial processes.

Developments in Industry 4.0 and a switch to deep decarbonisation technologies, such as green hydrogen-based DRI and CCU/S, would require retraining existing employees in the field and upgrading the curriculum for fresh graduates. It is anticipated that at least 25% of new jobs may be green jobs requiring training in technology-based skills in addition to occupation-based skills

SAIL: Green Transition – Future Ready Workforce

SAIL emphasises linking training with organisational and individual needs for which every employee's knowledge, attitude, and skill gap is measured. As new skill profiles are demanded, skills and qualifications must be updated to match changing task profiles.

To be able to meet the challenges of a skilled workforce, the company is focussing on creating a centre of excellence with leading Indian academic and R&D centres, foreign institutes and technology providers in a collaborative approach, partnering with Industries, competency mapping – sectoral level gap analysis; development of training module – resource persons- hands-on training; inbuilt training scope in projects with breakthrough technology; stakeholder consultation; evaluate effectiveness of training to prove its importance in running and managing the business.

Identified specialised training agencies, technology suppliers (foreign and Indian), original equipment manufacturers and needs based on the job training (including at overseas technology provider premises) for new technology deployment.

Source: *Steel Authority of India*

15.10.8 Effective Governance

The key challenge is implementing an effective governance mechanism for the coherent reskilling/upskilling pathways approach. In the decarbonisation process, there is a need to identify multiple stakeholders ranging from national-level ministries to regional departments, plants, value chain partners, training institutions, assessment agencies, beneficiary workers, etc. Some of the measures for effective governance are:

1. There is a need to build strategic leadership, effective communication practices, information dissemination, support, and feedback systems.
2. The Ministry of Steel may develop an umbrella framework/strategy wherein existing strengths can be exploited, existing roles can be adapted through process change and clear links to other areas at the strategy/decision-making level are made.
3. Strengthening stakeholder and institutional capacity and accountability (such as in terms of decision-making, spending, and technical capacity) is necessary to facilitate mutual understanding and maximise policy coherence and effective partnerships.

15.10.9 Financing the skilling

Financing the training is a major concern. The potential candidates for this task are training workers themselves, industry, government, and partners responsible for transferring technology. There are various mechanisms to finance skill training in the sector:

1. Many large industries can have their managers and workers trained by the technology supplier. However, the small companies, due to a paucity of funds, are not in a position to acquire the technology and train people. The large industry may be incentivised to handhold these secondary sector players and facilitate the training of their workforce. This may also promote ancillary units in the sector.
2. The government programmes across various departments may be accessed to train the workforce, at least for the secondary sector.
3. The secondary sector may access facilities through apprenticeship programmes.
4. The Ministry of Steel may rework the current regulations to include reskilling/upskilling the people for green jobs CSR activities. The step may encourage the industry to utilise their CSR fund for developing a skilled workforce, which will return to the industry later in the form of a pool of skilled workers. Skilling workers may further lead to better employability and sustainability in the labour market. Moreover, the employees' productivity may improve due to better skills and understanding of their job.
5. It may also consider mandating skill upgradation as part of operations/human resource management as an obligation on the employer.

15.10.10 Monitoring and Evaluation

Systematic and sustainable monitoring and evaluation may facilitate a coherent reskilling/upskilling pathways policy approach, which may guarantee effectiveness together with multiple policy domains and stakeholders Monitoring and evaluation may help with strategic goals, service planning, programme development, gap identification in training delivery, training needs, and optimal resource use.

Proposed Studies

The Ministry of Steel may carry out the following studies/pilots to develop skills in iron and steel sector.

1. Pilot project on skilling of secondary steel sector workforce: Decarbonisation requires reskilling a large number of secondary steel sector workforce on best operating practices related to energy efficiency improvement and renewable energy technologies. Before undertaking a large country-wide program, a pilot project on training 500 operators each, in say, 10 secondary steel clusters can be undertaken. Since it is difficult for the operators to get leave for such training, these programs should be conducted at the factory site. The pilot can be undertaken by an institution like IISSSC.
2. Studies to promote industry-academic linkages for upgradation/introduction of curriculums in engineering colleges and vocational training institutes: The existing courses/curriculums, at the engineering and vocational college levels need to align with new realities such as climate change and net zero goal. New courses/modules must be added on subjects such as energy efficiency, renewable energy, best operating practices, etc. A study to upgrade the curriculum of metallurgy and mechanical courses in engineering colleges must be undertaken jointly with industry stakeholders. A similar study for revising the present foundryman course curriculum at the diploma level and the need to add new trades such as EAF/EIF operators, and solar PV technicians in the vocational stream need to be undertaken in partnership with industry stakeholders, training institutes and recommendations to update them in view of the emerging technologies need to be conducted.

CHAPTER 16

GOVERNANCE FRAMEWORK

16.1. Introduction

Effective implementation of the strategy and action plan for decarbonisation of the steel sector requires strong coordination among various ministries and departments of central and state governments, industry, institutions, and other stakeholders, which is a challenging task. Hence, a robust governance framework and an institutional mechanism for monitoring and implementing action items are essential to ensure that the industry adheres to the roadmap with major milestones and emissions intensity reduction targets as set by the government to achieve its NDC goals.

This chapter discusses the proposed governance framework for implementing the action items discussed across various chapters.

16.2. Governance Framework

Figure 16.1 represents the governance framework for driving the green transition of the Steel Sector in India. The Steering Committee is the apex decision-making body on all aspects of transition. The National Green Steel advisory group envisaged in the RD&D chapter of this report would advise the Steering Committee on the research and technology front. The Executive Committee, reporting to the Steering Committee, oversees the execution of policy recommendations by the Steering Committee by formulating and coordinating with other Ministries.

The Steel Research & Technology Mission of India (SRTMI) is envisioned to be the cornerstone of the governance framework for decarbonising India's steel sector. It will act as the central hub for innovation, coordination, and implementation of green technologies and practices within the industry.

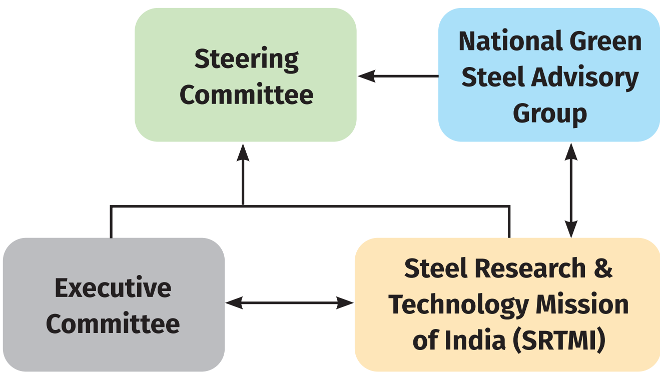


Figure 16.1: Governance framework for implementing action items

The following are broad areas kept in focus while designing this governance framework –

1. Strategic Alignment and Coherence
2. Coordination Among Stakeholders
3. Policy Formulation
4. Policy Implementation
5. Research and Technology Development
6. Knowledge Sharing and Capacity Building

7. Resource Allocation and Mobilisation
8. Monitoring, Reporting, and Verification (MRV)
9. International Collaboration and Knowledge Exchange
10. Risk Management

16.3. Roles and responsibilities of the committees

16.3.1. Steering Committee for Green Steel

The Steering Committee for Green Steel will provide overall direction and strategic guidance for implementing the action items.

Steering Committee for Green Steel	
Broad Mandate	**The Steering Committee will provide the overall direction and strategic guidance for steering the decarbonisation of the steel sector in India**
Roles and Responsibilities	• Set the overarching vision and strategic objectives for the decarbonisation of the steel sector. • Ensure alignment with national and international climate commitments, including India's Nationally Determined Contributions (NDCs). • Approve the long-term and short-term decarbonisation plans, including key milestones and targets for emissions reduction. • Facilitate high-level coordination between various ministries and state governments. • Recommend fiscal, monetary or regulatory interventions to appropriate authorities • Monitor performance and impacts of various initiatives/programs/policies/ projects Address policy bottlenecks and recommend adjustments to ensure smooth implementation.

16.3.2. National Green Steel Advisory Group

A National Green Steel Advisory Group will advise the Steering Committee on all matters related to R&D and technology for the decarbonisation of the steel sector.

National Green Steel Advisory Group	
Broad Mandate	**The basic function of the National Green Steel Advisory Group would be to advise the Steering Committee on research and technological advancements in green steel, while identifying and prioritising key research areas and fostering research cooperation among various Ministries, Departments and other stakeholders.**
Roles and Responsibilities	• Responsible for guiding the Steering Committee on overall strategy for research, technology development, demonstration and undertaking pilot projects. • Recommend R&D Roadmap for the decarbonisation of the steel sector. • Foster coherence and coordination among various Ministries and government institutions to align their research priorities while achieving a common goal.

	• Promote collaboration between academic institutions, research organisations, and industry players to conduct joint research projects. • Utilis e the expertise of leading scientists, engineers, and industry experts to address complex technical challenges in decarbonisation. • Carry out project appraisal for recommending proposals for large-scale projects for approval. • Set up a monitoring and evaluation system for the projects/activities sanctioned by the Ministry. • Review the technology landscape nationally and globally, carry out a technology gap analysis for various aspects of the value chain, and accordingly define research goals • Develop a database to capture existing institutional capabilities for R&D and encourage the setting up of a network of Centres of Excellence, each focusing on an R&D area of its proven competence and capability. • Oversee the development and implementation of pilot projects and demonstration plants. • Prepare recommendations for the consideration of the Steering Committee wherever required.

16.3.3. Executive Committee

An Executive committee (EC) serves as body guiding and overseeing the comprehensive transition to a low-carbon industry in India. It will be responsible for defining strategy, reviewing implementation progress, inter-ministerial and stakeholder coordination, reviewing activities taken by the RD&D committee, and ensuring international cooperation. The Executive Committee will receive inputs from SRTMI for day to day working.

Executive Committee	
Broad Mandate	**It will be the body providing guidance for the implementation of the decarbonisation strategy while defining strategic objectives, facilitating inter-ministerial coordination, and ensuring the effective and timely implementation of decarbonisation policies and achievement of milestones.**
Roles and Responsibilities	• Define the strategic objectives and approve the action plan and roadmap for decarbonisation of the steel sector. • Establish key performance indicators (KPIs) and set milestones for achieving decarbonisation targets. • Review the progress of implementation in terms of achievements. • Recommend policy interventions to accelerate the implementation of activities and address roadblocks. • Identify and address challenges and barriers to progress. • Recommend mid-course corrections in the implementation strategy as needed. • Oversee the development and enforcement of necessary regulations and standards. • Ensure that policies are effectively communicated to and implemented by the industry.

	• Promote effective communication and coordination among various ministries and government departments to ensure a unified approach to policy implementation. • Address and resolve any conflicts or overlaps in responsibilities among different ministries and departments. • Conduct regular reviews of progress reports from the Steering Committee, RD&D Committee, and SRTMI to assess the implementation of action plans. • Monitor performance against set targets and key performance indicators (KPIs), identifying areas needing improvement. • Guide overall strategy for technology development as well as technology adoption and guide undertaking of pilot projects. • Recommend and approve various studies to fill in the gap on information related to policy formulation, technology need assessment etc. • Approve RD&D and Technology Development Plan as formulated by SRTMI. • Review of the RD&D activities taken up by the SRTMI. • Appraise and approve the RD&D projects as recommended by SRTMI. • Encourage international cooperation and exchange of knowledge and best practices in green steel technologies. • Approve the budget and expenditure of both the steering committee and SRTMI. • Take stock of existing skills and capabilities in the steel manufacturing sector and suggest ways to develop programs for upskilling. • Any other relevant and important task.

16.3.4. Steel Research and Technology Mission of India

The Steel Research and Technology Mission of India (SRTMI), an existing Institute under the Ministry of Steel, is envisioned to be transformed into a pioneering Institution dedicated to advancing research, innovation, and technology development in the field of sustainable steel production in India. It will operate as a specialised research centre with a multidisciplinary approach to address the complex challenges of reducing the environmental footprint of the steel industry while enhancing its efficiency and competitiveness. It will act as the central hub for innovation, coordination, and implementation of green technologies and practices within the industry. It will work under the direction of the Executive Committee as well as seek guidance from the RD&D Committee.

1. Various areas of focus of SRTMI are:
2. Innovative Technology Development
3. Pilot Projects and Demonstration Plants
4. Policy Formulation Support
5. Implementation of Policies and Action Plan
6. Regulatory Framework Development
7. Research Institution Coordination
8. Industry Collaboration
9. Data Collection
10. Reporting Mechanisms

11. Stakeholder Engagement
12. Knowledge Repository
13. Economic Feasibility Studies
14. Resource Mobilisation
15. Funding and Incentive Programs
16. International Partnerships
17. IPRs and other legal issues
18. Monitoring, Reporting, and Verification (MRV)
19. Risk Management
20. Capacity Building and Knowledge Dissemination
21. Public Awareness and Engagement

Steel Research & Technology Mission of India (SRTMI)	
Broad Mandate	**An apex centre for all the research, development and demonstration work in India related to every aspect of decarbonisation of the steel sector, with a focus on technology development, technology adoption and technology indigenisation while actively pursuing global cooperation. It will act as an umbrella institute fostering innovative research on cutting-edge technologies across the country in this field.**
Roles and Responsibilities	● Develop comprehensive action plans outlining specific steps, timelines and responsibilities for achieving decarbonisation targets, under the directions of the Executive Committee. ● Develop and implement RD&D and Technology Development Plan for decarbonisation of the Steel Sector in India, under the guidance of the RD&D Committee ● Review the research and technology landscape at national and global levels, carry out extensive gap analysis and research and technology need assessment, and identify priorities for India. ● Coordinate the work of various RD&D & technology development centres (including IITs, CSIR, IMMT, RDCIS, NISST etc.) for decarbonisation of the steel sector and developing a repository to capture existing institutional capabilities for R&D and foster these to grow further, identifying their unique capabilities. ● Pursue and manage collaborations and synergy amongst industry, national laboratories and academic institutes. ● Provide a national platform for networking among different centres of excellence and research institutions, including foreign R&D institutions and high-tech companies. ● To develop a technology platform to encourage the meeting of like minds (e.g. start-ups and research institutions, start-ups and industrial houses) for networking and exchange of information among researchers in India as well as other countries, including high-tech companies. ● Develop and maintain best practice repositories from across the world on decarbonisation strategies and technologies. ● Assess the funding needs for decarbonisation and mobilise the funds

	● Formulate calls for proposals for pilot and R&D projects ● Evaluate all the proposals for research and technology development and put them across the Executive Committee through the RD&D Committee for approvals and grant of funds ● Assess performance and impact of projects and outcomes R&D projects to identify potential for further investment and scaling up. ● Serve as the monitoring agency for pilot demonstration projects ● Provide focus on international cooperation and collaboration for research and technology needs through bilateral MoUs. ● Serve as the main interface with international research institutions, research groups from foreign countries, high-tech start-up companies and multilateral programmes (such as those which may emerge from negotiations under the Paris Agreement) and encourage joint projects between international partners and Indian centres of excellence, with sharing of IPR, as also encourage the setting up of R&D bases in India by advanced high-tech companies from abroad. ● Establish systems for comprehensive data collection on emissions, energy use, and technology adoption in the steel sector. ● Conduct economic analyses to assess the cost-effectiveness and financial viability of green steel technologies. ● Provide financial and technical advisory services to steel companies transitioning to low-carbon processes. ● Design and manage funding schemes to support R&D, pilot projects, and the deployment of green technologies. ● Facilitate access to international climate finance and investment for decarbonisation projects. ● Facilitate collaboration between steel manufacturers, technology providers, and financial institutions. ● Organise forums, workshops, and conferences to foster dialogue and share best practices among stakeholders. ● Assist in drafting and updating regulations and standards related to green steel production and environmental compliance. ● Monitor global regulatory trends and recommend necessary adjustments to Indian policies. ● Analyse data to track progress towards decarbonisation targets and identify areas needing improvement. ● Develop standardised reporting protocols for steel companies to ensure consistent and transparent reporting of environmental performance. ● Prepare and publish periodic reports on the state of the steel sector's decarbonisation efforts. ● Frame structure for identifying, assessing, and mitigating these risks, thereby safeguarding the decarbonisation process. ● Set up a National Portal for applying for funds, projects, their approval, disbursal of funds, monitoring of projects, progress dashboard, dissemination of knowledge and awareness about the action items and connecting stakeholders would be established during the early stages of the programme and populated as the progress.

16.4. Conclusion

The proposed governance framework embodies a holistic approach, integrating advanced research, policy advocacy, and collaborative efforts to address the multifaceted challenges of green steel production. It involves a concerted effort across various stakeholders, including government agencies, industry partners, academic institutions, and environmental organisations.

In conclusion, this chapter provides a comprehensive framework for transforming the steel industry into a model of sustainability and innovation. By fostering collaboration, driving research, advocating for supportive policies, and ensuring continuous funding, this framework sets the stage for a greener, more efficient, and competitive steel industry. This transformative approach not only addresses the immediate environmental challenges but also contributes to global efforts in combating climate change and promoting sustainable industrial practices, ultimately paving the way for a more sustainable future.

CHAPTER 17

ACTION PLAN AND ROADMAP

17.1. Introduction

This chapter details the action plan and roadmap to reduce the steel sector's emission intensity trajectory in India. Figure 17.1 describes the pathway for decarbonisation of the steel sector in India, presenting a clear trajectory from setting targets for implementation and monitoring. The decarbonisation pathway for the steel sector is split into six key components: Targets, Strategy, Roadmap, Action Plan, Implementation, and Review & Monitoring.

The pathway begins with setting decarbonisation targets for the steel industry that align with national objectives and long-term visions based on existing policies and climate goals. The strategy for achieving the targets is based on creating a demand-side pull for incentivising emissions reduction while ensuring that supply-side levers are fully developed and available for the industry to decarbonise. The roadmap includes setting emission intensity milestones for the sector till 2030. The implementation of the action plan shall be facilitated through clearly defined mechanisms and financial support structures through the governance framework. Finally, review and monitoring of the progress shall be done periodically, which will enable adjustments and adaptability with respect to changing needs and scenarios.

Figure 17.1: *Pathways for decarbonisation of the steel sector in India.*

17.2. Major targets

India aims to become a global leader in green steel production and consumption through the adoption of clean energy and advanced technologies and by promoting a circular economy to achieve net-zero emissions by 2070. This will be accomplished by setting incremental decarbonisation targets for the steel industry, implementing policy interventions for a smooth transition, creating enabling conditions, and ensuring just transitions. Figure 17.2 lists the key targets for ensuring transitions in the steel sector. This section outlines the major strategies and actions to achieve these goals, demonstrating a commitment to sustainability and economic growth.

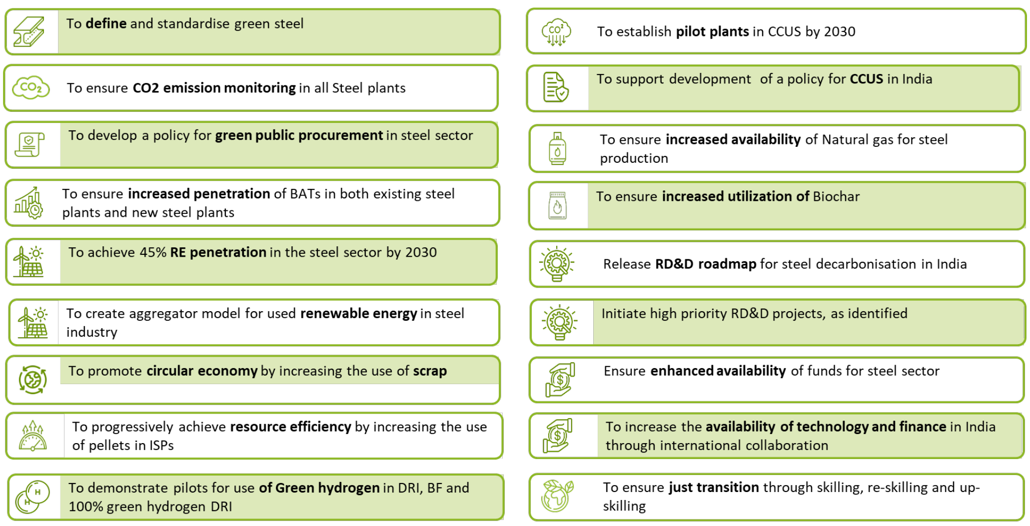


Figure 17.2: *Major targets for decarbonisation of steel sector*

17.3. Strategy for Transition

This section outlines a comprehensive strategy to facilitate the transition of the steel industry towards a low-carbon future. The strategy includes pillars of transition and an approach to transition. The former delves into the foundational pillars necessary for this transformation categorising the essential action items across policy, technology, and finance, and presents a detailed approach to achieve these targets. The strategy can be approached in many ways to leverage immediate opportunities, promote the adoption of alternative fuels, utilise a cluster-based approach, implement an aggregator model, and drive research, development, & deployment (RD&D) initiatives.

17.3.1. Three Pillars of Transition

Figure 17.3 outlines three pillars necessary for the successful implementation of various decarbonisation levers. The figure categorises each lever based on the requirements across three primary pillars of policy, technology, and finance.

Policy: The action items for developing a definition of green steel, international focus, and monitoring CO_2 emissions require strong policy support and guidelines. Further, creating demand for green steel, increasing energy efficiency, renewable energy, and material efficiency measures in the steel sector will also need policy development to a larger extent. Developing an ecosystem and policy for CCS, ensuring process transition for the DRI sector, accelerating the uptake of biochar, releasing RD&D roadmap and ensuring just transition through skill development will also need significant polity interventions in addition to other pillars like technology and finance.

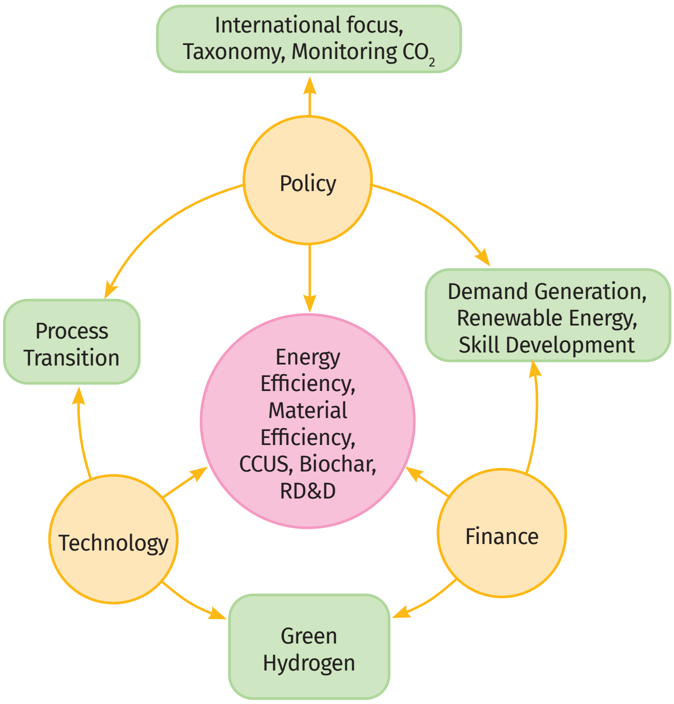


Figure 17.3: *Pillars of transition requirement for task forces.*

Technology: The technology pillars are mostly relevant for decarbonisation levers like energy efficiency, material efficiency, green hydrogen, CCUS, process transition in the DRI sector and biochar uptake that rely on technological advancements. While most energy efficiency technologies are commercially available, a few are still in the developmental stage and will need support for scaling up to commercial scale. Further, material efficiency will need technological interventions to reduce cost and adapt to Indian conditions based on raw material availability. Green hydrogen is still an evolving area, and technological innovation will be the key in reducing its production costs. Most CCU applications are an offshoot of green hydrogen, while the CCS ecosystem in India will take a few more years to develop through policy and technology interventions. Process transition in the DRI sector will also need innovation for handling domestic grade of fuels and developing modular small-to-medium scale shaft furnaces. Biochar production and uptake in the steel sector will also need technology development for production and use.

Finance: Finance is the most important lever for accelerating the transition in the steel sector. Green steel uptake by the private and public sectors will need significant financing, given that there is a premium associated with it. Further, the deployment of energy efficiency measures in the SSI sector will need innovative financing to ensure the availability of capital at affordable rates. Material efficiency measures, like beneficiation and pelletiation also need huge capital requirements. The scrap production sector is mostly an informal sector that will need financial intervention to meet the quality requirements of the steel sector. Green hydrogen and CCUS projects are very capital-intensive. These technologies are also in the early stage of deployment and carry significant risks. Therefore, financing would be instrumental in the initial phase of scaling up the technology. The biochar industry in India is small in volume and dominated by smaller players that will need financing to scale up to meet the requirements of the steel industry. RD&D needs significant investment in risky technology development that has a longer gestation period. Skill development also needs financial support for setting up training institutes and conducting training.

17.3.2. Approach for Transition

This section details some of the key strategies that can be used to support the steel sector's transition in India. Figure 17.4 shows a number of important approaches, such as low-hanging fruits, transition to alternative fuels, cluster-based approach, aggregator model, sectoral approach and RD&D and their levers.

Low-hanging fruits

The first part of the strategy focuses on unlocking the low-hanging fruits like energy efficiency and renewable energy. These technologies are commercially available and can be easily adopted in the sector without any significant modifications to the production process. A few energy efficiency technologies not only decrease emissions but also reduce production costs, increasing the competitiveness across the steel sector.

Transition to alternate fuels

Transitioning to alternate fuels is another critical strategy for the medium term. In this regard, natural gas has a big role to play as it is a bridge fuel to green hydrogen and has significantly lower carbon emissions compared to coal-based production processes. 100% green hydrogen-based DRI production can be used after it achieves cost competitiveness with incumbent production processes and fuels. CO_2 recycling provides the steel sector an avenue to reduce the uptake of fossil fuels for steel production. Further, CCU also offers the steel sector an opportunity to produce value-added fuels and chemicals that can reduce India's import dependency. The use of Biochar also presents a significant opportunity for the steel sector to reduce its emissions intensity while creating jobs and employment opportunities in India's rural areas.

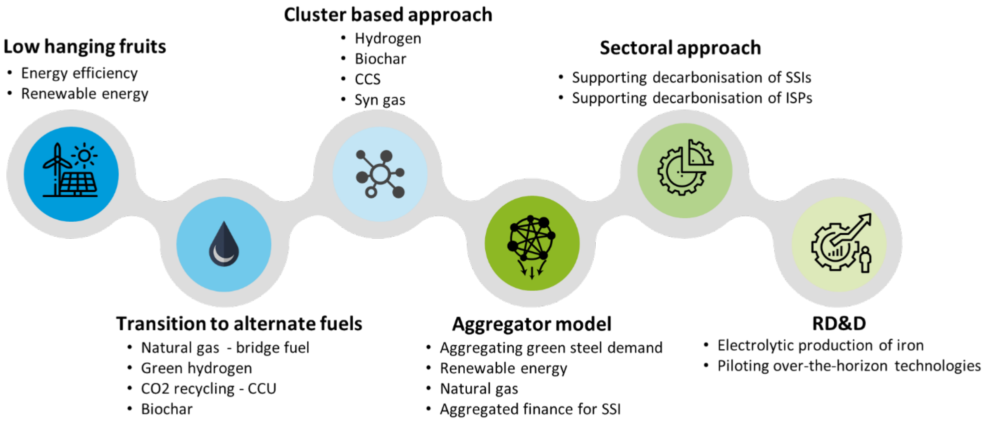


***Figure 17.4:** Strategies for transition in the steel sector*

Cluster-based approach

It is useful to synergise decarbonisation efforts within the sector. It is seen that most steel plants do not have space within the existing plants for producing green hydrogen. Further, most steel plants in India are geographically located within a few districts, while the SSIs mostly operate in clusters. Therefore, a cluster-based approach might be suitable for accelerating decarbonisation in the sector by providing access to alternative fuels like green hydrogen, biochar, syngas, and deep decarbonisation levers like CCS that can facilitate shared infrastructure, innovation, and resource optimisation. This approach enables the steel industry to collectively tackle common challenges and is useful for SSIs with less financial wherewithal to adopt high-cost interventions.

Aggregator model

This model supports aggregation of demand for green steel, renewable energy, and natural gas on a larger scale by pooling investments and resources. It is a business model that involves a third-party entity (the aggregator) that shall pool together the demand from multiple steel producers. The aggregator shall then procure these resources in bulk, often at a discounted rate due to economies of scale, and distribute them to the steel producers. This model is especially important for the SSIs that can potentially benefit from the economy of scale. Additionally, it promotes aggregated finance for SSIs, ensuring that smaller entities within the steel sector have access to the financial support needed to adopt sustainable practices. The key features involved are demand aggregation, bulk procurement, risk management, distribution, financial management, and market analysis.

RD&D

RD&D initiatives are crucial for driving innovation, developing indigenous technologies, and making India a manufacturing hub for new-age technologies. For the steel sector, breakthrough technologies like electrolytic production of iron, and piloting over-the-horizon technologies like hydrogen-based steel production and CCUS hold significant promise. RD&D can also help the steel sector in developing technologies that will help incremental decarbonisation of the existing processes for producing iron and steel.

17.4. Emissions intensity trajectory for the steel sector

The Bureau of Energy Efficiency (BEE) is developing targets for emissions intensity of steel production in India for the obligated entities under the ambit of Indian Carbon Markets through its Carbon Credit Trading Scheme (CCTS). The proposed industry-wide targets for emissions intensity of steel are indicated in Figure

17.5. It is seen that under the CCTS scheme, it is aimed to reduce the average emissions intensity of steel from 2.54 t-CO_2/TCS in 2023-24 to 2.2 t-CO_2/TCS by 2029-30.

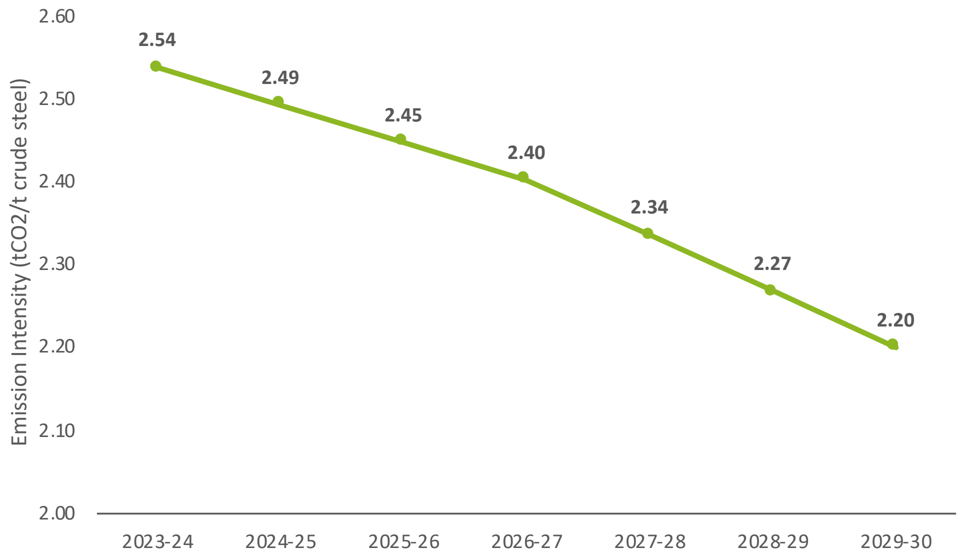


Figure 17.5: *Proposed emissions intensity targets for the steel sector*

17.5. Roadmap

Figure 17.6 illustrates the envisioned trajectory for transitioning the steel industry, spanning short-term (up to 2030), medium-term (up to 2047), and long-term (up to 2070) objectives. In the short term, until 2030, the emphasis lies on maximising the adoption of energy efficiency and renewable energy sources. Additionally, there is a concerted effort to maximise the utilisation of pellets and to increase the incorporation of scrap in steel production. These technologies are already deployed in some parts of the industry and can be readily incorporated throughout the sector.

In the medium term, until 2047, the focal points shift towards initiatives such as the development of green hydrogen, biochar, and CCUS, alongside enabling the process transition of the DRI industry. Finally, in the long term, attention may turn to the deployment of direct electricity technologies and other disruptive innovations aimed at facilitating the transition to achieve net-zero emissions.

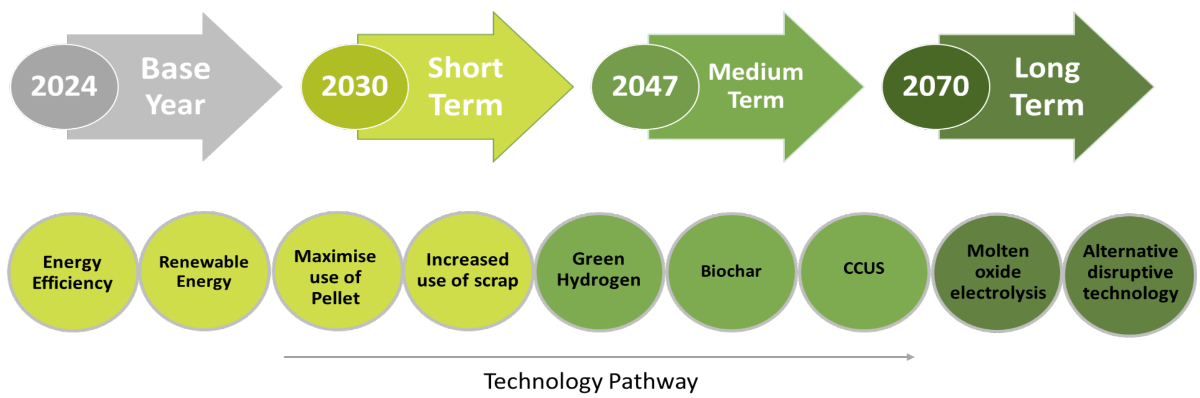


Figure 17.6: *Strategy for net zero transition in India*

Figure 17.7 illustrates the roadmap for decarbonising the steel industry in India, highlighting key milestones from 2023 to 2070. The journey begins in 2023 with the establishment of 14 task forces by the Ministry of Steel. In 2024, the focus is on defining green steel and developing an MRV framework. In 2025, a policy framework for green public procurement (GPP) is proposed to be developed, followed by initiatives to increase energy efficiency and renewable energy penetration. The roadmap then emphasises the uptake of pellets and scrap utilisation in steel production. By 2030, significant actions include biochar utilisation and the pilot testing of green hydrogen (GH2) and carbon capture, utilisation, and storage (CCUS) technologies. The period leading up to 2047 involves deep decarbonisation through commercial GH2 steelmaking, advanced CCUS, and breakthrough technologies like direct electrolysis. Finally, the roadmap aims to retire high-emission capacity and achieve net zero emissions by 2070.

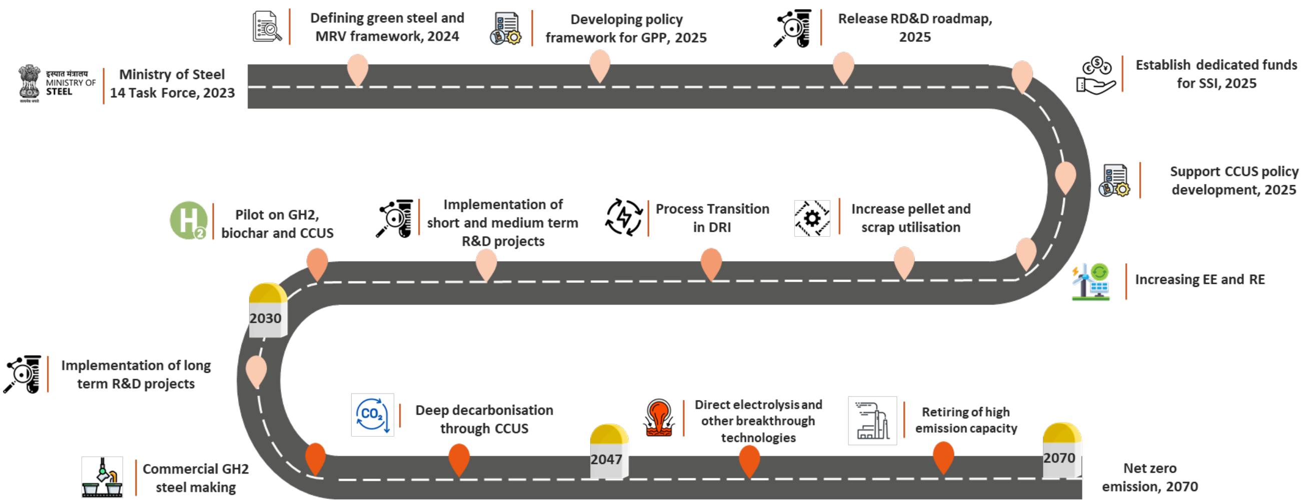


Figure 17.7: Roadmap for net zero transition in India

17.6. Action Plan

The action plans for decarbonising the steel sector in India, as outlined in the report, involve various tasks with distinct timelines and objectives. Figure 17.8 shows the timeline for major action items under each of the task forces from FY 2025 to 2030. Some actions are immediate and short-term, such as developing a definition for green steel and creating an MRV framework for CO_2 emissions monitoring, set to be completed by FY 2025 and FY 2026, respectively. Continuous efforts extending until 2030 include promoting energy efficiency, achieving 45% renewable energy penetration, and increasing the use of biochar and circular economy practices. Certain initiatives, like demonstrating pilots for green hydrogen use and establishing pilot plants for CCUS, are scheduled to start later in the timeline but are critical for long-term decarbonisation goals. The implementation of RD&D projects and enhancing finance availability for the steel sector, ensuring just transition are ongoing efforts that will span across the years, ensuring sustained progress towards reducing emissions. The emission intensity targets are also shown in the figure from FY 2025 to 2030, reducing from 2.54 to 2.2 T/TCS. This may be achieved by the successful implementation of the roadmap.

Sr. No	Action Items	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30
1	**Taxonomy**						
	a. Developing a definition of green steel in consultation with all relevant stakeholders.						
2	**Monitoring CO2**						
	a. To develop an MRV framework for CO2 emission monitoring in steel sector						
3	**Demand Generation**						
	a. To develop a policy for green public procurement in steel sector						
4	**Energy Efficiency**						
	a. To ensure increased penetration of BATs in both existing steel plants and new steel plants						
5	**Renewable Energy**						
	a. To achieve 45% RE penetration in the steel sector by 2030						
	b. To create aggregator model for using renewable energy in steel industry						
6	**Material Efficiency**						
	a. To promote circular economy by increasing the use of scrap by 2030						
	b. To ensure increased uptake of pellets in ISPs						
7	**Green Hydrogen**						
	a. To demonstrate pilots for use of Green hydrogen in blast furnace, gas shaft furnace and 100% green hydrogen DRI						
8	**CCUS**						
	a. To support development of a policy for CCUS in India						
	b. To establish pilot plants in CCUS in India						
9	**Process Transtion for DRI**						
	a. To ensure increased availability of Natural gas for steel production						
	b. To aggregate demand from steel industry and negotiate long term offtake contracts with LNG suppliers						
10	**Biochar**						
	a. To ensure increased utilization of Biochar						
11	**RD&D**						
	a. Release RD&D roadmap for steel decarbonisation in India						
	b. Implement the identified RD&D projects in the report						
12	**Finance**						
	a. Establish dedicated funds for SSIs						
	b. Ensure enhanced availability of funds for steel sector						
13	**International Focus**						
	a. To increase the availability of technology and finance in India through international collaboration						
14	**Skill Development**						
	a. To ensure just transition						
	Target % Reduction in Emission	0.00%	1.97%	3.54%	5.51%	7.87%	13.39%
	Target Carbon Emission Intensity (T/TCS)	2.54	2.49	2.45	2.4	2.34	2.2

Figure 17.8: *Roadmap for demand and supply side action items from 2024 to 2030.*

The action items for various decarbonisation measures are discussed in detail towards the end of each chapter of all the task forces (chapters 2 to 15). This section of the report consolidates these action items into seven categories – training, task, study, research, policy, pilot, and finance. Figure 17.9 below describes the various types of action plans for all 14 task forces. These plans vary according to the chapters; some call for policy interventions or tasks to be completed within a set timeline, others for studies to be conducted. A few action items focus on implementing training programs, piloting initiatives, and providing financial support. It can be seen that most action items tilt towards policy development, followed by tasks and finance.

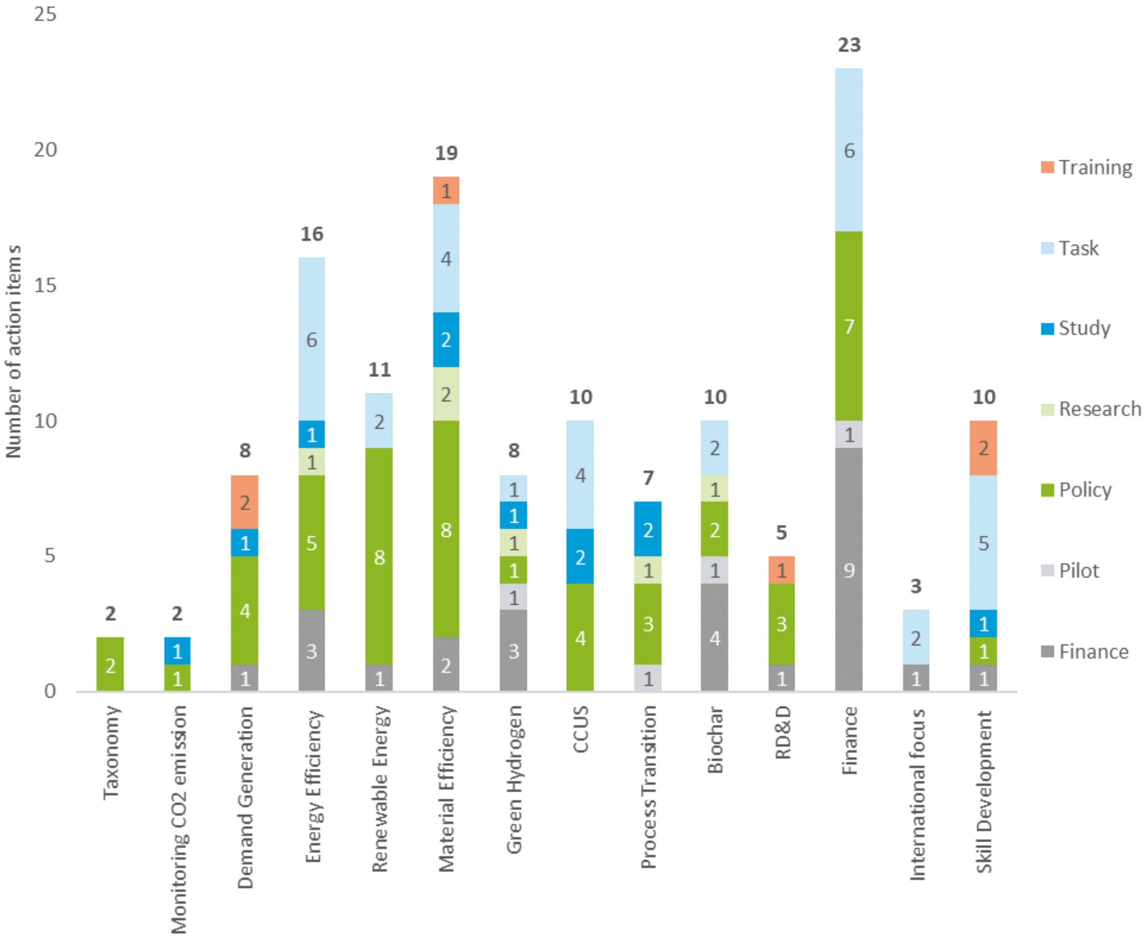


Figure 17.9: Action plan classification

17.7. Nodal agencies for all the action items

This section outlines all the 134 action items identified across various chapters aimed at decarbonising the steel sector. These action items are categorised under three key pillars: incentivisation & ecosystem development for green steel, levers to enable decarbonisation, and avenues to support the transition. Table 17.1 details the action items under the incentivisation and ecosystem development pillar, focusing on the areas of taxonomy, monitoring CO_2 emissions, and demand generation (Chapters 2 to 4). Each action item is accompanied by the respective nodal agencies that are identified to carry out the respective action items.

Table 17.1: *Nodal agencies for action items under the incentivisation and ecosystem development pillar*

Levers for transition	Action item	Nodal agencies
Taxonomy	• Developing a definition of green steel in consultation with all relevant stakeholders. • Developing an MRV framework and creating a registry for green steel certificates	Ministry of Steel (MoS), Bureau of Energy Efficiency (BEE)
Monitoring CO_2 emissions	• Coordinate with BEE to develop a protocol for measuring emissions from all the sector steel plants, including those that are not covered as Obligated Entities under CCTS. BEE to incorporate the provisions in relevant laws/rules. • Coordinate with BEE to develop a dataset for default emission values for all those input materials where the data is not available, with the help of the industry stakeholders.	MoS, BEE
Demand Generation	• Study to estimate premium on green steel • Development and implementation of GPP for green steel • Capacity Building and Training Programs for GPP • Identifying or creating a nodal agency for buying and selling green steel • Encourage scope 3 emissions disclosure by end users of steel • Include Green steel procurement in (ESG) rating evaluation criteria • Reducing GST or tax holiday for green steel purchase • Raising public awareness about green steel	Ministry of Finance (MoF), MoS, State Governments, Ministry of Environment, Forest and Climate Change (MoEFCC), Securities and Exchange Board of India (SEBI)

Table 17.2 details the action items and nodal agencies identified under the levers to enable the decarbonisation pillar, focusing on Energy efficiency, RE, material efficiency, green hydrogen, CCUS, process transition, and Biochar (Chapters 5 to 11).

Table 17.2: *Nodal agencies for action items under the levers to enable decarbonisation pillar*

Levers for transition	Action item	Nodal agencies
Energy Efficiency	• Mandatory implementation of identified BATs for greenfield and brownfield projects • Scale up of BATs implementation in existing ISPs and SSI • Mandatory implementation of star-rated equipment, VFDs • Promote the adoption of Industry 4.0 • Conduct a study to assess and evaluate the status of implementation of BATs across the technologies in SSIs and ISPs and understand the challenges for implementation • Periodically review, revise, and update the list of BATs and notify them • Setting benchmarks and energy-saving targets for different routes of steelmaking • Examine the possibility of making Energy audits mandatory • Monitoring and phasing out inefficient steel plants	MoS, MoEFCC, MoF, BEE,National Institute of Secondary Steel Technology (NISST), Biju Patanaik National Steel Institute (BPNSI),

Levers for transition	Action item	Nodal agencies
	• Expanding CCTS coverage to include more steel plants • Strengthening the national institutions/organisations such as National Institute of Secondary Steel Technology (NISST) and Biju Patnaik National Steel Institute (BPNSI) to provide technical support and handholding of SSI • Scheme to extend technical consultancy services at free-of-cost or subsidised cost to small SSI units • Incentivise WHR implementation in coal DRI plants • Incentivisation of small coal DRI plants of 100 TPD and below to upgrade capacity to 350/500 TPD • Extend financial incentives such as VGF, interest subvention, and risk guarantee fund for BATs • R&D for Indigenous development of BATs	
Renewable Energy	• Single Window Support System for SSIs to add RE • Align State Regulations with Green Energy Open Access Rules, 2022 • Specific modification in the Rule 5 of GEOA rules, 2022 for SSIs • Coordinate to maintain continuity in the relevant policies for at least 10 years • Aid the steel industries/RE developers in land identification and acquisition at concessional rates for the installation of captive RE plants • Financial Support for SSIs opting for third-party/captive RE open access (a. Risk coverage for loan repayment b. Demand Aggregation by SECI c. Payment Security Reserve Fund d. Concessional finance from MDBs e. GST reimbursement for captive RE projects f. Credit from coal cess g. Restructuring financing models for captive RE projects) • Support the steel industries/RE developers in land identification and acquisition at concessional rates for the installation of captive RE plants • Reduce STU drawal charges for RE-deficient states • Promote Green Power Market • Retirement of old and inefficient captive coal-based plants • Waste Heat Recovery (WHR) power to be excluded for RPO Compliance	Ministry of New and Renewable Energy (MNRE), Ministry of Power (MoP), MoF, MoS, State Governments
Material Efficiency	• Resources may be assessed preferably as above 62% Fe, 62 to 55% Fe, and below 55% up to 45% Fe to assess capacity additions and incentives requirements. • Developing an optimised beneficiation circuit to treat different Fe bands and mineralogical composition of iron ores (i.e., 45-50 % Fe, 50-55 % Fe, >55% Fe; and ore above 60% Fe for DRI/EAF route) and lean grade resources (BHQ/BHJ/BGQ) using conventional or reduction roasting processes. • MoS may coordinate with various Ministries and State governments to facilitate land allotment for the establishment of beneficiation plants and tailing disposal along with EC • Waiving off or imposing a nominal royalty on low-grade iron ore to incentivise their utilisation.	MoS, State governments, Ministry of Mines (MoM), MoF, MOEFCC, Department of Science and Tech-nology (DST), Department of Science and Technol-ogy (MoRTH)

Levers for transition	Action item	Nodal agencies
	• Encourage beneficiation through tax exemption on capital invested in the creation of a beneficiation facility. • Effective tailings management to maximise metal recovery from mining tailings • Periodically review and rationalise the base prices of iron ore fines. • Establish the beneficiated process for different mineralogical compositions of ores through either conventional/reduction roasting/dry or combination in lab and pilot scale through R&D study. Additional R&D studies will be conducted through public funding to commercialise benefaction. • Maximising pellet use in DRI and blast furnaces. • Logistics and Infrastructure support for setting up pellet plants by conducting feasibility studies, collaborating with local governments to secure approvals, and streamlining pellet delivery. • Facilitate installation of slurry pipelines • Encourage R&D to foster innovation by developing economically viable briquettes from iron ore fines and steel plant wastes while evaluating their usage against that of pellets. • Establishment of Circular Economy Parks and Recycling Zones • Create enhanced awareness of vehicle scrappage policies and potential benefits of the scrappage policy and schemes, encouraging the establishment of scrap collection centres. • Prioritise safety measures and testing involve mandating the installation of radiation detection equipment in all steel mills, foundries, and recycling units • Grant industry status to the recycling sector and develop an e-marketplace for unorganised sector players to integrate with the organised sector • Government procurement policies to prioritise products made from recycled material and provide market support • Standardising recycling operations and establishing a National Material Recycling Authority and reduce GST • Implementing Extended Producer Responsibility (EPR) in the automobile and white goods sectors	
Green Hydrogen	• Support pilot projects across end-use applications • Incentivise the installation of shaft furnaces • Coordinate with the ministries to extend benefits provided to green hydrogen projects to steel industry • Accelerate International and multilateral collaborations to increase green hydrogen use • Project to estimate the amount of green hydrogen that can be injected in rotary kilns • Development of experimental blast furnaces or shaft furnaces for hydrogen use • Incentivising the use of green hydrogen for DRI making. • Development/incentivisation of benefaction and pelletisation	MNRE, Niti Ayog, MoS, MoF, MoP, Ministry of External Affairs (MoEA), SIMA

Levers for transition	Action item	Nodal agencies
CCUS	• Coordinate and support Niti Aayog and other ministries/organisations to develop a dedicated policy for CCUS • Study the Techno-economic feasibility of CCUS by engaging technology providers • Develop RD&D roadmap for scaling up CCUS technologies in the steel sector • Support CO_2 storage capacities and risk assessment studies for secure storage of CO_2 • Develop a carbon-credits-based MRV framework (Accounting and monitoring frameworks, safety standards, environmental compliance requirements, and certification standards) • Advocate for developing clear and stable regulations for CO_2 storage, transportation, and utilisation • Develop policy guidelines for preferential procurement of CCU products manufactured in steel plants • Collaboration with International Partners with experience in CCUS for technology adoption • Encourage roadmap by all ISPs/Major steel producers for CCUS • Developing and scaling up of Indigenous technology providers and Original Equipment Manufacturers (OEMs) for CCUS	Niti Aaayog, MoP, MoS, MoPNG, Ministry of Earth Sciences (MoES), MoF, MoEA
Process Transition	• Leverage scale for process transition to natural gas by consolidating the natural gas demand from the steel sector • Develop natural gas cost curve for India on an annual basis • Provide access to natural gas in India's iron and steel belt • Develop modular shaft furnaces for smaller DRI units by engaging with OEMs • Assess the feasibility and develop a pilot of group captive gas-based DRI production • Co-develop and scale up technologies for gasifying high-ash domestic coal. • Evaluate feasibility of a centralised coal gasification plant	Ministry of Petroleum and Natural Gas (MoPNG), MoS, DST, Ministry of Coal (MoCoal)
Biochar	• Utilisation of Biochar and other relevant products in the iron and steel industry, by developing a policy framework for blending biochar with coal. • Support Research and Development to innovate and promote Indigenous technologies, scaling up the technologies & Establishing lighthouse projects • Facilitating International collaborations to enable technology transfer and build innovative business models • Support to develop an enabling environment and Ecosystem for Biomass resource assessment, collection, and storage of process to produce biochar through Public-Private-Partnership	MoF, MNRE, DST, MoEA, MoS, Ministry of Agricilture (MoA), GST council

Levers for transition	Action item	Nodal agencies
	• Coordinate with relevant ministries to bring different types of biomasses suitable for biochar-making under a Minimum Support Price Scheme of the Ministry of Agriculture and Farmers Welfare applicable across India under the commercial crop category • Support working capital needs and promote biomass aggregators • Reduce GST on biochar meant for blending scheme from 18 % to 5% to reduce costs for the steel industry • Support plantation activities such as Incentivising and promoting bamboo cultivation through the Employment Guarantee Act by providing subsidies to the farmers who take up bamboo cultivation, also ensuring chain of custody. • The priority sector lending scheme of the Government of India may be extended to the biochar production industries for certain non-staple energy crops • Bring together industries and the private sector through incentive schemes to evolve workable business pilot models for biochar generation and utilisation in the iron and steel industrial sector in a cluster-based approach.	

Table 17.3 details the action items and nodal agencies identified under the avenues to support the transition pillar, with action items from chapters 12 to 15, which include levers for RD&D, Finance, International focus and skill development. RD&D chapter has 5 action items, the Finance chapter contains the maximum number of action items among all chapters, and it has identified nodal agencies MoF, MoS, BEE, SEBI, GST council and SIDBI to address the 23 action items.

Table 17.3: *Nodal agencies for action items under the support transition pillar*

Levers for transition	Action itemp	Nodal agencies
RD&D	• Setting up an RD&D committee to coordinate and regulate RD&D efforts • Coordinate with other government entities and ANRF for cross-sectoral research • Releasing guidelines on the RD&D roadmap for steel decarbonisation in India • Implementation of RD&D Projects as per roadmap and budget • Convening workshops and disseminating information on RD&D efforts	MoS, DST
Finance	• Adopt a public procurement target aligned with the green taxonomy. • Incentivise private end consumers for using green steel (e.g., lower GST rates, green steel quotas). • Establish time-bound regulatory targets for emission reduction in the steel industry. • Provide viability gap funding through innovative business models for the adoption of BATs.	MoF, MoS, BEE, SEBI, GST council, SIDBI

	• Set up a Technology Upgradation Fund Scheme (TUFS) to reduce the cost of capital for adopting BATs. • Include specific provisions in the Domestic Carbon Market and Green Credit Scheme for SSPs. • Develop a policy package to reduce upfront capital requirements for green industry setup. • Ensure long-term low-cost credit availability for green interventions. • Introduce fiscal support instruments (e.g., interest subventions, tax holidays) to encourage green technology investments. • Set up a pilot financing facility to demonstrate the economic attractiveness of technological interventions. • Infuse targeted capital in select banks to enhance credit for decarbonising the iron and steel sector. • Issue guidelines for export-oriented priority sector lending (PSL) towards green steel and lower risk weight for decarbonization projects. • Support sector-specific green bonds with sovereign guarantees and rebates on certification fees. • Introduce risk reduction measures for accessing international finance, including partnerships with multilateral development banks. • Explore cooperative approaches under Article 6 of the Paris Agreement to mobilise international finance for green steel. • Partner with the Glasgow Financial Alliance for Net-Zero (GFANZ) for affordable finance in the steel sector. • Build capacity in financial institutions to evaluate and invest in decarbonisation technologies. • Establish a pooled finance platform under the Ministry of Steel to provide long-term finance to SSPs. • Establish a dedicated fund under NIIF to support decarbonisation of the iron and steel sector, with initial 50% government contribution and capital raised from multilateral financial institutions, investors, and philanthropies. • Create a revolving fund with a comprehensive financial package for SSPs, blending grants, loans, risk guarantees, equity, and innovative business models, housed in SIDBI • Set up a multi-stakeholder technical assistance platform to address knowledge gaps and develop innovative financial instruments for green steel • Develop a supply chain-linked market-based decarbonisation model allowing industries to meet emission reduction targets by investing in the steel sector, facilitating finance mobilisation and reducing transaction costs for SSPs and MSMEs. • Consider establishing an enabling policy framework with necessary guidelines for industry and financial institutions. This framework should include: i. green certification, ii. Sustainable STEEL Principles (SSP), iii. Exclusion from Large Exposure Framework (LEF), iv. ESG-linked finance, v. Dedicated platform to list projects that need financing, vi. Grant infrastructure status to Iron & Steel industries implementing green technology, vii. Adoption of best global practices, viii. Monitoring mechanism, and ix. International sustainability exchange.	

Interna-tional focus	• Avail multilateral funding for new energy-efficient technologies • Establish a global advisory council for India's Steel Sector Decarbonization • Establish India's Green Steel Think Tank	MoS, MoEA, NITI Aayog
Skill Devel-opment	• Estimate the skill requirement (technical and non-technical) of the secondary sector • Strengthening Training Infrastructure, including capacity building for training, needs assessment • Training of trainers and assessors in the iron and steel sector • Promoting industry-academia collaboration • Addressing secondary skill requirements to make India globally competitive. • Development of skill gap identification, Training Need Assessments, skill matching/ mapping and course revision mechanism • Increasing Digitalisation to focus on Transversal skills • Implementing an effective governance mechanism for the coherent reskilling/upskilling pathways approach • Finance skill training with various mechanism in the government and private sector • Systematic and sustainable monitoring and evaluation	Ministry of Skill Devel-opment and Entrepreneur-ship (MoSDE), MoS, MoF, IISSSC, IITs, BPNSI, UGC, HRD, Ministry of Education, NCVET

17.8. Implementation Mechanism

The implementation mechanism for decarbonising India's steel sector, led by the Ministry of Steel, involves establishing an institutional and governance framework to ensure coordinated efforts across various initiatives, as indicated in Chapter 16. By fostering collaboration among government bodies, industry stakeholders, and research institutions, the Ministry aims to create a cohesive strategy that drives the sector towards achieving its decarbonisation targets. This structured approach ensures that all efforts are aligned with India's net zero goals, facilitating a smooth, iterative, effective, and just transition to a low-carbon future for the steel industry.

17.9. Review & Monitoring

As discussed in Chapter 16, National Green Steel Research and Technology Centre will be responsible for checking the progress of action items. It may monitor emission intensity targets and report to the steering committee about the progress of action items, and recommend course corrections, if any.

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ANRF	Anusandhan National Research Foundation
AVB	Aços Verde do Brasil
BAT	Best Available Technology
BF	Blast Furnace
BCCA	Buy Clean California Act
BEE	Bureau of Energy Efficiency
BHEL	Bharat Heavy Electricals Limited
BNB	Sustainable Building
BOO	Build-Own-Operate
BTX	Xylene Isomers
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CBAM	Carbon Border Adjustment Mechanism
CBM	Coal-Bed Methane
CCA	Carbon Capture and Utilisation
CCTS	Carbon Credit Trading Scheme
CDA	Carbon Direct Avoidance
CDPQE	Caisse de dépôt et placement du Québec
CDRCs	Carbon Dioxide Removal Credits
CDQ	Coke Dry Quenching
CIMFR	Central Institute of Mining and Fuel Research
CFLs	Compact Fluorescent Lamps
CERI	Clean Energy Research Initiative
CECRI	Central Electro Chemical Research Institute
CERs	Certified Emission Reductions
CEMS	Continuous Emissions Monitoring Systems
CHP	Combined Heat and Power
CPCB	Central Pollution Control Board
CoC	Chain of Custody

CoE	Centre of Excellence
CO	Carbon Monoxide
CO2	Carbon Dioxide
CSR	Coke Strength after Reaction
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCC	Dankuni Coal Complex
DCF	Direct Carbon Fuel Cells
DC	Designated Consumers
DFI	Development Finance Institutions
DGS	Department of General Services
DoE	Department of Energy
DoHa	Duisburg district of Hamborn
DRI	Direct Reduced Iron
EC	Executive Committee
ECA	Emissions Control Area
ECerts	Energy Savings Certificates
ECL	Eastern Coalfields Limited
EERF	Energy Efficiency Revolving Funds
EESL	Energy Efficiency Services Limited
EET	Emissions Trading Scheme
EIA	Environmental Impact Assessment
ELS	Energy Management Systems
EMI	Equated Monthly Instalment
EMS	Energy Management System
ENDS	Electronic Nicotine Delivery Systems
EPA	Environmental Protection Agency
EPDs	Environmental Product Declarations
EPI	Energy Performance Indicator
ESG	Environmental, Social and Governance
ESCO	Energy Service Companies
EU	European Union

FAO	Food and Agriculture Organization
FMC	First Movers Coalition
FS	Financial Stability Board
GBA	Global Biofuel Alliance
GCF	Green Climate Fund
GCV	Gross Calorific Value
GEF	Global Environment Facility
GHG	Greenhouse Gases
GNS	Government National Savings Fund
GPPP	Green Public Procurement Policy
GST	Goods and Services Tax
GWP	Global Warming Potential
H-DRI	Hydrogen in Direct Reduction of Iron ore
H4D	Hydrogen for Development Partnership
HBI	Hot-Briquetted Iron
HIsmelt	High-Intensity Smelting
HM	Hot Metal
HYBRIT	Hydrogen Breakthrough Ironmaking Technology
HYFOR	Hydrogen-based Fine-Ore Reduction
IHFCA	International Hydrogen Fuel Cell Association
IIT	Indian Institute of Technology
ICL	Incandescent Lamps
ICM	Indian Carbon Market
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IP	Intellectual Property
IPHE	International Partnership for Hydrogen Fuel Cells in the Economy
ISO	International Organisation for Standardisation
ISP	Integrated Steel Plants
ITC	International Trade Centre
JHBDPL	Jagdishpur-Haldia-Bokaro-Dhamra pipeline

KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LEC	Lower Embodied Carbon
LCT	Low Carbon Technology
LRC	Lined Rock Cavern
MNRE	Ministry of New and Renewable Energy
MOE	Ministry of Environment
MOEFCC	Ministry of Environment, Forest and Climate Change
MoS	Ministry of Steel
MRV	Monitoring, Reporting, And Verification
MSME	Micro, Small and Medium Enterprises
MT	Million Tonnes
MTPA	Million Tonnes Per Annum
NDC	Nationally Determined Contribution
NIT	National Institutes of Technology
NMEEE	National Mission for Enhanced Energy Efficiency
OECD	Organisation for Economic Co-operation and Development
OPEX	Operational Expenditure
PAT	Perform Achieve and Trade
PCI	Pulverized Coal Injection
PPP	Public Private Partnership
R&D	Research and Development
RBI	Reserve Bank of India
RE	Renewable Energy
RLNG	Regasified Liquefied Natural Gas
SIMA	Sponge Iron Manufacturers Association
SCB	Sugarcane Bagasse
SPP	Sustainable Public Procurement
SRPP	Socially Responsible Public Procurement
SSAB	Svenskt Stål AB
SuSteel	Sustainable Steelmaking

TCS	Tonne of Crude Steel
TFL	Talcher Fertilizers Limited
TRLs	Technology Readiness Levels
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation
USD	United States Dollar
VGF	Viability Gap Funding
WHR	Waste Heat Recovery

ANNEXURES

Annexure-1

Task force: Developing Taxonomy for Green Steel

Chairperson: Saraswati Prasad(Former Special Secretary, Ministry of Steel)

Members: Ruchika Govil (AS, MoS), JS (MoEFCC), Prof. N.N.Vishwanathan (IITB), Sanjiv Maini, (BIS), Prabodha Acharya (JSW), Koustuv Kakati (TATA Steel), R K Goyal (Kalyani Steel), Naveen Ahlawat (JSPL), Kalyan Bhattacharjee (JSL), A K Singh (SAIL), Vaibhav Pokharna (AMNS), Deependra Kashiva (SIMA), Pranav Bhardwaj (ASPA), Devendra Agarwal (AIIFA), Rajib Paul (NISST), Sunita Narain (CSE), Girish Sethi (TERI), Noel Peters (MRAI), M Jayapal Reddy (NMDC), R K Bhan (ISA), Saurabh Diddi (BEE)

Coordinator: Neha Verma (Dir,MoS) Member **Secy:** FICCI **Knowledge Partner:** CEEW

Task force: Monitoring of CO_2 emissions

Chairperson: R P Gupta (Former Secretary, MoEF&CC)

Members: Ruchika Govil(AS,MoS), Sharath Kumar Pallerla (MoEFCC), Abhay Bakre (BEE), Prof. Srinivas S (IIT B), Sanjiv Maini (BIS), S K Das (SAIL), Badal Balchandani (JSW), Subhojyoti Datta (Tata Steel), Yogesh Sindhu (JSPL), Vaibhav Pokharna (AMNS), Rajib Paul (NISST), Karthik Ganesan (CEEW), R K Bhan (ISA)

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** FICCI **Knowledge Partner:** TERI

Task force: Demand Generation

Chairperson: Aruna Sharma (Former Secretary, Ministry of Steel)

Members: Ruchika Govil (AS,MoS), JS (Dept. of Expenditure, Ministry of Finance), JS/Member (PMAY, Ministry of Housing and Urban Affairs), JS (Railways/Nominee of Chairman Railway Board), Koustuv Kakati (Tata Steel), Ranjan Dhar (AMNS), Ashutosh Kumar (JSW), A. K. Singh (SAIL), Kalyan Bhattacharjee (JSL), S. Pradhan (JSPL), R. K. Goyal (Kalyani Steel), Sanjay Kumar Verma (MECON), R. Krishnamurthy (ISSDA), Anil Dhawan (ASPA), Shailendra Sharma (CPWD), Dilip Kumar Gupta (Sagarmala Development Corp. Ltd.), Atul Kumar (NHIDCL), Ranjan Bandopadhyay (JPC), Director Commercial (L&T), Rajesh Menon (SIAM), P.K. Mishra (INSDAG), Atul Gupta (EIL), R K Bhan (ISA)

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** FICCI **Knowledge Partner:** CEEW

Task force: Energy Efficiency

Chairperson: Shri Ashok K Tripathy (Independent Director, SAIL)

Members: Ruchika Govil (AS, MoS), Prof. Srinivas S (IIT Bombay), Prof. Ashish Garg (IIT Kanpur), Rajib Paul (NISST), Prof. Shabina Khanam (IIT Roorkee), Arun Kumar Agarwal (MECON), A.C.R. Das, Dr. Sharad Kumar (Tata Steel), Deependra Kashiva (SIMA), Manish Mandal (CG-SIMA), Nirvik Banerjee (SAIL), Charanjiv Singh (CNCS, Enabling Excellence), Mukesh Kumar (JSPL), Devendra Agarwal (AIIFA), Pranav Bhardwaj (ASPA), Nimish Parikh (AMNS), Vivek Agarwal (Godawari Ispat), M.K. Gupta (Starwire), V. Atul (SMS Paul Wurth), Sidhartha Patel (Danieli), Biswadeep Bhattacharjee (Primetals Technologies India), Praveen Chaturvedi (Tenova), Abhay Bakre (BEE), N.P. Padhy (MNIT Jaipur), Alok Sahay (ISA), R.K. Bhan (ISA), Anup Kashyap (ISA), Prunendu Pradhan (JSL), Sunil Kisan Khandare (Guest Member), Vivek Negi (BEE), Himashu Chaudhary (BEE), Kedar Palekar, Anirban Dasgupta (SAIL), Jagdish Arora (SAIL), Pranab Sarkar

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** CII **Knowledge Partner:** TERI

Task force: Renewable Energy Transition

Chairperson: Aniruddha Kumar (Former Additional Secretary, MNRE)

Members: Ruchika Govil (AS, MoS), Ajay Yadav (JS/Director, MNRE), Hemant Kumar Pandey (MoP), Ashvini Kumar (SECI), R.K. Goyal (Kalyani Steel), Abhishek Ambasta (SECI), Rajib Paul (NISST), Gautam Reddy (Greenko), Kajol (WRI), Atanu Mukherjee (Dastur), Sandeep Kashyap (ACME), Sachit Jain (Vardhman Steel), Kalayan Bhattacharjee (JSL), Anil Nachrani (CG, SIMA), Bimal Jindal (L&T), Shakti Sustainable Energy Foundation, K. Mukundan (National Investment and Infrastructure Fund), Devendra Agarwal (AIIFA), Pranav Bhardwaj (ASPA), Alok Sahay (Indian Steel Association), Ashok Kumar (BEE), R.K. Bhan (Indian Steel Association), Anup Kashyap (Indian Steel Association), Vatsala Joseph (Shakti Sustainable Energy Foundation), Gaurav Verma (M N Dastur), Siddarth Malik (JSP Advisory), Prasad A. Chaphekar (MNRE), Amit Kaushik (Shakti Sustainable Energy Foundation), Harish Anand (Vardhman Steel), Sanjeev Singhla (Vardhman Steel), Vishwa Bandhu, Sharad Kumar (Tata Steel), Aditya Agarwal (JSW), Aparna Pavate (Govt. of Karnataka), Sameer Mathur (AMNS)

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** CII **Knowledge Partner:** CEEW

Task force: Material Efficiency

Chairperson: Dr Anup K Pujari (Former Secretary, Ministry of Mines)

Members: Ruchika Govil (AS, MoS), P N Sharma (IBM), N N Viswanathan (IIT B), Arun Kumar Agarwal (MECON), Atanu Ranjan Pal (Tata Steel), Prabhat Kumar Ghorui (JSW), Akshay Gujral (AMNS), Damodar Mittal (JSPL), Nirvik Banerjee (SAIL), Deependra Kashiva (SIMA), Deepak Bhatnagar (PMAI), Vijay Dwivedi (PMAI), S K Biswal (ex-IMMT), Bhagyadhar Bhoi (IMMT), Jagannath Pal (NML), , Alok Sahay (Indian Steel Association), R K Bhan (Indian Steel Association), Anup Kashyap (Indian Steel Association), Satish Kohli (MRAI), Ritesh Maheshwari (MRAI), Lalit (WRI), Manish Kharbanda (PMAI), Rameshwar Sah (JSW)

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** CII **Knowledge Partner:** TERI

Task force: Green Hydrogen

Chairperson: Indu Shekhar Chaturvedi (Former Secretary, MNRE)

Members: Ruchika Govil (AS, MoS), Dr. Prasad A. Chaphekar (MNRE), A K Singh (SAIL), Naresh Lalwani (JSW), Ramanuj Narayan (CSIR-IMMT), Saurabh Kundu (TATA), Vaibhav Pokharna (AMNS), Naveen Ahlawat (JSPL), Deependra Kashiva (SIMA), Anil Nachrani (CG-SIMA), Manoranjan Ram (Danieli), Praveen Chaturvedi (Tenova), Kedar Palekar (Midrex), Biswadeep Bhattacharjee (Primetals Technologies India Pvt. Ltd), Rakesh Aulaya (Indian Hydrogen Alliance), Bimal Jindal (L&T), Dada Saheb (H2E), Gautam Reddy (Greenko), Sandeep Kashyap (ACME),, Alok Sahay (Indian Steel Association), Kajol (WRI), R K Bhan (Indian Steel Association), Anup Kashyap (Indian Steel Association), Vijay Jhanwar (CG, SIMA), Neeraj Agrawal (JSL), Siddharth Mayur (H2E), S Dipak (SMS India), Kiran Kumar Alla (Plug Power), S K Das (SAIL), Nikita Lewis (H2E), Dipesh Pherwani (MNRE)

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** CII **Knowledge Partner:** CEEW/ WRI

Task force: Carbon Capture Utilization and Storage (CCUS)

Chairperson: Dr. V.K. Saraswat (Member, NITI Aayog)

Members: Ruchika Govil (AS, MoS), Dr. S. Chandrasekhar (DST), Shaswattam (CGM, NTPC), Dr. SSV Ramakumar (IOCL), Prof. N.N. Vishwanathan (IIT Bombay), Prof. Jayant K Singh (IIT Kanpur), S K Das (SAIL), Dr. Ashish Lele (NCL, Pune), Prof. Vikram Vishal (IIT B), Dr. Anjan Ray (IIP Dehradun), Dr. Preeti Jain (Lenzatech), Atanu Mukherjee (Dastur), Naveen Ahlawat (JSPL), Vaibhav Pokharna (AMNS), Pratik Swarup Dash (TATA), Prabodha Acharya (JSW), Mr. Deependra Kashiva (SIMA), Mr. Vijay Jhanwar (CG, SIMA), Mr. Alok Sahay (ISA), Mr. Abhay Bakre (Director General, BEE), Mr. R K Bhan (ISA), Mr. Anup Kashyap (ISA), Mr. Neeraj Agrawal (JSL), Mr. Jawahar Lal (NITI Aayog), Mr. Manoj Kumar Upadhyay (NITI Aayog), Ms. Anita Gupta (DST), Siddharth R Mayur (H2E), Dr. Nivedita Panda (SMS Group), Mr. Arunava Maity (M N Dastur & Co. Pvt Ltd), Prof. Rajnish Kumar (IIT Madras), Dr. Ramakrishna Sonde (IIT Delhi), Dr.Suprotim Ganguly (M N Dastur), Prof. Shantanu Roy (IIT Delhi), Mr. Niraj Singh (Carbon Clean), Dr. Neelima Alam (DST), Mr. S Dipak (SMS Group), Prof. Arnab Dutta (IIT Bombay), Prof. S. P. Pradhan (IIT Roorkee), Dr.Bodhisatwa Hazra (CSIR-Central Institute of Mine and Fuel Research), Prof. Bankim C. Mahanta (IIT Bhubaneswar), Dr. Ajay Kumar Singh (PMRC), Mr. Gaurav K Mishra (ONGC), Mr. Baroruchi Mishra (Shell India), Ms. Amrita Ghosh (Geological Survey of India, Pune), Mr. Rohit Kumar (CMA), Shri Biswadeep Bhattacharjee (Vice President Sales & Head of Green Steel India), AK Jha (Carbfix)

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** CII **Knowledge Partner:** CEEW

Task force: Process Transition from coal based to gas based DRI

Chairperson: Indranil Chattoraj (Former Director, NML)

Members: Ruchika Govil (AS, MoS), Mr. Peeyush (M/o Coal), Mr. Anand Jha (MoPNG), JS (M/o New and Renewable Energy), Dr. Dipak Mazumdar (IIT Kanpur), Prof. Viswanathan N Nurni (IIT Bombay), Prof. Shabina Khanam (IIT Roorkee), Prof. G G Roy (IIT Kharagpur), Dr. Mukesh Kumar (JSPL), Baiju Masrani (AMNS), Dr. Dhiren Kumar Panda (JSW), Saurabh Kundu (TATA), Mr. Atanu Mukherjee (M N Dastur & Co. Pvt Ltd), Rajib Paul (NISST), Charanjiv Singh (Enabling Excellence), Deependra Kashiva (SIMA), Vijay Jhanwar (SIMA, Chattisgarh), Mr. Alok Sahay (Indian Steel Association), Mr. R K Bhan (Indian Steel Association), Mr. Anup Kashyap (Indian Steel Association), Mr. Saptarshi Bhattacharya (M N Dastur & Co. Pvt Ltd), Mr. Arunava Maity (M N Dastur & Co. Pvt Ltd), Mr. Shankarlal Agarwal, Mr. Baiju Masrani (AM/NS India - Operations (Hazira)), RAMAKRISHNA.

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** CII **Knowledge Partner:** CEEW

Task force: Research, Demonstration and Development (RD&D)

Chairperson: Dr. Parvinder Maini (Scientific Secretary of Principle Scientific Advisor to PM)

Members: Ruchika Govil (AS, MoS), Dr. Raghunath Reddy (Scientist F, Dept of Science and Technology), Prof. Abhay Karandikar (Director, IIT Kanpur), Prof. Dipak Mazumdar (IIT Kanpur), Prof. Viswanathan N Nurni (IIT Bombay), Prof. Gaur Gopal Roy (IIT Kharagpur), Dr. Dhiren Panda (JSW), Pratik Swarup Dash (TATA Steel), Dr. Rajib Paul (NISST), Dr. Mukesh Kumar (JSPL), Sirshendu Chattopadhyay (AMNS), Dinesh Likhi (CMD MIDHANI (Retd.)), Prof. Digavalli Ravi Kumar (Dept. of Mechanical Engineering, IIT Delhi)

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** FICCI **Knowledge Partner:** CEEW

Task force: Finance

Chairperson: Sunil Mehta (Chief Executive, Indian Bank Association)

Members: Ruchika Govil (AS, MoS), JS (Ministry of Finance, nominated Pushpendra Singh), Ateesh Kumar Singh (JS-AFI, MSME), Abhay Bakre (BEE), Chetan Jansari (AMNS), Ananya Maitra (AMNS), Mukundan K (NIIF), Anil Chaudhary (Essar Steel), Pradeep Tharakan (ADB, nominee Abhinav Sultania), Abhishek Kumar (HDFC), Mudit Jain (Tata Cleantech Capital Ltd.), Surbhi Goyal (World Bank), Dibirath Sen (HSBC), Dr. Mukund Rajan (ECube Investment Advisors Pvt. Ltd.), S.S. Acharya (SIDBI), Shailesh Haribhakti (Haribhakti& Co. Ltd.), Dr. Rajib Paul (NISST), Ashok Kr. Sharma (SBI), Sameer Shahapurkar (Axis Bank), Ms. Vineeta Kanwal (Bureau of Energy Efficiency), Mr. Kapil Arora (Jindal Stainless Limited), R R Rashmi, Brij Mohan, Mr. V Chandrasekar (retd. CGM of SBI)

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** FICCI **Knowledge Partner:** TERI

Task force: International Focus

Chairperson: Ajay Bisaria (Former Indian High Commissioner of India to Pakistan)

Members: Ruchika Govil (AS, MoS), JS (MoEF&CC, nominated Sharath Kumar Pallerla), JS (Ministry of External Affairs, nominated Siddharth Mallik), Prof. Viswanathan N Nurni (IIT Bombay), Dr. Snighda Ghosh (IIT Bhubaneswar), Prabodha Acharya (JSW), V. R. Sharma (JSPL), Rajiv Mangal (TATA), Raghavan A (AMNS), R K Goyal (Kalyani Steel), AK Chaudhary (Essar Steel), Abhishek Sinha (SAIL), Jagdish Arora (SAIL)

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** FICCI **Knowledge Partner:** TERI

Task force: Skill Development

Chairperson: Smt. Sunita Sanghi (Former Principal Adviser, Ministry of Skill Development & Entrepreneurship)

Members: Ruchika Govil (AS, MoS), Prof. Viswanathan N Nurni (IIT Bombay), Pritam Purkayastha (BPNSI), Dr. Rajib Paul (NISST), SK Das (SAIL), Anil Dhawan (ASPA), Anil Mattoo (AMNS), Prosanto Pal (TERI), Deependra Kashiva (SIMA), Devendra Agarwal (AIIFA), Koustuv Kakati (TATA Steel, represented by Ms. Aparajita Agarwal, Vaibhav Pokharna (AMNS), Mr. Ashok Sharma (Jindal Stainless), Prabodha Acharya (JSW), Swaroop Banerjee (JSW), R Bhan (ISA), Sushim Banerjee, Ms. Swapna Bhattacharya, Vijay Jhanwar (Vraj Metaliks Pvt Ltd)

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** FICCI **Knowledge Partner:** TERI

Task force: Biochar

Chairperson: Sanak Mishra (Former President of the Indian National Academy of Engineering)

Members: Ruchika Govil (AS, MoS), Ministry of Power, M/o PNG, DST, TJ Purkayastha (ICAR), Director (IMMT - Bhubaneswar), Prof. G G Roy (IIT Kharagpur), Prof. Shatrughen Soren (IIT (ISM) Dhanbad), Nirvik Banerjee (SAIL), Mukesh Kumar (JSPL), Vaibhav Pokharna (AMNS), Pratik Swarup Dash (TATA Steel), Prabodh Acharya (JSW), Deependra Kashiva (SIMA), Vijay Jhanwar (CG SIMA), Krunal Jagtap (HAB Biomass), Prateek Khanna (Solfinder Research), Pawan Mehndiratta (Thermax), Sanjeev Shanhikant Karpe (KONBAC), Amit Garg, (IIM Ahmedabad)

Coordinator: Neha Verma (Dir,MoS) **Member Secy:** FICCI **Knowledge Partner:** TERI

Annexure-2

Green jobs emerging in the renewable energy sectors

	Large	MSMEs	Rural	Urban	National	JV /MNC	
Geothermal	✓	✓	✓	✗	✓	✗	Mechanical/ Geothermal engineer Electrician
Big hydro	✓	✗	✓	✗	✓	✗	Civil/Hydro engineer/ Electrician
Micro-hydro	✓	✓	✓	✗	✓	✗	Civil/Hydro engineer Electrician
Solar	✓	✓	✗	✓	✓	✗	Electrical /Mechanical engineer/Software/Solar engineer Electrician
Wind power	✓	✓	✗	✓	✓	✓	Mechanical /Civil/ Structural/ Wind turbine engineer Electrician
Biogas/ biofuels	✓	✓	✓	✓	✓	✗	Civil/Mechanical/ Chemical / Instrumentation & Control/ Biogas engineer
Municipal waste	✓	✓	✗	✓	✓	✗	Environmental/ Chemical/ Biochemical/ Mechanical/ Waste management engineer

Annexure-3

Green jobs emerging in the environmental services sector

Sector	Company scale		Location		Ownership		New occupation
	Large	SMEs	Rural	Urban	National	JV/MNC	
Environmental impact assessment	✓	✓	✗	✓	✓	✗	Civil/Chemical/ Mechanical /Environmental engineering
Recycle	✓	✓	✗	✓	✓	✓	Solid Waste Management Recycle officer and engineer for large scale operation
Environmental management (ISO 14000)	✓	✓	✗	✓	✓	✓	Civil/Chemical/ Mechanical/ Environmental engineering ISO 14000 expert
Waste management	✓	✓	✓	✓	✓	✓	Environment engineering/ Waste management expert
Environmental lab	✓	✓	✓	✓	✓	✓	Physicists / Biologist/ Engineer / Chemist
Environmental quality monitoring	✓	✓	✗	✓	✓	✓	Environmental expert
Maintenance	✓	✓	✗	✓	✓	✗	Environmental officer Instrumentation engineers Electricians
Environmental training and education	✓	✓	✗	✓	✓	✗	Educator, Psychologist, faculty with environment experience
Carbon consultants	✓	✓	✗	✓	✓	✓	Carbon accounting expert Financial analyst for carbon projects

Annexure-4

Mapping of green jobs and greening of jobs in steel industry

Green technologies for improving energy efficiency	Greening of jobs		
	Material procurement	**Plant production**	**O&M staff**
BF process optimization	None	New skilling required for control room operators	None
Waste heat recovery system (WHRS) Top gas pressure recovery turbine (TGT)	Training on new spares required	R&D team, Skilling of control room operators	Skilling of electrical & mechanical maintenance staff
Energy efficient variable speed drives	Training on new spares required	Skilling of engineers, control room operators	Skilling of electrical maintenance staff
Technologies for use of alternative fuels and raw material			
Pulverized coal injection in blast furnace (PCI)	Stores and procurement staff to understand the new spares required.	Skilling of process engineers, control room operators	Skilling of O&M staff of coal mills
Use of natural gas	--	Skilling of process engineers, control room operators	Skilling of O&M staff of gas storage and use areas
Biomass based charcoal	Skilling of procurement and storage people for charcoal	Skilling of process engineers, control room operators	Skilling of O&M staff operating the charcoal firing
Oxygen injection	Skilling on procurement & storage of oxygen	Skilling of process engineers, control room operators	Skilling of O&M staff on the oxygen plant
Hydrogen as reducing agent	Skilling on procurement and storage of hydrogen	Skilling of process engineers, control room operators	Skilling of O&M staff on hydrogen storage
Waste plastics	Skilling on procurement and storage	Skilling of process engineers, control room operators	Skilling of O&M staff on trouble shooting

Annexure-5

Incremental Manpower Demand in production of steel, rerolling and DRI: FY23 to FY34

Projected Year	Projected Capacity in Year, MT	Incremental Capacity MT	BF BOF	EAF	IF	Re-Rolling	DRI	Incremental Manpower
2022-23	161	7	6,300	315	2,450	11,149	1,818	22,032
2023-24	171	10	8,694	435	3,381	10,469	1,981	24,960
2024-25	181	10	9,216	461	3,584	11,149	1,818	26,227
2025-26	192	11	9,769	488	3,799	11,874	1,981	27,911
2026-27	203	12	10,355	518	4,027	12,646	2,160	29,705
2027-28	215	12	10,976	549	4,268	13,468	2,354	31,615
2028-29	228	13	11,635	582	4,525	14,343	2,566	33,650
2029-30	242	14	12,333	617	4,796	15,276	2,797	35,818
2030-31	257	15	13,073	654	5,084	16,269	3,049	38,128
2031-32	272	15	13,857	693	5,389	17,342	3,323	40,604
2032-33	288	16	14,688	734	5,712	18,243	3,495	42,873
2033-34	306	17	15,570	778	6,055	19,123	3,654	45,180
Total incremental Manpower required	-	-	**1,36,463**	**6823**	**53,069**	**1,71,351**	**30996**	**3,98,703**

NSP 2017: *BF BOF 60%, EAF: 15% and IF: 25%.*

Source: *NISST, JPC & IISSSC*

Annexure-6

Current Manpower requirement for steel production, related industries and fresh trainings required in 10 years

Current Manpower requirement for steel production

Process Route	Current Technical Manpower/MT	Working capacity MT: Fy 22	Consolidated Manpower	Estimated technical Manpower/MT: Fy34
BF BOF	3,500	67.3	2,35,550	1,500
EAF	400	36.6	14,640	300
IF	2,000	57.4	1,14,800	1,400
DRI	700	54.8	38,360	500
Rerolling	3,000	93.4	2,80,200	2,500
Total			**6,83,550**	

Source: *NISST, JPC & IISSSC*

Current manpower engaged in steel related industries

Category	Consolidated Manpower
Steel Production & Rerolling	6,83,550
Foundry	5,00,000
Ferro Alloys	6,250
Requirement of Trades (Welder, fitter, Machinist etc).for overseas skilled jobs	1,50,000
Total	**13,39,800**

Source: *NISST & IISSSC*

Fresh Training required for 2023-34 (Same as the anticipated manpower requirement in iron and steel sector)

Areas	Numbers
Crude steel production& Rerolling	3,98,703
Foundry	5,00,000
Ferro Alloys	12,875
Overseas	1,50,000
Total	**10,61,578**

Source: *NISST & IISSSC*

50% needed to undergo skill upgradation & Reskilling

Areas	Numbers
Crude steel production& Rerolling	6,83,550
Foundry	5,00,000
Ferro Alloys	12,875
Overseas	1,50,000
Total	13,46,425
50% for upskilling and Reskilling	6,73,213

Annexure-7

Lab Set-up costing

S.no.	Name of Qualification	NSQC Code	NSQF Code	Total Amount (in Lakhs)
1	Asst. Electrician	ISC/Q1001	3	1,50,000
2	Asst. Fitter: Levelling, Alignment & Balancing	ISC/Q0905	3	1,50,000
3	Welder (GTAW)	ISC/Q0911	4	3,00,000
4	Assistant- Machinist – Iron and Steel	ISC/Q0909	3	9,00,000
5	Assistant Electronic Mechanic	ISC/Q1101	3	1,50,000
6	Asst. Mechanic – Bearing Maintenance	ISC/Q0906	3	70,000
7	Housekeeper – Mechanised Equipment	ISC/Q0408	2	4,00,000

***The total cost of the centre will also depend on the infrastructure, faculty, administration, number of classrooms, counselling rooms, A.C, washrooms, Passage area, CCTV camera and many more*

*** Approximate set up cost of a Training Centre to run 7 of the above Courses with all other Infra cost would be approx.Rs.45 lakhs.*

Source: *NISST & IISSSC*

REFERENCES

Chapter 1

1 MoEFCC. 2022. India's long-term low-carbon development strategy. Available at: https://unfccc.int/sites/default/files/NDC/2022-08/India%20Updated%20First%20Nationally%20Determined%20Contrib.pdf

2 MoEFCC. 2023. India Third National Communication and Initial Adaptation Communication. Available at: https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1987752

3 PIB. 2022. India's Stand at COP-26. Available at: https://pib.gov.in/PressReleasePage.aspx?PRID=1795071

All data on domestic production and capacity, unless mentioned otherwise are obtained from Joint Plant Committee. In addition, all figures for FY 2024 are provisional.

4 World Steel Association. 2024.World steel in Figures. Available at: https://worldsteel.org/wp-content/uploads/World-Steel-in-Figures-2024.pdf

5 ibid

6 Joint Plant Committee. 2023. The Indian Iron and Steel Database. Available at:https://jpcindiansteel.nic.in/pages/display/148-jpc-publications

7 Parmionova Strengthening Sustainability in the Steel Industry. Sector Background. Available at: https://issuu.com/parmionova/docs/strengthening_sustainability_in_the_steel_industry/s/28523683

8 Joint Plant Committee. 2023. The Indian Iron and Steel Database. Available at:https://jpcindiansteel.nic.in/pages/display/148-jpc-publications

9 Out of total resources of iron ore (haematite), about 6,209 million tonnes (26%) fall under 'reserves' category and the balance about 17,849 million tonnes (74%) under 'remaining resources' category. National Mineral Inventory 2020. Metallic Minerals (Ferrous Group) Chapter 2. Available at https://ibm.gov.in/writereaddata/files/1696338854651c13a6a0f16Chapter2.pdf

10 BHP 2023. Commodity Fact Sheets-Iron Ore. Accessed on 27nd February 2024. Available at https://www.bhp.com/-/media/documents/business/2019/191119_whatisironore.pdf

11 Joint Plant Committee. 2023. The Indian Iron and Steel Database. Available at:https://jpcindiansteel.nic.in/pages/display/148-jpc-publications

12 PIB. 2019. Steel Scrap Recycling Policy issued. https://pib.gov.in/newsite/PrintRelease.aspx?relid=19435910 BHP 2023. Commodity Fact Sheets-Iron Ore. Accessed on 27nd February 2024. Available at https://www.bhp.com/-/media/documents/business/2019/191119_whatisironore.pdf

13 Ministry of Road Transport and Highway. 2021. Motor Vehicles (Registration and Functions of Vehicle Scrapping Facility) Rules. Available at: https://morth.nic.in/sites/default/files/notifications_document/RVSF%20Notification.pdf

14 Joint Plant Committee. 2023. The Indian Iron and Steel Database. Available at:https://jpcindiansteel.nic.in/pages/display/148-jpc-publications

15 Joint Plant Committee. 2023. The Indian Iron and Steel Database. Available at:https://jpcindiansteel.nic.in/pages/display/148-jpc-publications

16 Joint Plant Committee. 2023. The Indian Iron and Steel Database. Available at:https://jpcindiansteel.nic.in/pages/display/148-jpc-publications

17 Joint Plant Committee. 2023. The Indian Iron and Steel Database. Available at:https://jpcindiansteel.nic.

in/pages/display/148-jpc-publications

18 SIMA 2023. Dilemma of Indian DRI Industry, Available at: http://www.spongeironindia.com/images/publications/May-2023.pdf

19 ESA 2023. EUROPEAN STEEL IN FIGURES 2023, Available at: https://www.eurofer.eu/assets/publications/brochures-booklets-and-factsheets/european-steel-in-figures-2023/FINAL_EUROFER_Steel-in-Figures_2023.pdf

20 WSA 2023, 2023 PRESS RELEASE – December 2023 crude steel production and 2023 global crude steel production totals, Available at https://worldsteel.org/wp-content/uploads/December-2023-crude steel-production-and-2023-global-crude-steel-production-totals-1.pdf

21 ibid

22 WSA 2024, 2024 World Steel in Figures, Available at: https://worldsteel.org/wp-content/uploads/World-Steel-in-Figures-2023-4.pdf

23 WSA 2024, 2024 World Steel in Figures, Available at: https://worldsteel.org/wp-content/uploads/World-Steel-in-Figures-2023-4.pdf

24 Steelmint. 2023. Scrap consumption in steelmaking by country in 2022.

25 IEA. Emissions Measurement and Data Collection for a Net Zero Steel Industry. Available at: https://www.iea.org/reports/emissions-measurement-and-data-collection-for-a-net-zero-steel-industry/executive-summary

26 Experience I. Nduagu , Deepak Yadav , Nishant Bhardwaj , Sabarish Elango , Tirtha Biswas , Rangan Banerjee , Srinivasan Rajagopalan. Comparative life cycle assessment of natural gas and coal-based directly reduced iron (DRI) production: A case study for India. Available at : https://www.sciencedirect.com/science/article/pii/S0959652622008277?

27 Somers, J., Technologies to decarbonise the EU steel industry, Publications Office of the EuropeanUnion, Luxembourg, 2021, ISBN 978-92-76-47147-9 (online), doi:10.2760/069150 (online), JRC127468

28 Ankur Malyan and Vaibhav Chaturvedi CEEW 2021. The Carbon Space Implications of Net Negative Targets. Available at: https://www.ceew.in/sites/default/files/ceew-study-on-how-negative-emissions-targets-impact-global-carbon-budget-space.pdf

29 EWSA. 2023. Indicators. Available at: https://worldsteel.org/steel-topics/sustainability/sustainability-indicators-2023-report/

30 OECD.2024. Latest developments in steelmaking capacity and outlook until 2026 Available at: https://one.oecd.org/document/DSTI/SC(2024)3/FINAL/en/pdf#:~:text=According%20to%20the%20Secretariat's%20latest,demand%20by%20almost%20500%20mmt.

31 WSA. 2024. Available at: https://worldsteel.org/data/wp-content/uploads/World-Steel-in-Figures-2024.pdf

32 Joint Plant Committee. 2023. The Indian Iron and Steel Database. Available at:https://jpcindiansteel.nic.in/pages/display/148-jpc-publications

33 PIB. 2022. India's Stand at COP-26. Available at: https://pib.gov.in/PressReleasePage.aspx?PRID=1795071

34 ibid

35 Srinivas S N, Sanghani M, Mukherjee A, Kumar S S, and Shanmuganathan K. 2017.Energy-efficient technologies driving India's secondary steel production New Delhi: United Nations Development Programme.

36 ibid

37 Ministry of New and Renewable Energy 2024. Solar Overview. Available at: https://mnre.gov.in/solar-overview/

38 Ministry of New and Renewable Energy 2024. Potential of Wind Energy in India. Available at:https://mnre.gov.in/wind-overview/

39 MoNRE 2023.Physical Achievements Programme Scheme wise Cumulative Physical Progress as on December, 2023. Available at: https://mnre.gov.in/physical-progress/

40 PIB. 2023. MoNRE. Renewable energy capacity has increased from ~ 76 GW in March 2014 to ~ 179 GW in October 2023; solar power capacity has become 25.5 times during the same period: Union Power and New & Renewable Energy Minister Available at: https://pib.gov.in/PressReleaseIframePage aspx?PRID=1983810

41 CERC. 2003. The Electricity Act. Available at: https://cercind.gov.in/Act-with-amendment.pdf

42 CEA. 2005. National Electricity Policy. Available at: https://cea.nic.in/wp-content/uploads/legal_affairs/2020/09/National%20Electricity%20Policy%20(1).pdf

43 CEA. 2006. Tariff Policy. Available at: https://cea.nic.in/wp-content/uploads/legal_affairs/2020/09/Tariff%20policy.pdf

44 CEA. 2016. Tariff Policy. Available at: https://cercind.gov.in/2018/whatsnew/Tariff_Policy-Resolution_Dated_28012016.pdf

45 MinistryofPower.2022. RenewablePurchaseObligation(RPO)andEnergyStorageObligation(ESO)Trajectory till 2029-30 regarding. Available at: https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/08/2023082875180908.pdf

46 NEDO. 2024. Available at :https://www.nedo.go.jp/english/index.html

47 Ministry of Steel. 2017. National Steel Policy. Available at: https://steel.gov.in/sites/default/files/draft-national-steel-policy-2017.pdf

48 SMinistry of Steel. 2017. "Policy for providing preference to domestically manufactured Iron & steel products in government procurement". Available at: https://steel.gov.in/sites/default/files/steel_policy2_eng.pdf

49 Ministry of Steel. 2019. Steel Scrap Recycling Policy. Available at: https://steel.gov.in/sites/default/files/Steel%20Scrap%20Recycling%20Policy%2006.11.2019.pdf

50 Ministry of Road Transport and Highway. 2021. Motor Vehicles (Registration and Functions of Vehicle Scrapping Facility) Rules. Available at: https://morth.nic.in/sites/default/files/notifications_document/RVSF%20Notification.pdf

51 Ministry of Power. 2021. National Mission on use of Biomass in Thermal Power Plants. Available at: https://samarth.powermin.gov.in/content/policies/80e5db53-014e-4dbf-ad85-a9d0ce9b654a.pdf

52 PIB. 2023.Ministry of Power. CO-FIRING BIOMASS PELLETS IN THERMAL POWER PLANTS – Study establishes 5-10% biomass can be safely co-fired with Coal without adverse impact on the power plant – Union Power & NRE Shri R. K. Singh. Available at: https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1907726

53 Ministry of Environment, Forest and Climate Change. 2021. Lifestyle for Environment (LiFE). Available at: https://www.niti.gov.in/sites/default/files/2022-10/Brochure-10-pages-op-2-print-file-20102022.pdf

54 PIB. 2022.MoEFCC, Mission LiFE – Lifestyle for Environment Available at: https://static.pib.gov.in/WriteReadData/specificdocs/documents/2022/nov/doc2022119122601.pdf

55 Ministry of New and Renewable Energy. 2023. National Green Hydrogen Mission

Chapter 2

1 Worldsteel. 2024. Climate Action Data Collection https://worldsteel.org/climate-action/climate-action-data-collection/#:~:text=In%202008%2C%20Climate%20Action%20Data,which%20it%20can%20compare%20itself

2 Responsiblesteel. 2022. Responsible Sourcing Requirements for 'ResponsibleSteel Certified steel'. Available at:https://www.responsiblesteel.org/wp-content/uploads/2022/07/ResponsibleSteel_additional_requirements_responsible_sourcing_and_GHG.pdf

3 ArcelorMittal. 2022. ArcelorMittal publishes concept for global low-carbon emissions physical steel standard. Available at: https://corporate.arcelormittal.com/media/news-articles/arcelormittal-publishes-concept-for-global-low-carbon-emissions-physical-steel-standard

4 Pei et al. 2020. Toward a Fossil Free Future with HYBRIT: Development of Iron and Steelmaking Technology in Sweden and Finland. Available at:https://www.mdpi.com/2075-4701/10/7/972/htm

5 Clean Energy Ministerial. Industrial Deep Decarbonisation Initiative IDDI) summary of progress and outlook. Accessed on 24th August 2023. Available at: https://www.cleanenergyministerial.org/initiatives-campaigns/industrial-deep-decarbonisation-initiative/

6 First Movers Coalition. Steel commitment. Available at: https://www3.weforum.org/docs/WEF_FMC_Steel_2022.pdf

7 GSCC. The Steel Climate Standard. Available at: https://globalsteelclimatecouncil.org/the-standard/

8 Kloeckner & Co. Green steel FAQ and glossary. Available at:https://www.kloecknermetals.com/products-services/green-steel/

9 STEELZERO. 2023. India net zero steel demand outlook report. Available at: https://www.theclimategroup.org/sites/default/files/2023-02/India%20Net%20Zero%20Steel%20Demand%20Outlook%20Report.pdf

10 World Steel Association.2022. Blog: What we mean when we talk about low-carbon steel. Available at:https://worldsteel.org/media-centre/blog/2021/blog-low-carbon-steel-meaning/

11 Experience I. Nduagu, Deepak Yadav, Nishant Bhardwaj, Sabarish Elango,Tirtha Biswas, Rangan Banerjee, Srinivasan Rajagopalan. 2022. Comparative Life Cycle Assessment of Natural Gas and Coal-Based Directly Reduced Iron (DRI) Production: A Case Study for India. Journal of Cleaner Production. 131196. https://doi.org/10.1016/j.jclepro.2022.131196

Chapter 3

1 World Steel Association. 2022.CO2 data collection user guide (version 11). Available at https://worldsteel.org/wp-content/uploads/CO2_User_Guide_V11.pdf

2 World Steel Association. 2017.LIFE CYCLE INVENTORY METHODOLOGY REPORT. Available at https://worldsteel.org/wp-content/uploads/Life-cycle-inventory-methodology-report.pdf

3 ISO. 2020. ISO 14404-4:2020. Available at https://www.iso.org/standard/77622.html

4 ISO. 2018. ISO 20915:2018. Available at https://www.iso.org/standard/69447.html

5 Responsible steel. 2022. ResponsibleSteel International Standard. Available at https://www.responsiblesteel.org/wp-content/uploads/2022/09/ResponsibleSteel-Standard-2.0.pdf

6 IEA. 2023. Emissions Measurement and Data Collection for a Net Zero Steel Industry, Available at https://iea.blob.core.windows.net/assets/8f6568aa-1dd8-4578-bc61-24ceba4a07ddEmissionsMeasurementandDataCollectionforaNetZeroSteelIndustry.pdf

7 IEA. 2023. Emissions Measurement and Data Collection for a Net Zero Steel Industry, Available at https://iea.blob.core.windows.net/assets/8f6568aa-1dd8-4578-bc61-24ceba4a07dd/EmissionsMeasurementandDataCollectionforaNetZeroSteelIndustry.pdf

Chapter 4

1 Elango, Sabarish, Kartheek Nitturu, Deepak Yadav, Pratheek Sripathy, Rishabh Patidar, and Hemant Mallya. 2023. Evaluating Net-zero for the Indian Steel Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies. New Delhi: Council on Energy, Environment and Water. Available at: https://www.ceew.in/sites/default/files/How-Can-India-Decarbonise-For-Net-Zero-Sustainable-Steel-Production-Industry.pdf

2 World Economic Forum. 2022. Green Public Procurement: Catalysing the Net-Zero Economy. Available at: https://www3.weforum.org/docs/WEF_Green_Public_Procurement_2022.pdf

3 Directorate-General for Environment (European Commission). 2016. A handbook on green public procurement. Available at: https://op.europa.eu/en/publication-detail/-/publication/8c2da441-f63c-11e5-8529-01aa75ed71a1/language-en

4 Greenly. An Overview of EU Green Public Procurement (GPP). Available at: https://greenly.earth/en-gb/blog/company-guide/an-overview-of-eu-green-public-procurement-gpp

5 Netcompany.n.d. What Is DuboCalc?. Available at: https://www.dubocalc.nl/en/what-is-dubocalc/

6 Dutch Public Procurement Expertise Centre.Sustainable Public Procurement (SPP). Available at: https://www.pianoo.nl/en/public-procurement-in-the-netherlands/sustainable-public-procurement-spp

7 National Plan on Sustainable Public Procurement for 2021-2025. Commissioning with ambition, procuring with impact. Available at: https://www.government.nl/documents/publications/2021/01/29/commissioning-with-ambition-procuring-with-impact

8 German Environment Agency. Green Public Procurement eco-friendly and cost-saving. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/180802_uba_fl_umweltfreundloeffentlbeschaffung_en_bf.pdf

9 ibid

10 Stockholm Environment Institute 2022. Decarbonizing the EU's road and construction sectors through green public procurement. Available at: https://www.sei.org/wp-content/uploads/2022/10/gpp-france-germany-sei2022.044.pdf

11 The White house 2023. Biden-Harris Administration Announces Plan to Maximize Purchases of Sustainable Products and Services as Part of the President's Investing in America Agenda. Available at: https://www.whitehouse.gov/ceq/news-updates/2023/08/01/biden-harris-administration-announces-plan-to-maximize-purchases-of-sustainable-products-and-services-as-part-of-the-presidents-investing-in-america-agenda/

12 The White House 2022. Biden-Harris Administration Announces Plan to Maximize Purchases of Sustainable Products and Services as Part of the President's Investing in America Agenda. Available at: https://www.whitehouse.gov/briefing-room/statements-releases/2022/09/15/fact-sheet-biden-harris-administration-announces-new-buy-clean-actions-to-ensure-american-manufacturing-leads-in-the-21st-century/

13 Office of the Federal Chief Sustainability Officer. 2023. Federal Buy Clean Initiative. Available at: https://www.sustainability.gov/buyclean/

14 California Legislative Information,2017. Buy Clean California Act. Available at: https://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?division=2.&chapter=3.&part=1.&lawCode=PCC&article=5.

15 Department of General Services 2024. Buy Clean California Act. Available at: https://www.dgs.ca.gov/PD/Resources/Page-Content/Procurement-Division-Resources-List-Folder/Buy-Clean-California-Act

16 US Congress.1992.Energy Policy Act of 1992. Available at: https://www.congress.gov/bill/102nd-congress/house-bill/776

17 ENERGY STAR.n.d.ENERGY STAR Focus on Energy Efficiency in Iron and Steel Manufacturing. Available at: https://www.energystar.gov/industrial_plants/measure-track-and-benchmark/energy-star-energy-5

18 Resources for the Future.2020.Green Public Procurement for Natural Gas, Cement and Steel. Available at: https://media.rff.org/documents/RFF_WP_20-17_Green_Public_Procurement_for_Natural_Gas_Cement_and_Steel.pdf

19 ENERGY STAR Energy Performance Indicators for plants. Available at: https://www.energystar.gov/industrial_plants/measure-track-and-benchmark/energy-star-energy

20 US Congress.2022.CLEAN Future Act. Available at: https://www.congress.gov/bill/117th-congress/house-bill/1512#:~:text=The%20bill%20establishes%20an%20interim,plan%20to%20achieve%20the%20goals

21 Comitte on Energy and Commerce 2021. The Climate Leadership and Environmental Action for our Nation's (CLEAN) Future Act.Available at: https://tonko.house.gov/uploadedfiles/clean_future_act_one-pager_final.pdf

22 USDOE.Investing in America. Available at: https://www.energy.gov/articles/biden-harris-administration-announces-100-million-transform-climate-pollution-sustainable

23 Government of Canada,2022.Green procurement. Available at: https://www.canada.ca/en/treasury-board-secretariat/services/innovation/greening-government/green-procurement.html

24 OEC.2014.Going green: best practices for green procurement - CHINA. Available at: https://www.oecd.org/governance/procurement/toolbox/search/china-best-practices-green-public-procurement-gpp-environmental-standards.pdf

25 UNFCC.n.d.Green Credit Card I Republic of Korea. Available at: https://cop23.unfccc.int/climate-action/momentum-for-change/ict-solutions/green-credit-card-i-republic-of-korea

26 Government of Japan.2016.Introduction to Green Purchasing Legislation in Japan. Available at: https://www.env.go.jp/policy/hozen/green/kokusai_platform/2015report/handbook_eng.pdf

27 UNIDO 2023.Industrial Deep Decarbonisation Initiative. Available at: https://www.unido.org/IDDI

28 UNIDO 2023. IDDI GREEN PUBLIC PROCUREMENT PLEDGE ANNOUNCEMENT Available at: https://www.industrialenergyaccelerator.org/wp-content/uploads/IDDI-GPP-Pledge-Announcement_5-December-2023.pdf

29 The White house. 2021. The United States and European Union To Negotiate World's First Carbon-Based Sectoral Arrangement on Steel and Aluminium Trade. Available at: https://www.whitehouse.gov/briefing-room/statements-releases/2021/10/31/fact-sheet-the-united-states-and-european-union-to-negotiate-worlds-first-carbon-based-sectoral-arrangement-on-steel-and-aluminum-trade/

30 Climate Group. 2023. Building demand for net zero steel. Available at: https://www.theclimategroup.org/steelzero

31 First Movers Coalition. n.d. Members. Available at: https://initiatives.weforum.org/first-movers-coalition/community

32 H2 Green Steel. Powering a new, clean industrial revolution. Available at: https://www.h2greensteel.com/

33 H2 Green Steel. H2 green steel has pre-sold over 1.5 million tonnes of green steel to customers Available at : https://www.h2greensteel.com/latestnews/h2-green-steel-has-pre-sold-over-15-million-tonnes-of-green-steel-to-customers

34 OECD 2014. SMART PROCUREMENT Going green: best practices for green procurement - INDIA Available at: https://www.oecd.org/governance/procurement/toolbox/search/india-best-practices-green-public-procurement-gpp-market-capacity-cost-benefit-assessment.pdf

35 MoP 2017. A Note LED Programme Available at: http://ujala.gov.in/documents/about-ujala.pdf

36 EESL. n.d. Home-Energy Efficiency Services. Available at: https://eeslindia.org/en/

37 Lodhagroup2023. Net - Zero Roadmap. Available at: https://www.lodhagroup.in/sustainability/

38 JLL 2022. Transition to net-zero. Available at: https://www.jll.co.in/content/dam/jll-com/documents/pdf/research/jll-research-sustainability-transition-to-net-zero.pdf

39 ABB 2023. Enabling a low-carbon society. Available at: https://global.abb/group/en/sustainability/low-carbon

40 Cummins 2024. PLANET 2050. Available at: https://www.cummins.com/company/esg/environment/destination-zero

41 Climate Group SteelZero 2023. India Net Zero Steel Demand Outlook Report Available at: http://www.indiaenvironmentportal.org.in/files/file/India%20Net%20Zero%20Steel%20Demand%20Outlook%20Report.pdf

42 Ministry of Steel,2022. Annual Report 2022-23. Available at: https://steel.gov.in/sites/default/files/MoS%20AR%202022-23.pdf

43 Ministry of Steel. 2017. National Steel Policy. Available at: https://steel.gov.in/sites/default/files/draft-national-steel-policy-2017.pdf

44 JPC.2023. Annual Statistics 2022-23.Available at https://jpcindiansteel.nic.in/pages/display/149-jpc-statistical-reports

45 IMF. 2023. India Can Balance Curbing Emissions and Economic Growth. Available at: https://www.imf.org/en/Countries/IND

46 IBEF. 2023. Infrastructure Sector in India. Available at: https://www.ibef.org/industry/infrastructure-sector-india

47 IMF 2023. World Economic Outlook database: April 2023. Available at: https://www.imf.org/en/Publications/WEO/weo-database/2023/April/weo-report?c=534,&s=NGDP_RPCH,NGDPD,PPPGDP,PCPIPCH,TM_RPCH,TX_RPCH,GGXCNL_NGDP,GGXWDG_NGDP,BCA_NGDPD,&sy=2001&ey=2024&ssm=0&scsm=1&scc=0&ssd=1&ssc=0&sic=0&sort=country&ds=.&br=1

48 ibid.

49 IMF. 2023. India Can Balance Curbing Emissions and Economic Growth. Available at: https://www.imf.org/en/Countries/IND

50 Budget 2022: how the capex push through infrastructure is likely to play out. Available at: https://www.businesstoday.in/union-budget-2022/opinion/story/budget-2022-how-the-capex-push-through-infrastructure-is-likely-to-play-out-321654-2022-02-06

51 ibid

52 Gadkari writes to PM over steel price hike, says projects becoming unviable. Available at: https://www.hindustantimes.com/business-news/gadkari-writes-to-pm-over-steel-price-hike-says-projects-becoming-unviable/story-f2MrrjSujJLIhDwibgyMrI.html

53 IBEF. Infrastructure Sector in India. Available at: https://www.ibef.org/industry/infrastructure-sector-india

54 MoS 2019. Monthly Summary for the Cabinet for the month of March, 2019. Available at : https://steel.gov.in/sites/default/files/March%202019.pdf

55 Elango.2023. Evaluating Net-zero for the Indian Steel Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies. Available at: https://www.ceew.in/sites/default/files/How-Can-India-Decarbonise-For-Net-Zero-Sustainable-Steel-Production-Industry.pdf

56 ibid

57 Elango.2023. Evaluating Net-zero for the Indian Steel Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies. Available at: https://www.ceew.in/sites/default/files/How-Can-India-Decarbonise-For-Net-Zero-Sustainable-Steel-Production-Industry.pdf

58 ibid

59 ibid

60 Yadav. 2021. Greening Steel: Moving to Clean Steelmaking Using Hydrogen and Renewable Energy. Available at https://www.ceew.in/sites/default/files/ceew-study-on-clean-and-carbon-neutral-hydrogen-based-steel-production.pdf

61 ibid

62 Energy Transitions Commission and Material Economics. 2021. Steeling Demand: Mobilising buyers to bring net-zero steel to market before 2030. Available at: https://www.energy-transitions.org/wp-content/uploads/2021/07/2021-ETC-Steel-demand-Report-Final.pdf

63 "Monthly Summary for the Cabinet for the month of March 2019". Available at: https://steel.gov.in/sites/default/files/March%202019.pdf

64 Budget 2022: how the capex push through infrastructure is likely to play out. Available at: https://www.businesstoday.in/union-budget-2022/opinion/story/budget-2022-how-the-capex-push-through-infrastructure-is-likely-to-play-out-321654-2022-02-06

65 CRISIL.2021. New Opportunities for Steel in Construction and Infrastructure. available at: https://www.crisil.com/content/dam/crisil/our-analysis/reports/Research/documents/2021/01/new-opportunities-for-steel-in-infrastructure-and-construction.pdf

66 CRISIL.2021. New Opportunities for Steel in Construction and Infrastructure. available at: https://www.crisil.com/content/dam/crisil/our-analysis/reports/Research/documents/2021/01/new-opportunities-for-steel-in-infrastructure-and-construction.pdf

67 "Monthly Summary for the Cabinet for the month of March 2019". Available at: https://steel.gov.in/sites/default/files/March%202019.pdf

68 CRISIL.2021. New Opportunities for Steel in Construction and Infrastructure. Available at: https://www.crisil.com/content/dam/crisil/our-analysis/reports/Research/documents/2021/01/new-opportunities-for-steel-in-infrastructure-and-construction.pdf

69 Government of India,2023.Pradhan Mantri Awas Yojana – Urban. "Urban (PMAY-U). Available at: https://pmay-urban.gov.in/

70 Dedicated Freight Corridor Corporation of India Limited". Available at: https://dfccil.com/Home/DynemicPages?MenuId=78

71 Government of IndiaI. Jal Jeevan Mission (JJM). Available at: https://jalshakti-ddws.gov.in/sites/default/files/JJM_note.pdf

72 Ministry of Shipping. SagarMala - Projects under Sagarmala. Available at: https://sagarmala.gov.in/projects/projects-under-sagarmala

73 Mission Possible Partnership. 2021. Steeling Demand: Mobilising buyers to bring net-zero steel to market before 2030. Available at https://www.energy-transitions.org/wp-content/uploads/2021/07/2021-ETC-Steel-demand-Report-Final.pdf

74 ibid

75 ibid

Chapter 5

1 https://Pib.gov.in/pressRelease posted on 2nd February 2022

2 IEA- Energy demand for iron and steel by fuel in the Net Zero Scenario, 2010-2030

3 IEA (2020), Energy consumption in the iron and steel sector by scenario, IEA, Paris https://www.iea.org/data-and-statistics/charts/energy-consumption-in-the-iron-and-steel-sector-by-scenario, Licence: CC BY 4.0

4 Fact Sheet, Steel and Raw Materials, World Steel Association, 2023

5 Fact Sheet, Steel and Raw Materials, World Steel Association, 2023

6 Fact Sheet- Energy use in the steel industry, World Steel Association

7 IEA- steel-fact-sheet.pdf (https://ieefa.org/sites/default/files/2022-06/steel-fact-sheet.pdf)

8 Energy Use in Steel Industry, World Steel Association

9 IEA. 2020. Iron and Steel Technology Roadmap Towards more sustainable steelmaking. Available at https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

10 Brief Note on Iron and Steel industry by BEE

11 Impact of Energy Efficiency Measures for The Year 2022-23 (Bureau of Energy Efficiency) https://beeindia.gov.in/sites/default/files/publications/files/Impact%20Assessment%202022-23_%20FINAL%20Report.pdf

12 Impact of Energy Efficiency Measures, BEE, 2022-23

13 https://steel.gov.in/en/glossary-terms-definitions-commonly-used-iron-steel-industry

14 Retrieved fromhttps://steel.gov.in/en/energy-environment-management-steel-sectorhttps://steel.gov.in/en/energy-environment-management-steel-sector

15 "Towards a Low Carbon Steel Sector", Consultation Document, The Energy and Resources Institute (TERI)

16 WSP. Parsons Brinckerhoff and DNV GL, 2015; JISF. 2014; CII. 2013; Morrow, Hasanbeigi, Sathaye, & Xu, 2014; BEE. 2018

17 https://www.ctc-n.org/system/files/dossier/3b/ctcn_comprehensive_report_of_outcomes.pdf

18 https://pib.gov.in/PressReleasePage.aspx?PRID=1515278

19 "Theoretical Minimum Energies to Produce Steel for Selected Conditions" by RJ Fruehan, O. Fortini HW Paxton and R Brindle, Carnegie Mellon University, USA

20 "Towards a Low Carbon Steel Sector", Consultation Document, The Energy and Resources Institute (TERI)

21 Compendium on Energy Efficient Technology Packages for Electric Arc Furnace, UNDP, TERI

22 Compendium: Energy Efficient Technology Packages for Electric Arc Furnace, TERI, UNDP

23 Indian Secondary Steel Sector – Cluster mapping and resource consumption study, TERI/GIZ

24 https://steel.gov.in/en/energy-environment-management-steel-sector

25 India Technology Customised List for BF-BOF and EAFs, recommended technologies for energy saving, environmental protection and recycling in Indian iron and steel industry, The Japan Iron and Steel Federation, 2022 (https://jisf.or.jp/en/activity/climate/Technologies/documents/India_TCL_2022ver_part1_BF-BOF_v.5.0.pdf)

26 The 2023 revised directive raises the EU energy efficiency target, making it binding for EU countries to collectively ensure an additional 11.7% reduction in energy consumption by 2030, compared to the projections of the EU reference scenario 2020. As a result, overall EU energy consumption by 2030 should not exceed 992.5 million tonnes of oil equivalent (Mtoe) for primary energy and 763 Mtoe for final energy. This is equivalent to new annual savings of at least 0.8% of final energy consumption in 2021-2023, at least 1.3% in 2024-2025, 1.5% in 2026-2027 and 1.9% in 2028-2030

27 European Commission Energy Efficiency Directive 2023 (https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive)

Chapter 6

1 https://cea.nic.in/wp-content/uploads/2020/02/installed_capacity-12-1.pdf

2 https://cea.nic.in/wp-content/uploads/installed/2023/12/IC_31_Dec_2023.pdf

3 Based on the RPO compliance data obtained for DISCOMs and the RE penetration in captive sources for the iron and steel industry as per the CEA General Review 2023

4 https://ourworldindata.org/

5 https://www.statista.com.

6 https://www.iea.org/reports/renewables-2023/electricity

7 https://ember-climate.org/app/uploads/2023/04/Global-Electricity-Review-2023.pdf

8 https://pib.gov.in/PressReleasePage.aspx?PRID=1992732

9 *RES includes Small Hydro Power, Bio Power, Urban & Industrial Waste Power, Solar and Wind Energy

10 https://meritindia.in/

11 https://cea.nic.in/wp-content/uploads/installed/2023/12/IC_31_Dec_2023.pdf

12 https://cea.nic.in/cdm-co2-baseline-database/?lang=en

13 https://cea.nic.in/wp-content/uploads/general/2022/GR_Final.pdf

14 Renewable Purchase Obligation (RPO) and Energy Storage Obligation Trajectory till 2029-30 - regarding.

15 "Renewable Purchase Obligations (RPO)." Anert. Accessed August 2, 2023. https://anert.gov.in/node/114.

16 powermin.gov.in/Notification_Renewable_Purchase_Obligation.pdf

17 "Press Information Bureau." 2023. Press Information Bureau. https://pib.gov.in/PressReleasePage.aspx?PRID=1897038.

18 "Press Information Bureau." 2023. Press Information Bureau. https://pib.gov.in/PressReleasePage.aspx?PRID=1897041.

19 "Press Information Bureau." 2023. Press Information Bureau. https://pib.gov.in/PressReleasePage.aspx?PRID=1907702.

20 “Renewable energy cover Final.cdr.” Central Electricity Authority. Accessed July 28, 2023. https://cea.nic.in/wp-content/uploads/notification/2022/12/CEA_Tx_Plan_for_500GW_Non_fossil_capacity_by_2030.pdf.

21 “Green Energy Corridor | Government of India.” Ministry of Power. Accessed August 21, 2023. https://powermin.gov.in/en/content/green-energy-corridor.

22 “Press Information Bureau.” 2022. Press Information Bureau. https://pib.gov.in/PressReleasePage.aspx?PRID=1846078.

23 https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1983085

24 https://greenopenaccess.in/rules

25 2021.https://powermin.gov.in/sites/default/files/Electricity%20%28Promotion%20of%20generation%20of%20Electricity%20from%20Must-Run%20Power%20Plant%29%20Rules%2C%202021.pdf.

26 “Press Information Bureau.” 2022. Press Information Bureau. https://pib.gov.in/PressReleasePage.aspx?PRID=1885071.

27 “Renewable Energy.” Make In India. Accessed August 23, 2023. https://www.makeinindia.com/sector/renewable-energy.

28 “MCA 21 Version 3.0: Digital Corporate Compliance Portal.” 2021. Drishti IAS. https://www.drishtiias.com/daily-updates/daily-news-analysis/mca-21-version-3-0-digital-corporate-compliance-portal.

29 “Business Responsibility and Sustainability Report.” 2021. Drishti IAS. https://www.drishtiias.com/daily-updates/daily-news-analysis/business-responsibility-and-sustainability-report.

30 “Ministry of Power Notification New Delhi, 28 June, 2023.” 2023. Bureau of Energy Efficiency. https://beeindia.gov.in/sites/default/files/CCTS.pdf.

31 https://cea.nic.in/wp-content/uploads/general/2022/GR_Final.pdf

32 Renewable Purchase Obligation (RPO) and Energy Storage Obligation Trajectory till 2029-30 - regarding.

33 “GOAR.” 2022. https://greenopenaccess.in/state-regulations

34 ibid

35 ibid

36 Joshi, Arjun. 2023. “Punjab Issues Clarifications to Green Energy Open Access Rules.” Mercom India. https://www.mercomindia.com/punjab-clarifications-green-open-access.

37 “UTTARAKHAND ELECTRICITY REGULATORY COMMISSION Notification.” 2023. UERC. https://uerc.gov.in/Draft%20documents/2023/July/Green%20Energy%20Open%20Access/UERC%20GREEN%20Open%20Acces%20Regulation%202023_AD%20C&L_12.07.2023.pdf.

38 “Final Draft regulations GEOA Regulations 2023 dated 23.06.” 2023. Gujarat Electricity Regulatory Commission.https://gercin.org/wp-content/uploads/2023/06/Final-Draft-regulationsGEOA-Regulations-2023-dated-23.06.pdf.

39 “Chhattisgarh State Electricity Regulatory Commission.” 2022. https://solarquarter.com/wp-content/uploads/2023/07/1690340477428.pdf.

40 https://www.uperc.org/App_File/Draft_CRE_Regulations_2019-pdf44201991905PM.pdf

41 2022. Green Energy Open Access Rules. https://greenopenaccess.in/assets/files/Green%20Energy%20Open%20Access_rules.pdf.

42 https://forumofregulators.gov.in/Data/study/Final%20Report%20of%20FOR-GEOA.pdf

43 "Detailed Procedure for Banking of Power and Model Banking Agreement From RE based Captive Generating Plants In accordance with Punjab." pserc. Accessed September 6, 2023. https://pserc.gov.in/pages/Banking-Procedure-19.04.23.pdf.

44 Joshi, Arjun. 2023. "Ministry Asks State Regulators to Comply with Green Energy Open Access Rules." Mercom India. https://www.mercomindia.com/regulators-comply-green-open-access-rules.

45 2022. Green Energy Open Access Rules. https://greenopenaccess.in/assets/files/Green%20Energy%20Open%20Access_rules.pdf.

46 "PUNJAB STATE ELECTRICITY REGULATORY COMMISSION Draft Notification, 2022." pserc. Accessed September 6, 2023. https://pserc.gov.in/pages/Draft-Notification-OA-Regulations-18.11.2022.pdf.

47 Gagal, Varchasvi. 2022. "Land acquisition continues to be a roadblock for renewable energy projects." The Hindu BusinessLine, August 25, 2022. https://www.thehindubusinessline.com/opinion/land-acquisition-continues-to-be-a-roadblock-for-renewable-energy-projects/article65809202.ece.

48 https://cea.nic.in/Techno_Economic_Analysis_of_Renewable_Energy_Round_the_Clock

49 For the scenario-based analysis, we have assumed that MoP's RPO target of 43.33% RE for 2029-30 extends to FY 2030-31

50 Renewable Purchase Obligation (RPO) and Energy Storage Obligation Trajectory till 2029-30 - regarding.

51 2022. Green Energy Open Access Rules. https://greenopenaccess.in/assets/files/Green%20Energy%20Open%20Access_rules.pdf.

52 "(Published in Part II, Section 3, Sub-section (i) of the Gazette of India, Extraordinary)." CEA. Accessed July 30, 2023. https://cea.nic.in/wp-content/uploads/legal_affairs/2020/09/Electricity-rules-2005.pdf

53 "What are RECs?" I-REC Standard. Accessed July 31, 2023. https://www.irecstandard.org/what-are-recs/.

54 "Credibility." I-REC Standard. Accessed July 31, 2023. https://www.irecstandard.org/credibility/.

55 Hindustan Times. 2023. "Making land available at concessional rates to set up industries, says UP minister." July 26, 2023. https://www.hindustantimes.com/cities/lucknow-news/recordbreaking-investments-and-preparations-for-2024-elections-lucknow-s-industrial-development-minister-sheds-light-101690389688468.html.

56 The Times of India. 2022. "UP will give free land for new projects: CM Yogi Adityanath | Lucknow News - Times of India." October 9, 2022. https://timesofindia.indiatimes.com/city/lucknow/up-will-give-free-land-for-new-projects-cm-yogi-adityanath/articleshow/94732662.cms.

57 Gagal, Varchasvi. 2022. "Land acquisition continues to be a roadblock for renewable energy projects." The Hindu Business Line, August 25, 2022. https://www.thehindubusinessline.com/opinion/land-acquisition-continues-to-be-a-roadblock-for-renewable-energy-projects/article65809202.ece.

58 "Simplifying Virtual Power Purchase Agreements (VPPA)- Indian perspective." 2022. JMK Research. https://jmkresearch.com/simplifying-virtual-power-purchase-agreements-vppa-indian-perspective/.

Chapter 7

1 IEA (2020), Iron and Steel Technology Roadmap, IEA, Paris https://www.iea.org/reports/iron-and-steel-technology-roadmap

2 Bhagat, R. P., H. S. Ray, and S. K. Gupta, Improvement in performance of the blast furnace at Bhilai through statistical analysis and improvement in burden preparation, ISIJ Inter., 31, (1991), 669 - 676., For scrap: Sources: WSA 2023 Factsheet ; Iron& steel raw materials,and Ministry of Steel 2019. Steel scrap recycling policy 2019

3 IBID

4 IEA (2020), Iron and Steel Technology Roadmap, IEA, Paris https://www.iea.org/reports/iron-and-steel-technology-roadmap, Licence: CC BY 4.0 Available at https://www.iea.org/reports/iron-and-steel-technology-roadmap

5 World steel association 2023. Fact sheet steel and raw materials. Accessed on 22nd February 2024 Available at https://worldsteel.org/wp-content/uploads/Fact-sheet-raw-materials-2023.pdf

6 Simon Nicholas, Soroush Basirat, June 2022.Iron Ore Quality a Potential Headwind to Green Steelmaking. The Institute for Energy Economics and Financial Analysis (IEEFA). https://ieefa.org/sites/default/files/2022-06/Iron%20Ore%20Quality%20a%20Potential%20Headwind%20to%20Green%20Steelmaking_June%202022.pdf

7 Out of total resources of iron ore (haematite), about 6,209 million tonnes (26%) fall under 'reserves' category and the balance about 17,849 million tonnes (74%) under 'remaining resources' category. National Mineral Inventory 2020. Metallic Minerals (Ferrous Group) Chapter 2. Available at https://ibm.gov.in/writereaddata/files/1696338854651c13a6a0f16Chapter2.pdf

8 EquityPandit. (November 19, 2022). India scraps export duties on low-grade iron ore, some steel intermediates. EquityPandit. Retrieved from https://www.equitypandit.com/india-scraps-export-duties-on-low-grade-iron-ore-some-steel-intermediates/

9 National Mineral Inventory 01.04.2020 SOURCE: Indian Bureau of Mines, Indian Minerals Yearbook: 2021,2020,2019,2018, 2017, 2016; Table 5(A), 5(B)

10 National Mineral Inventory 01.04.2020 SOURCE: Indian Bureau of Mines, Indian Minerals Yearbook: 2021,2020,2019,2018, 2017, 2016; Table 5(A), 5(B)

11 Sengupta P K, Mukherjee S K and Prasad N, (2003) In: Proceeding National Seminar on Beneficiation of Raw Materials for Iron Making (R & DC, SAIL) Ranchi, India.

12 Dr. Rubina Sahin. (2020). Beneficiation of low/off grade iron ore: a review. International Journal of Research -granthaalayah, 8(8), 328-335. https://doi.org/10.29121/granthaalayah.v8.i8.2020.934

13 Annual Statistics 2022-23, JPC

14 Pellet Manufacturers Association of India, PMAI 2023

15 Steelmint and Pellet Manufacturers Association of India, 2023

16 Steelmint 2023. India's iron ore beneficiation capacity poised to grow by 25% in FY'30. Accessed on 09th April 2024. Available at https://www.linkedin.com/pulse/indias-iron-ore-beneficiation-capacity-poised-grow-25-fy30/

17 Pelletising or Pelletisation is a process of converting very fine iron ore (100 micron) into uniform sized pellets (balls with diameter 6mm~16mm), which are suitable for use in blast furnaces and direct reduction furnaces.

18 Bhagat, R. P., H. S. Ray, and S. K. Gupta, Improvement in performance of the blast furnace at Bhilai through statistical analysis and improvement in burden preparation, ISIJ Inter., 31, (1991), 669 - 676.

19 PR newswire 2021, News from fact.mr. Accessed on 22nd February 2024 Available at https://www.prnewswire.com/news-releases/iron-ore-pellets-demand-to-surpass-399-mn-tons-in-2021-as-

application-in-steel-production-surges-301405815.html

20 Steelmint BIR, WSA

21 SRTMI (Indian Industries' Input)

22 N. Pardo, J. A. Moya and K. Vatopoulos: Prospective Scenarios on Energy Efficiency and CO_2 Emissions in the EU Iron & Steel Industry, JRC Scientific and Policy Reports, European Union, Luxembourg, (2012)

23 Indian pellet plant capacity, production and export inputs from Pellet Manufacturers Association of India (PMAI)

24 ABB 2022. Energy efficiency in iron and steel making. https://www.energyefficiencymovement.com/wp-content/uploads/2023/01/ABB_EE_2022-05-WhitePaper_Metals.pdf

25 Vallet box.co. 2024 . .Accessed on 23rd April 2024. Available at: https://www.valleybox.com/blog/benefits-of-using-scrap-steel

26 WSA 2021. Factsheet on Scrap. Accessed on 04th April 2024. Available at https://worldsteel.org/wp-content/uploads/Fact-sheet-on-scrap_2021.pdf

27 Söderholm, P., and Ekvall, T. (2020), "Metal markets and recycling policies: impacts and challenges", Mineral Economics, Vol. 33/1, pp. 257–72, https://doi.org/10.1007/s13563-019-00184-5

28 WSA 2021. Factsheet on Scrap. Accessed on 04th April 2024. Available at https://worldsteel.org/wp-content/uploads/Fact-sheet-on-scrap_2021.pdf

29 Lack of continuous supply of scrap & relatively lesser quantity of steel scrap availability leads to the manual processing in India, also manual labour is efficient and cheap, that's why Indian steel scrap recycling industry is dominated by the manual segregation and sorting. It is to be noted that once the scrap supply is intact and formal along with the availability of a considerable quantity of steel scrap, the shredder will automatically dominate the industry.

Chapter 8

1 MHI. 2022. HYFOR – HYdrogen-based Fine-Ore Reduction. Available at: https://www.mhi.co.jp/technology/review/pdf/e592/e592070.pdf

2 Voestalpine. n.d. Breakthrough technologies. Available at: https://www.voestalpine.com/greentecsteel/en/breakthrough-technologies/

3 Sohn, H.Y., Mohassab, Y. Development of a Novel Flash Ironmaking Technology with Greatly Reduced Energy Consumption and CO2 Emissions. J. Sustain. Metall. 2, 216–227 (2016). https://doi.org/10.1007/s40831-016-0054-8 https://www.energy.gov/sites/prod/files/2016/12/f34/fcto_h2atscale_workshop_sohn.pdf

4 Ministry of Steel. 2017.National Steel Policy. Available at https://steel.gov.in/en/national-steel-policy-nsp-2017#:~:text=The%20policy%20projects%20crude%20steel,current%20consumption%20of%2061%20Kgs

5 Ministry of Steel,2019.Monthly Summary for the Cabinet for the month of March. Available at: https://steel.gov.in/sites/default/files/March%202019.pdf

6 Ministry of Power, 2022, Green Hydrogen/ Green Ammonia Policy. Available at: https://powermin.gov.in/sites/default/files/Green_Hydrogen_Policy.pdf

7 PIB 2023. ISTS waiver of Green Hydrogen and Green Ammonia projects extended. Available at https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1928128

8 IEA.2023.Tracking Steel.Available at:https://www.iea.org/energy-system/industry/steel

Chapter 9

1 JPC. 2023. Annual Statistics 2022–23. Kolkata: Joint Plant Committee

2 IEA. 2020. Iron and Steel Technology Roadmap. Available at: https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

3 Elango, Sabarish, Kartheek Nitturu, Deepak Yadav, Pratheek Sripathy, Rishabh Patidar, and Hemant Mallya. 2023. Evaluating Net-zero for the Indian Steel Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies. New Delhi: Council on Energy, Environment and Water.

4 World Steel Association. 2023. Carbon capture and use and storage (CCUS). Factsheet. Available at: https://worldsteel.org/wp-content/uploads/Carbon-capture-use-and-storage-2023.pdf

5 Leadership Group for Industry Transition. Green Steel Tracker. Available at: https://www.industrytransition.org/

6 IEA. 2022. CO2 Storage Resources and Their Development. Available at https://www.iea.org/reports/co2-storage-resources-and-their-development .

7 Bakshi, Tuli, Hemant Mallya, and Deepak Yadav. 2023. Assessing India's CO_2 Storage Potential: A Critical Analysis of What Lies Beyond the Theoretical Potential. Available at: https://www.ceew.in/publications/how-can-india-scale-carbon-capture-storage-projects-co2-storage-potential-sequestration

8 Atanu Mukherjee, Saurav Chatterjee. 2022. Carbon Capture, Utilisation and Storage (CCUS) - Policy Framework and its Deployment Mechanism in India. NITI Aayog. Available at: link www.niti.gov.in

9 Atanu Mukherjee, Saurav Chatterjee. 2022. Carbon Capture, Utilisation and Storage (CCUS) - Policy Framework and its Deployment Mechanism in India. NITI Aayog. Available at: link www.niti.gov.in

10 IEA. Direct Air Capture: A key technology for net zero. 2022. Available at https://iea.blob.core.windows.net/assets/78633715-15c0-44e1-81df-41123c556d57/DirectAirCapture_Akeytechnologyfornetzero.pdf

11 Srinivasan V, Temminghoff M, Charnock S, Moisi A, Palfreyman D, Patel J, Hornung C, Hortle A (2021). CO2 Utilisation Roadmap. CSIRO

12 Shell, 2016. Shell Sustainability Report.

13 Martin-Roberts, E., Scott, V., Flude, S., Johnson, G., Haszeldine, R.S., Gilfillan, S., 2021. Carbon capture and storage at the end of a lost decade. One Earth 4, 1569–1584.Available at: https://doi.org/10.1016/J.ONEEAR.2021.10.002

14 IEA, 2021. Net Zero by 2050. Available at Net Zero by 2050 - A Roadmap for the Global Energy Sector (iea.blob.core.windows.net)

15 Vishal, V., Chandra, D., Singh, U., Verma, Y., 2021a. Understanding initial opportunities and key challenges for CCUS deployment in India at scale. Resour Conserv Recycl 175, 105829. Available at:

16 Bakshi, Tuli, Hemant Mallya, and Deepak Yadav. 2023. Assessing India's CO_2 Storage Potential: A Critical Analysis of What Lies Beyond the Theoretical Potential. Available at: https://www.ceew.in/publications/how-can-india-scale-carbon-capture-storage-projects-co2-storage-potential-sequestration

17 Vishal, V., Singh, U., Bakshi, T., Chandra, D., Verma, Y., Tiwari, A.K., 2023. Optimal source-sink matching and prospective hub-cluster configurations for CO 2 capture and storage in India. Geological Society, London, Special Publications 528. https://doi.org/10.1144/SP528-2022-76

18 Heddle, Gemma, Herzog, Howard, Klett, M., 2003. The economics of CO_2 storage, MIT Laboratory for Energy and the Environment.

19 IEA. 2021. Net Zero by 2050 A Roadmap for the Global Energy Sector. IEA. Available at: https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

20 Elango, Sabarish, Kartheek Nitturu, Deepak Yadav, Pratheek Sripathy, Rishabh Patidar, and Hemant Mallya. 2023. Evaluating Net-zero for the Indian Steel Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies. New Delhi: Council on Energy, Environment and Water.

21 Vishal et al.,2023.A systematic capacity assessment and classification of geologic CO2 storage systems in India.Available at https://doi.org/10.1016/j.ijggc.2021.103458; Smith et al., 2021.The Cost of CO2 Transport and Storage in Global Integrated Assessment Modeling.Available at https://globalchange.mit.edu/sites/default/files/Smith-TPP-2021.pdf

22 Srinivasan V, Temminghoff M, Charnock S, Moisi A, Palfreyman D, Patel J, Hornung C, Hortle A (2021). CO2 Utilisation Roadmap. CSIRO

23 Elango, Sabarish, Kartheek Nitturu, Deepak Yadav, Pratheek Sripathy, Rishabh Patidar, and Hemant Mallya. 2023. Evaluating Net-zero for the Indian Steel Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies. New Delhi: Council on Energy, Environment and Water.

24 USDOE.Investing in America. Available at: https://www.energy.gov/articles/biden-harris-administration-announces-100-million-transform-climate-pollution-sustainable

Chapter 10

1 Wiencke, J., Lavelaine, H., Panteix, PJ. et al. 2018. Electrolysis of iron in a molten oxide electrolyte. J Appl Electrochem 48, 115–126 (2018). Available at: https://doi.org/10.1007/s10800-017-1143-5

2 Koutsoupa, Sevasti, Stavroula Koutalidi, Efthymios Balomenos, and Dimitrios Panias. 2021. ΣIDERWIN—A New Route for Iron Production Materials Proceedings 5, no. 1: 58. Available at: https://doi.org/10.3390/materproc2021005058

3 MIDREX: 2022 World Direct Reduction Statistics, Available at: https://www.midrex.com/wp-content/uploads/MidrexSTATSBook2022.pdf

4 MIDREX: 2022 World Direct Reduction Statistics, Available at: https://www.midrex.com/wp-content/uploads/MidrexSTATSBook2022.pdf

5 Deependra Kashiva: Dilemma of Indian DRI Industry, DRI update, Sponge Iron Manufacturers Association, May 2023.

6 I. Nduagu, et al. 2022: Comparative life cycle assessment of natural gas and coal-based directly reduced iron (DRI) production: A case study for India, Journal of Cleaner Production v347, 2022.

7 Elango, Sabarish, Kartheek Nitturu, Deepak Yadav, Pratheek Sripathy, Rishabh Patidar, and Hemant Mallya. 2023. Evaluating Net-zero for the Indian Steel Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies. New Delhi: Council on Energy, Environment and Water.

8 Ministry of Coal 2019. Ash Content in the Coal Available at: https://sansad.in/getFile/loksabhaquestions/annex/171/AU677.pdf?source=pqals

9 Ibid.

10 PNGRB 2023. Natural Gas Pipelines Network in India - As on 31.12.2023 Available at : https://www.pngrb.gov.in/data-bank/NGPL-21022024.pdf

11 Mission Document: National Coal Gasification Mission, Ministry of Coal, Government of India, September, 2021.

12 PPAC 2024. Sectoral Consumption. Available at :https://ppac.gov.in/natural-gas/sectoral-consumption

13 Ministry of Commerce and Industry.2023.Commodity-wise imports.

14 Fischedick, M., Marzinkowski, J., Winzer, P., and Weigel, M. (2014). Techno-economic evaluation of innovative steel production technologies. Journal of Cleaner Production, 84, 563–580

15 European Commission 2021.International Just Energy Transition Partnership with South Africa. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_5768;

16 European Commission 2022.Just Energy Transition Partnership with Indonesia. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6926

Chapter 11

1. M. John, R. Harold, S. Michael, R. Phillip & Jahanshahi Sharif (2011). Use of biomass in the iron and steel industry
2. Latawiec, A. E., Strassburg, B. B., Junqueira, A. B., Araujo, E., D. de Moraes, L. F., Pinto, H. A., ... & Hale, S. E. (2019). Biochar amendment improves degraded pasturelands in Brazil: environmental and cost-benefit analysis. Scientific reports, 9(1), 11993.
3. https://www.csiro.au/en/work-with-us/industries/mining-resources/processing/green-steelmaking
4. https://www.csiro.au/en/news/all/news/2023/may/pyrochar-and-csiro-collaborate-to-decarbonise-steelmaking
5. https://cosmosmagazine.com/news/bamboo-fuels-biocarbon-factory-in-malaysia/
6. https://arena.gov.au/projects/unsw-blast-furnace-innovations-sustainable/
7. Size, B. M. (2023). Share & Trends Analysis Report By Technology (Nanobiotechnology, DNA Sequencing, Cell-based Assays), By Application (Health, Bioinformatics), By Region, And Segment Forecasts, 2023-2030. Report ID: 978-1-68038-134-4.
8. MNRE 2021 Evaluation study for assessment of biomass power and bagasse cogeneration
9. potential in India
10. https://renewablewatch.in/2024/01/30/analysis-study-on-coke-replacement-with-bio-coal-in-eaf/#:~:text=Examining%20the%20data%2C%20bio%2Dcoal,carbon%20composition%20(82.51%25%20vs.
11. https://worldsteel.org/wp-content/uploads/Presentation_Samik-NAG_JSW-Steel-Limited-1.pdf
12. International Bamboo and Rattan Organisation (INBAR), 2021.
13. North Eastern Development Finance Corporation Limited (NEDFI) Action Plan, 2020.
14. 2023 World Steel in Figures, WSA, pg 10
15. Bazaluk, O.; Kieush, L.; Koveria, A.; Schenk, J.; Pfeiffer, A.; Zheng, H.; Lozynskyi, V. Metallurgical Coke Production with Biomass Additives: Study of Biocoke Properties for Blast Furnace and Submerged Arc Furnace Purposes. Materials 2022, 15, 1147
16. Kieush, L.; Schenk, J.; Pfeiffer, A.; Koveria, A.; Rantitsch, G.; Hopfinger, H. Investigation on the Influence of Wood Pellets on the Reactivity of Coke with CO2 and Its Microstructure Properties. Fuel 2022, 309, 122151
17. 2023 World Steel in Figures, pg 18
18. 2023 World Steel in Figures, pg 18

19. Guerrero, A.; Diez, M.A.; Borrego, A.G. Influence of Charcoal Fines on the Thermoplastic Properties of Coking Coals and the Optical Properties of the Semicoke. Int. J. Coal Geol. 2015, 147–148, 105–114

20. Suopajärvi, H.; Umeki, K.; Mousa, E.; Hedayati, A.; Romar, H.; Kemppainen, A.; Wang, C.; Phounglamcheik, A.; Tuomikoski, S.; Norberg, N.; et al. Use of Biomass in Integrated Steelmaking—Status Quo, Future Needs and Comparison to Other Low-CO2 Steel Production Technologies. Appl. Energy 2018, 213, 384–407

21. Provisional Coal Statistics 2022-23. Office of the coal controller, MoC, GoI, 18

22. Such high variation in range is due to variation in biomass. Different source of biomass have different coal replacement potential.

23. 2023 World Steel in Figures, WSA, pg 18

24. Ooi, T.C.; Thompson, D.; Anderson, D.R.; Fisher, R.; Fray, T.; Zandi, M. The Effect of Charcoal Combustion on Iron-Ore Sintering Performance and Emission of Persistent Organic Pollutants. Combust. Flame 2011, 158, 979–987

25. Scarpinella, C.A.; Cyro, T.; Tagusagawa, S.Y.; Mourao, M.B.; Lenz e Silva, F.B. Charcoal ironmaking: A contribution for CO2 mitigation. In Proceedings of the Fray International Syymposium, Cancun, Mexico, 27 November–1 December 2011; Metals and Materials Processing in a Clean Environment. pp. 109–121

Chapter 12

1 R.R. Wang, Y.Q. Zhao, A. Babich, D. Senk, X.Y. Fan, “Hydrogen direct reduction (H-DR) in steel industry—An overview of challenges and opportunities” Journal of Cleaner Production, Volume 329, (2021)

2 Allanore, A., Yin, L. & Sadoway, D. A new anode material for oxygen evolution in molten oxide electrolysis. Nature 497, 353–356 (2013). https://doi.org/10.1038/nature12134

3 Boston Metal: “Decarbonizing steel production - Boston Metal”; available at: https://www.bostonmetal.com/;

4 Science Direct: “Electrowinning”. Available at: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/electrowinning

5 SIDERWIN project; available at: https://www.siderwin-spire.eu/

6 Tata Steel “HIsarna - Building a sustainable steel industry”; available at: https://www.tatasteeleurope.com/sites/default/files/tata-steel-europe-factsheet-hisarna.pdf

7 Tata Steel “HIsarna - Building a sustainable steel industry”; available at: https://www.tatasteeleurope.com/sites/default/files/tata-steel-europe-factsheet-hisarna.pdf

8 Naseri Seftejani, Masab & Schenk, Johannes. (2018). Fundamentals of hydrogen plasma smelting reduction (HPSR) of iron oxides, a new generation of steelmaking processes.

9 Viostalpine “Donawitz: from plasma to green steel” available at: https://www.voestalpine.com/blog/en/commitment/donawitz-from-plasma-to-green-steel/

10 Goodman, Neil & Dry, Rod. (2009). Hismelt Plant Ramp-Up. 1228-1233.

11 GWFA “HIsmelt Kwiwana Plant”; available at: https://gfwa.com.au/pdffiles/References/HIsmeltKwinanaPlant.pdf

12 Goodman, Neil. (2019). Operation of the First HIsmelt Plant in China. 593-600. 10.33313/377/063.

13 Nippon Steel Engineering: “Rotary Hearth Furnace”, Available at: https://www.eng.nipponsteel.com/english/whatwedo/steelplants/ironmaking/rotary_hearth_furnace/

14 Nippon Steel Engineering: "Rotary Hearth Furnace", Available at: https://www.eng.nipponsteel.com/english/whatwedo/steelplants/ironmaking/rotary_hearth_furnace/

15 Leadership Group for Industry Transition: "Green Steel Tracker"; Available at: https://www.industrytransition.org/green-steel-tracker/; accessed 25th Aug 2023

16 Leadership Group for Industry Transition: "Green Steel Tracker"; Available at: https://www.industrytransition.org/green-steel-tracker/; accessed 25th Aug 2023

17 SIDERWIN project; available at: https://www.siderwin-spire.eu/

18 Boston Metal "Green Steel Solution"; available at: https://www.bostonmetal.com/green-steel-solution/

19 HYBRIT "A fossil-free development"; available at: https://www.hybritdevelopment.se/en/a-fossil-free-development/

20 MIT Deshpande Center for Technological Innovation: "Boston Metal", Available at: https://deshpande.mit.edu/spinouts/boston-metal/;

21 SIDERWIN (2023). "SIDERWIN_Concluding_webinar2023_slides". Available at: https://zenodo.org/records/7785032#.ZCVyxXZByUk;

22 EU Innovation Fund (2022): "HYBRIT Demonstration: Swedish largescale steel value chain demonstration of Hydrogen Breakthrough Iron-making Technology". Available at: Link accessed: 25 Aug 2023

23 Vattenfall (2019): "HYBRIT: SEK 200 million invested in pilot plant for storage of fossil-free hydrogen in Luleå". Available at: Link accessed on 25th August 2023

24 Vattenfall (2019): "HYBRIT: SEK 200 million invested in pilot plant for storage of fossil-free hydrogen in Luleå". Available at: https://group.vattenfall.com/press-and-media/pressreleases/2019/hybrit-sek-200-million-invested-in-pilot-plant-for-storage-of-fossil-free-hydrogen-in-lulea#:~:text=About%20HYBRIT&text=of%20carbon%20dioxide.-,The%20initiative%20has%20the%20potential%20to%20reduce%20Sweden's%20total%20carbon,to%20invest%20SEK%201.1%20billion.; accessed on 25th August 2023

25 Survey response to the RD&D task force by respective institutes

26 The World Bank. 2023. "Research and development expenditure (% of GDP)". Available at: https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?most_recent_value_desc=true

27 Department of Science & Technology. 2023. RESEARCH & DEVELOPMENT STATISTICS AT A GLANCE. New Delhi: Department of Science & Technology. Available at: https://dst.gov.in/sites/default/files/R%26D%20Statistics%20at%20a%20Glance%2C%202022-23.pdf

28 Department of Science & Technology. 2023. RESEARCH & DEVELOPMENT STATISTICS AT A GLANCE. New Delhi: Department of Science & Technology. Available at: https://dst.gov.in/sites/default/files/R%26D%20Statistics%20at%20a%20Glance%2C%202022-23.pdf

29 Darrell M. West. 2022. R&D for the public good: Ways to strengthen societal innovation in the United States. Brookings. Available at: https://www.brookings.edu/articles/rd-for-the-public-good-ways-to-strengthen-societal-innovation-in-the-united-states/

30 UK Parliament. 2023. Research and development spending. Available at: https://commonslibrary.parliament.uk/research-briefings/sn04223/#:~:text=In%202021%2C%20the%20business%20sector,billion%20(5%25)%20of%20R%26D

31 OECD Food and Agricultural Reviews. The agricultural innovation system in China. OECD iLibrary. Available at: https://www.oecd-ilibrary.org/sites/9789264085299-9-en/index.html?itemId=/content/component/9789264085299-9-en#:~:text=The%20private%20sector%20has%20become,level%20as%20

the%20OECD%20average

32 Ministry of Steel, GoI. "Invitation for R&D Proposals 2023-24". Available at: https://steel.gov.in/sites/default/files/Invitation%20for%20R&D%20Proposals%202023-24.pdf

33 EU. "Research Fund for Coal and Steel (RFCS)". Available at: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/research-fund-coal-and-steel-rfcs_en; accessed on 17 Aug 2023

34 Australian Renewable Energy Agency. "Iron and Steel Research and Development Funding Round". Available at: https://arena.gov.au/funding/iron-and-steel-research-and-development-funding-round/; Accessed on 17 Aug 2023

35 Eureka. "Eurostars". Available at: https://www.eurekanetwork.org/countries/spain/eurostars/; Accessed on 17 Aug 2023

36 World Bank. "World Bank approves 1.5 BN in financing to support India's low-carbon transition". Available at:https://www.worldbank.org/en/news/press-release/2023/06/29/world-bank-approves-1-5-billion-in-financing-to-support-india-s-low-carbon-transition; accessed on 17 Aug 23

37 Aaron Maltais, Linus Linde, Felipe Sanchez and Gökçe Mete: "The role of international finance institutions in the low-carbon steel transition". Leadership Group for Industry Transition (2022). Available at: https://www.industrytransition.org/content/uploads/2022/06/ifi-green-steel-transition-brief.pdf;

38 Nixon Peabody. "The Inflation Reduction Act, A big deal for green steel" (2022). Available at: https://www.nixonpeabody.com/insights/articles/2022/09/12/the-inflation-reduction-act-is-a-big-deal-for-green-steel; accessible on 17 Aug 23

39 Union Cabinet, Government of India. "Union Cabinet approves Production-linked Incentive (PLI) Scheme for Specialty Steel" (2021) Press Information Bureau. Available at:https://pib.gov.in/PressReleasePage.aspx?PRID=1737722; accessed on 17 Aug 2023

40 Reuters. "EU clears USD 3.2 bn in green subsidies for Thyssenkrupp, ArcelorMittal" (2023). Business Standard 20 July. Available at: https://www.business-standard.com/companies/news/eu-clears-3-2-bn-in-green-subsidies-for-thyssenkrupp-arcelormittal-123072000738_1.html; accessed on 17 Aug 23

41 Bloomberg. "Brookfield Eyes Green Steel for Multibillion New Transition Fund" (2023). Bloomberg. Available at: https://www.bloomberg.com/news/articles/2023-05-01/brookfield-eyes-green-steel-for-multibillion-new-transition-fund; accessed on 17 Aug 2023.

42 H2 Green Steel. "H2 Green Steel Completes USD 190 Million Funding Round". H2 Green Steel. Available at:https://www.h2greensteel.com/latestnews/h2-green-steel-completes-190-million-funding-round; Accessed on 17 Aug 2023.

43 The Australian Financial Review (AFR). "PE Firm Roc Partners Backs Victorian Green Steel Roll-Up" (2022). Available at: https://www.afr.com/street_talk/pe-firm-roc-partners-backs-victorian-green-steel-roll-up-20220704-p5ayyb; accessed on 17 Aug 2023

44 Boston Metal. "The World Bank's International Finance Corporation Invests USD 20 Million in Boston Metal". Available at: https://www.bostonmetal.com/news/the-world-banks-international-finance-corporation-invests-20-million-in-boston-metal/. Accessed on 17 Aug 2023.

45 H2 Green Steel. "H2 Green Steel has pre-sold over 1.5 million tonnes of green steel to customers". Available at:https://www.h2greensteel.com/latestnews/h2-green-steel-has-pre-sold-over-15-million-tonnes-of-green-steel-to-customers. Accessed on 17 Aug 2023.

46 ArcelorMittal Europe. "Gestamp xCarb green steel certificates" Available at: https://europe.arcelormittal.

com/newsandmedia/pressreleases/5607/gestamp-xcarb-green-steel-certificates; accessed on 17 Aug 2023.

47 Eurometal. “ArcelorMittal expanding steel sales in 2022 with carbon certificates”. Available at: https://eurometal.net/arcelormittal-expanding-steel-sales-in-2022-with-carbon-certificates/; Accessed on 17 Aug 2023.

48 H2 Green Steel. “Leading European Financial Institutions Support H2 Green Steel’s USD 3.5 Billion Debt Financing”. Available at: https://www.h2greensteel.com/latestnews/leading-european-financial-institutions-support-h2-green-steels-35-billion-debt-financing; accessed on 17 Aug 2023.

49 European Investment Bank (EIB). “Donor funded Instruments”. Available at: https://www.eib.org/en/products/mandates-partnerships/donor-partnerships/instruments.html; Accessed on 17 Aug 2023.

Chapter 13

1 UNEP. (2022). Emissions Gap Report 2022: The Closing Window. Climate Crisis Calls for Rapid Transformation of Societies. UN.

2 CPI. 2024. Discussion Paper: Financing Industrial Decarbonisation. Challenges and Solutions for the Indian Iron and Steel Sector.

3 Soni, S. (2023, March 2). Over Rs 2,600 crore in MSME payment yet to be cleared by central PSUs, ministries, departments: Govt data. The Financial Express. https://www.financialexpress.com/industry/sme/msme-fin-over-2600-crore-in-msme-payment-yet-to-becleared-by-central-psus-ministries-departments-govt-data/2997811/

4 International Finance Corporation. (2018). Financing India’s MSMEs: Estimation of Debt Requirement of MSMEs in India. International Finance Corporation.

5 TERI. (2023). Financing Decarbonisation of the Secondary Steel Sector in India: Towards an Enabling Environment. New Delhi, India: The Energy and Resources Institute.

6 https://www.ceicdata.com/en/indicator/india/gross-savings-rate

7 Ministry of Environment, Forest, and Climate Change (2023). INDIA: Third National Communication and Initial Adaptation Communication to the United Nations Framework Convention on Climate Change. Government of India.

8 Singh and Shrivastava (2024). Accelerating the Growth of Green Bonds in India. TERI.

9 T E R I. 2022 Financing Low Carbon Transition for India‘s MSME Sector New Delhi: The Energy and Resources Institute. 88 pp.

10 TERI. (2023). Financing Decarbonisation of the Secondary Steel Sector in India: Towards an Enabling Environment. New Delhi, India: The Energy and Resources Institute.

11 Lukas, A. (2018). Financing Energy Efficiency, Part 1: Revolving Funds. In World Bank Group. Retrieved July 11, 2023, from https://openknowledge.worldbank.org/server/api/core/bitstreams/647835bc-ffbe-5e01-baf5-e3b45120847d/content

12 Alliance for Financial Inclusion. (2022, March). Credit Guarantee Schemes: Facilitating MSME Financing in Africa During The COVID-19 Pandemic. https://www.afi-global.org/wp-content/uploads/2022/03/CreditGuarantee-Schemes-Facilitating-MSME-Financing-in-Africa-during-the-COVID-19-Pandemic_070322.pdf

13 De la Torre, A., Gozzi, J. C., & Schmukler, S. L. (2017). Credit guarantees: FOGAPE’s experience in Chile. Innovative Experiences in Access to Finance: Market-Friendly Roles for the Visible Hand? 195-220. https://doi.org/10.1596/978-0-8213-7080-3_ch7

14 TERI. (2023). Financing decarbonisation of the Secondary Steel Sector in India: Towards an Enabling Environment. New Delhi, India: The Energy and Resources Institute.

15 Ibid.

16 Chaturvedi, Vaibhav, and Ankur Malyan. 2021. Implications of a net-zero target for India's sectoral energy transitions and climate policy. New Delhi: Council on Energy, Environment and Water.

17 Mission Possible Partnership (2021). MAKING NET-ZERO STEEL POSSIBLE An industry-backed, 1.5° C-aligned transition strategy. Mission Possible Partnership.

18 Chaturvedi and Malyan (2021), ibid.

19 TERI (2023). Ibid.

20 https://www.climatebonds.net/standard/Steel.

21 CPI. 2024. Discussion Paper: Financing Industrial Decarbonisation. Challenges and Solutionsfor the Indian Iron and Steel Sector.

22 CPI. 2024. Discussion Paper: Financing Industrial Decarbonisation. Challenges and Solutions for the Indian Iron and Steel Sector.

23 https://projects.worldbank.org/en/projects-operations/project-detail/P181032

24 CPI. 2024 (ibid)

25 CPI. 2024 (ibid)

26 UNEPCCC. (2024, May). Article 6 Pipeline. https://unepccc.org/article-6-pipeline/

27 Adopted from Shrivastava et. al (2023), https://t20ind.org/research/a-framework-for-enhancing-international-climate-finance-flows/

28 The international experience of financing low carbon transition of industrial and energy sectors has demonstrated the application of diverse financial instruments, often in combinations as well. Energy Efficiency Revolving Funds (EERF) for specific sectors, for instance, have been utilized across the globe, with the backing of international finance from the World Bank or the Global Environment Facility (GEF). These EERFs have been utilized to provide guarantees (in Bulgaria, Hungary, and Slovenia), to enable credit lines for mobilizing private investments (in Thailand), or to finance projects around renewable energy and energy efficiency. In India, as well, EERFs have been availed to support urban infrastructure sprawl in Tamil Nadu. Similarly, the effective implementation of credit guarantees in parts of Africa has alleviated market distortion challenges to a great extent and helped resolve the bottleneck of payment delays to MSMEs in Chile.

Chapter 14

1 Institute of Climate Change and Sustainable Development of Tsinghua University

2 Source https://www.meti.go.jp/policy/energy_environment/global_warming/transition/transition_finance_technology_roadmap_iron_and_steel_eng.pdf

3 Source http://www.motie.go.kr/motie/ne/presse/press2/bbs/bbsView.do?bbs_seq_n=166810&bbs_cd_n=81

4 page 41 of the "2021 Iron and Steel Sector Report": https://www.sanayi.gov.tr/plan-program-raporlar-ve-yayinlar/sektor-raporlari/mu1406011405

5 https://unfccc.int/sites/default/files/NDC/2023-04/T%C3%9CRK%C4%B0YE_UPDATED%201st%20NDC_EN.pdf

6 German Steel Industry Association (WV Stahl)

7 EuropeanCommision:https://ec.europa.eu/commission/presscorner/detail/en/ip_24_585#:~:text=The%20European%20Union%20is%20committed,then%20store%20or%20utilise%20it.

8 UNDP Climate Promise: https://climatepromise.undp.org/what-we-do/where-we-work/south-africa#:~:text=In%20its%20updated%20NDC%2C%20South,its%20Low%2DEmission%20Development%20Strategy.

9 Sweden's draft integrated national energy and climate plan, Government of Sweden: Link

10 US Steel Weblink to include https://www.ussteel.com/newsroom/-/blogs/united-states-steel-corporation-announces-goal-to-achieve-carbon-neutrality-by-2050?_com_liferay_blogs_web_portlet_BlogsPortlet_redirect=https%3A%2F%2Fwww.ussteel.com%3A443%2Fnewsroom%3Fp_p_id%3Dcom_liferay_blogs_web_portlet_BlogsPortlet%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_p_mode%3Dview%26_com_liferay_blogs_web_portlet_BlogsPortlet_cur%3D5%26_com_liferay_blogs_web_portlet_BlogsPortlet_delta%3D5%26p_r_p_resetCur%3Dfalse

11 Low Carbon Work Promotion Committee of China Iron and Steel Association

12 Source: https://www.meti.go.jp/policy/energy_environment/global_warming/transition/transition_finance_technology_roadmap_iron_and_steel_eng.pdf

13 Ministry of Trade, Industry and Energy (MOTIE), Korea https://www.korea.kr docViewer/skin/doc.html?fn=6edabc4005c40af9225651251ae2d12a&rs=/docViewer/result/2023.02/17/6edabc4005c40af9225651251ae2d12a

14 Source: EPE website https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/roteiro-tecnologico-para-descarbonizacao-do-setor-siderurgico-brasileir

15 Source: https://www.sanayi.gov.tr/plan-program-raporlar-ve-yayinlar/sektor-raporlari/mu1406011405 (in Turkish only)

16 German Federal Ministry of Economic Affairs & Climate Action (BMWK). Copy the Germany´s steel Concept is available on the link: https://www.bmwk.de/Redaktion/EN/Publikationen/Wirtschaft/the-steel-action-concept.pdf?__blob=publicationFile&v=1

17 Source: Steel Roadmap : https://fossilfrittsverige.se/wp-content/uploads/2020/10/ffs_stalindustrin.pdf (in Swedish only)

18 Source A: https://www.energy.gov/sites/default/files/2022-09/Industrial Decarbonization Roadmap Fact Sheet.pdf and Source B: https://www.energy.gov/sites/default/files/2022-09/Industrial Decarbonization Roadmap.pdf

19 https://www.bostonmetal.com/green-steel-solution/

20 Low Carbon Work Promotion Committee of China Iron and Steel Association

21 Ministry of Trade, Industry and Energy (MOTIE), Korea https://newsroom.posco.com/en/posco-starts-to-design-the-hyrex-demonstration-plant/#:~:text=POSCO%20plans%20to%20achieve%20carbon,friendly%20hydrogen%20reduction%20steelmaking%20model.

22 Source: EPE website address: https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/roteiro-tecnologico-para-descarbonizacao-do-setor-siderurgico-brasileir

23 German Federal Ministry of Economic Affairs & Climate Action (BMWK)

24 Source: Steel Roadmap: https://fossilfrittsverige.se/wp-content/uploads/2020/10/ffs_stalindustrin.pdf (in Swedish only)

25 US Department of Energy Industrial Decarbonisation Roadmap https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonisation%20Roadmap.pdf

26 China Iron and Steel Association Weblink to include http://english.chinaisa.org.cn/do/

27 Source METI: https://www.meti.go.jp/policy/energy_environment/global_warming/transition/transition_finance_technology_roadmap_iron_and_steel_eng.pdf

28 https://unfccc.int/sites/default/files/NDC/2022-06/211223_The%20Republic%20of%20Korea%27s%20Enhanced%20Update%20of%20its%20First%20Nationally%20Determined%20Contribution_211227_editorial%20change.pdf

29 German Federal Ministry of Economic Affairs & Climate Action (BMWK)

30 Available on weblink: https://www.corporateleadersgroup.com/system/files/documents/swedish-steel-working-towards-a-climate-neutral.pdf

31 https://www.sustainability.gov/buyclean/index.html

32 https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf

33 https://www.energy.gov/mesc/advanced-energy-manufacturing-and-recycling-grants

34 https://www.energy.gov/oced/regional-clean-hydrogen-hubs

35 http://www.usclimatealliance.org/

36 Centre of Excellence for Climate Action in Energy-Intensive Industries (KEI), Cottbus: https://www.klimaschutz-industrie.de/en/topics/energy-intensive-industries/translate-to-english-stahlindustrie/

37 Federal Environment Agency: https://www.umweltbundesamt.de/search/content/green%2520and%2520steel?keys=green%20steel

38 Max Planck Society: https://www.mpie.de/newsroom/green steel/en

39 Fraunhofer-Society: https://www.ise.fraunhofer.de/en/press-media/press-releases/2022/fraunhofer-ise-demonstrates-first-long-term-operation-of-methanol-synthesis-from-blast-furnace-gas-with-miniplant.html

Chapter 15

1. National Steel policy 2017, Ministry of Steel, Government of India
2. Annual report 2021-22, Ministry of Steel, Government of India
3. A study on requirement and availability of technical manpower for steel industry in India, May 2015, IIT Kanpur
4. Achieving green steel, roadmap to a net zero steel sector in India, W. Hall, S.Kumar, S.Kashyap, S.Dayal, 2022, TERI
5. Towards a low carbon steel sector, overview of the changing market, technology and policy context of Indian steel, W. Hall, T Spencer, S. Kumar, 2020, TERI
6. Skill gap study cum labour market survey in iron and steel sector, Human resource demand analysis in iron and steel sector till -2030, 2022, NISST & IISSSC
7. Climate Compatible Growth (CCG) in the iron and steel industry in India: rethinking patterns of innovation, Alexandra Mallet, Prosanto Pal, 2021, CCG
8. Skills trends for green jobs in the steel industry in India, 2016, International Labour Organization
9. The Global Green Economy, 2023, Oxford economics

10. Gearing up the Indian workforce for a green economy, Mapping Skills Landscape for Green Jobs in India, Sattva, Skill council for green jobs.
11. Towards Greener steel, 2021, Ernst & Young
12. Preparing for a just transition, meeting green steel needs for a sustainable steel industry, 2021,Antonazzo, Luca, Stroud, Dean , Weinel, Martin, Dearden, Kate and Mowbray, Anna
13. Skill Gap Study: NISST for IISSSC,2022, IISSSC
14. IISSSC working papers on NCVET guidelines relating to development of QP/NOS, 2023, IISSSC

Chapter 17

1. CO2- Carbon Dioxide (https://climate.nasa.gov/vital-signs/carbon-dioxide/?intent=121)
2. CCS/CCUS- Carbon Capture, Utilization & Storage (https://www.dghindia.gov.in/assets/downloads/62bbedfa49947DraftUFCCRoadmap2030.pdf)
3. RD&D- Research Development & Deployment (Referred from this document)
4. DRI- Direct Reduced Iron (https://steel.gov.in/en/glossary-terms-definitions-commonly-used-iron-steel-industry)
5. SSI- Small Scale Industries (https://msme.gov.in/sites/default/files/CreditLinkCapitalSubsidyScheme%282%29%282%29.pdf)
6. TCS- Tonne of Crude Steel (https://ieefa.org/resources/steel-decarbonisation-india#:~:text=India's%20steel%20sector%20accounts%20for,intensity%20of%201.85%20tCO2%2Ftcs)
7. MRV- Monitoring-Reporting-Verification (https://pib.gov.in/PressReleasePage.aspx?PRID=1968882)
8. ANRF- Anusandhan National Research Foundation (https://dst.gov.in/)
9. BATs- Best Available Technologies (https://steel.gov.in/en/energy-environment-management-steel-sector)

Note

इस्पात मंत्रालय
MINISTRY OF
STEEL

सत्यमेव जयते