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Date: 31st July, 2025

To
The Hon'ble National Green Tribunal (NGT)
Principal Bench
Faridkot House, Copernicus Marg
New Delhi – 110001
India

Subject: Submission of Report on Grievances Related to Coal-Based Rotary Kiln Technology in the Indian Steel Sector

Respected Sir/Madam,

Greetings and best wishes from IIT Kharagpur!

We express our sincere gratitude to the Hon'ble National Green Tribunal for the opportunity to support this critical discourse on sustainable steel production in India. With utmost respect, I hereby submit the report titled "***Recommendations for Decarbonizing the Coal-Based Rotary Kiln Steel Sector in India***" for the kind consideration of the Hon'ble National Green Tribunal. This report has been prepared in response to the environmental concerns raised by the Hon'ble Tribunal regarding the decarbonization of coal-based Direct Reduced Iron (DRI) technologies [**referring to Application No: 766/2024 (I.A. No.: 562/2024)**], specifically those employing rotary kiln systems.

The report outlines strategic, actionable measures aimed at addressing the environmental and operational challenges inherent in the coal-based DRI route. Special attention has been given to the widespread adoption of rotary kilns by medium, small and micro enterprises, with the report proposing pragmatic solutions (in **Section 9**), also highlighting the associated challenges (in **Section 7**) and implications (in **Section 8**). The recommended decarbonization strategy aligns with the Government of India's vision and policy. It emphasizes waste heat recovery, the transition to cleaner and renewable fuels, and strict regulations on coal-based DRI producers.

This submission is intended to constructively support the national agenda on sustainable industrial practices and aid in the development of well-informed, equitable, and implementable policy frameworks. We trust that the insights and recommendations provided herein will contribute meaningfully to the NGT's deliberations.

We respectfully place this report before the Hon'ble Tribunal for its kind perusal and further guidance. Should any additional information or clarification be required, we remain at your service.

Yours sincerely,

479/1tep/NGT
06/08/2025

(Suman Chakraborty)

Recommendations for Decarbonizing the Coal-Based Rotary Kiln Steel Sector in India

This Document has been prepared in response to the National Green Tribunal Principal Bench, New Delhi [Application No: 766/2024 (I.A. No.: 562/2024)]

By
Indian Institute of Technology Kharagpur
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1 Background and Context

This report has been prepared by Prof Brajesh Kumar Dubey, who works in the area of Sustainability and Decarbonization at the Department of Civil Engineering, Indian Institute of Technology-Kharagpur, as per the directions issued by Honourable Mr. Justice Mr. Prakash Shrivastava, Chairperson, Honourable Mr. Justice Arun Kumar Tyagi, Judicial Member and Honourable Dr Afroz Ahmad, Expert Member before the National Green Tribunal (NGT) Principal Bench, New Delhi (Original Application No. 766/2024 (I.A. No. 562/2024) after the hearing dated 19.05.2025 to Indian Institute of Technology, Kharagpur. A grievance has been raised in the said application against the Coal-based Rotary Kiln Technology for manufacturing steel. Applicant raised the concerns related to Direct Reduced Iron (DRI), also known as Sponge Iron, which is predominantly manufactured using Rotary Kiln Technology that relies on coal as the primary raw material, causing pollution while urging for restrictions on this polluting process and only allowing this technology that uses green/clean fuel. The applicant has also referred to the report "Financing Decarbonisation of the secondary steel sector in India towards an enabling environment" and potential pathways for decarbonization of DRI production processes, Electric Arc Furnace (EAF) and Electric Induction Furnace (EIF) (or Induction Furnace (IF)). In view of the directions from NGT, A detailed independent study has been conducted to examine the veracity of the grievance pertaining to the pollution issue, including higher carbon footprint (a measure of climate change impact in terms of greenhouse gas emissions t-CO_2/t sponge iron and t-CO_2/t steel produced) of coal-based DRI product produced from the rotary kiln process. A detailed assessment has also been carried out to check the suitability, applicability and effectiveness of recommended decarbonization measures.

2 Introduction

Steel is essential for growing economies, and demand is expected to rise in the coming decades to support social and economic development, particularly in India, ASEAN nations, and Africa. Infrastructure development, urbanization, and industrialization in these regions are fuelling the need for steel, shaping the future of global supply and investment. As such, it significantly contributes to the continuous growth of the economy. On a global scale, the iron and steel industry generate around USD 1.6 trillion in revenue and provides jobs for more than 6 million individuals[1].

The steel industry plays a crucial role in India's economic development, accounting for around 2% of the country's GDP[2]. India is the world's second-largest producer of crude steel, with a production capacity of 179.5 million tonnes (MT). It also leads globally in sponge iron production, reaching 60.5 MT in FY 2023-24[2]. 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[1]. The Indian steel industry consists of primary and secondary producers, differentiated by their scale and methods of production. Primary producers predominantly employ the Blast Furnace-Blast Oxygen Furnace (BF-BOF) technique, whereas secondary producers utilize the DRI-EAF or the DRI-IF (or DRI-EIF) methods for the production of crude steel.

The Asia-Pacific region, spearheaded by India, stands as the global leader in the sponge iron industry. Worldwide, DRI production mainly uses natural gas as fuel, whereas in India, over 80% of this production comes from coal-powered rotary kilns[3]. India is the world's leading producer of sponge iron through the DRI process, accounting for 36% of global production. India's sponge iron output for 2024-25 was 55.6 MT, with the majority of production coming from coal-based rotary kilns, around 46 MT[13].

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[1] https://www.teriin.org/sites/default/files/2023-12/SNAPFI%20Steel%20Report%202023.pdf

[2] https://steel.gov.in/sites/default/files/2025-03/GSI%20Report.pdf

[3] https://www.sciencedirect.com/science/article/pii/S2211467X22001626

The remaining 8.9 MT is produced through natural gas-based vertical shaft technology[1] Error! Bookmark not defined.

Sponge iron plants operate either as integrated units, stand-alone facilities, or within industrial clusters. Most are concentrated in states like Odisha, Karnataka, Chhattisgarh, Jharkhand, and West Bengal. The coal-based sponge iron production is a highly energy-intensive sector. Approximately 98% of the energy consumed by coal-based DRI plants comes from thermal sources, while the remaining 2% is derived from electricity used to operate motors and auxiliary equipment[1]. The average specific energy consumption (SEC) of coal-based DRI plants ranges from 17-23 GJ/t-DRI[1].

Apart from being more energy intensive, the CO_2 emissions intensity of crude steel production via coal-based sponge iron-EIF route is ~4.1 t-CO_2/tonne of crude steel (tcs), which is significantly higher than the average intensity of steel production via the BF-BOF route (2.5 t-CO_2/tcs) in India. Over the years, coal-based sponge iron plants have still suffered from significant operational inefficiencies, substantial air emissions owing to the use of poor-quality coal, and the processing of raw materials has degraded local air quality.

To address these challenges, the industry requires a range of mitigation measures, including phasing out small-sized, old and technologically inefficient coal-based DRI Kilns. Some of the immediate decarbonization measures include the optimization of operational parameters to enhance energy efficiency, the adoption of waste heat recovery (WHR) systems, and the use of higher-quality raw materials such as iron ore pellets and low-ash coal to reduce emissions for medium and large-sized DRI Kilns. Medium and Long-term technologies may include replacing coal with syngas, natural gas and biochar. These methods have the potential to significantly lower the carbon footprint of DRI production.

This document provides a comprehensive review of CO_2 emission form steel production via coal-based sponge – EIF route, highlighting other environmental issues with coal based sponge iron production, mitigation approaches, and offers recommendations designed to support the sustainable transformation and decarbonization of India's coal-based rotary kiln technology for DRI production, in line with the request from the NGT Principal Bench (New Delhi, India) [Application No: 766/2024 (I.A. No.: 562/2024)].

3 Climate Change

Climate change refers to long-term shifts in temperatures and weather patterns, primarily driven by human activities, particularly the combustion of fossil fuels such as coal, oil, and natural gas. These actions release greenhouse gases (GHGs), notably CO_2, into the atmosphere where they trap heat and contribute to global warming.

The 1.5 °C target, established under the Paris Agreement, serves as a crucial benchmark in the global effort to address climate change. It aims to restrict the rise in average global temperature to no more than 1.5 °C above pre-industrial levels, in order to avert the most dangerous and irreversible consequences of a warming planet, such as extreme weather events, rising sea levels, ecosystem degradation, and large-scale human displacement.

Achieving this goal necessitates swift and comprehensive action, including significant reductions in greenhouse gas emissions, a rapid transition to clean energy sources, sustainable land management, and innovation in low-carbon technologies. Despite heightened international pledges, scientific assessments warn that current trajectories suggest this threshold may be surpassed within the coming decade if urgent and transformative measures are not implemented. Upholding the 1.5 °C limit is not only critical for safeguarding the environment but also for ensuring the resilience and security of communities worldwide. According to the Intergovernmental Panel on Climate Change (IPCC), exceeding 1.5 °C could trigger irreversible tipping points in the Earth's climate system.

The impacts are far-reaching: rising sea levels threaten coastal communities, extreme weather events like floods, droughts, and heatwaves are becoming more frequent and severe, and ecosystems are under stress, leading to loss of biodiversity. Climate change also poses significant risks to food and water security, global health, economic stability, and geopolitical peace, especially affecting vulnerable populations with limited resources for adaptation. Addressing it requires coordinated global efforts to reduce emissions and enhance resilience. The broader socio-economic implications are equally alarming. Climate-induced disruptions to food and water security, heightened disease transmission, and the displacement of vulnerable populations pose significant threats to global stability. Developing nations, in particular, face disproportionate burdens due to limited adaptive capacities and resource constraints.

Addressing this global crisis necessitates concerted international cooperation, focused on the mitigation of greenhouse gas emissions through decarbonization, the advancement of sustainable technologies, and the implementation of robust adaptation strategies to safeguard both human and ecological well-being.

To meet global energy and climate goals, emissions from the steel industry must fall by at least 50% by 2050[4], with continuing declines towards zero emissions being pursued thereafter. The IEA Sustainable Development Scenario sets out an ambitious pathway to net-zero emissions for the energy system by 2070[4]. By embracing innovation, deploying low-carbon technologies, and improving resource efficiency, steel producers have a significant opportunity to lower energy consumption and greenhouse gas emissions. These advancements can lead to more sustainable products while strengthening industry competitiveness.

By 2050, almost one-fifth of the steel produced globally is expected to come from India, a significant rise from its current share of about 5%[4]. India has therefore committed to lowering the emissions intensity of its GDP by 45% by 2030[5] and 100% 2070 compared to 2005 levels under its Nationally Determined Contributions (INDCs)[5]. To support this goal, the Ministry of Steel (MoS) has submitted sector-specific NDCs to the Ministry of Environment, Forest, and Climate Change (MoEF&CC), focusing on reducing greenhouse gas emissions. The strategy emphasizes adopting clean and sustainable technologies to enhance environmental performance in steel production while aligning with India's broader climate objectives[6].

4 Indian Steel Industry at a Glance

The Indian steel sector has an output multiplier of 1.4 and an employment multiplier of 6.8, underscoring its significance in driving economic growth and supporting India's ambitious infrastructure development plans[7]. The MoS introduced the National Steel Policy (NSP) with the objective of expanding India's steelmaking capacity to 300 million tonnes by 2030[8]. This initiative aims to support the country's growing demand for steel, drive industrial development, and enhance global competitiveness in the sector[9]. The objectives of the National Steel Policy are:

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[4] https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

[5] https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=1987752

[6] https://steel.gov.in/energy-and-environment-management-iron-steel-sector

[7] https://steel.gov.in/national-steel-policy-nsp-2017

[8] https://steel.gov.in/

[9] https://www.teriin.org/sites/default/files/2022-07/Achieving%20Green%20Steel%20Roadmap%20to%20a%20Net%20Zero%20Steel%20Sector%20in%20India.pdf

To domestically meet the entire demand of high-grade automotive steel, electrical steel, special steels and alloys for strategic applications by 2030-31.

- Increase domestic availability of washed coking coal so as to reduce import dependence on coking coal from ~85% to ~65% by 2030-31[7].
- Attain global standards in Industrial Safety and Health.
- **To substantially reduce the carbon footprint of the steel industry**.
- Research & Development in the sector through the establishment of the Steel Research and Technology Mission of India (SRTMI).

The crude steel production in 2023-24 was 144.3 MT with 43% through the BF-BOF route, 35% through the sponge iron/scrap-induction furnace route, and 22% through the scrap electric arc furnace route (***Figure 1***).

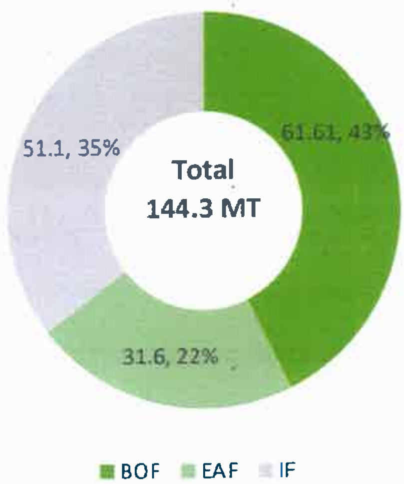

Figure 1: Crude steel production (MT) by route (FY2023-24)[2]

The BF-BOF route is the most commonly adopted and widely used route for large-scale steel production. In the conventional BF-BOF steelmaking process, iron ore is reduced in a blast furnace using coke and pulverized coal. The resulting pig iron is then refined in a BOF by blowing oxygen to reduce the carbon content of the hot metal and transforming it into liquid steel[10].

The EAF melts sponge iron and/or scrap steel under extremely high temperatures produced by electric arcs between electrodes. This EAF route in India accounts for about 21.9 % of the country's total crude steel production[11]. The steel production process in an EAF generally consists of three main phases: melting, oxidation, and reduction. While EAFs enable rapid melting of metals, they pose significant environmental challenges due to the emission of toxic gases, dust, and heat loss through radiation and convection[4].

IF is also one of the two primary methods of electric steel production, which operates using electrical energy. The melting process in an IF is based on electromagnetic induction, where a high-voltage current in the primary coil generates a low-voltage, high-current in the metal, acting as the secondary coil. This high-frequency alternating magnetic field induces strong eddy currents within the charge, producing rapid and efficient heating[12]. A major distinction between EAFs and IFs is their method of heating and thermal efficiency, with IFs tending to have faster heating and be more efficient.

[10] https://www.sciencedirect.com/science/article/abs/pii/S1364032113002918
[11] https://steel.gov.in/sites/default/files/2025-04/Steel_English_AR_2024%20%281%29.pdf
[12] https://www.ispatguru.com/steelmaking-by-induction-furnace/

India produced 152 MT crude steel in 2024-25, which includes hot metal of 91.3 MT, Pig Iron of 8.3 MT and Sponge Iron of 55.6 MT[13]. It is also to be noted that 84% of sponge Iron is produced through the coal-based route (~46.7 MT)[13]. India's steel production grew at an annual rate of 8% between 2002 and 2023[13]. Among different steelmaking processes, the EAF and IF methods experienced higher growth rates of 8% and 12%, respectively, while the BOF route saw a slightly lower growth of 7% (***Figure 2***). This trend reflects the increasing adoption of EAF and IF technologies in India's steel industry.

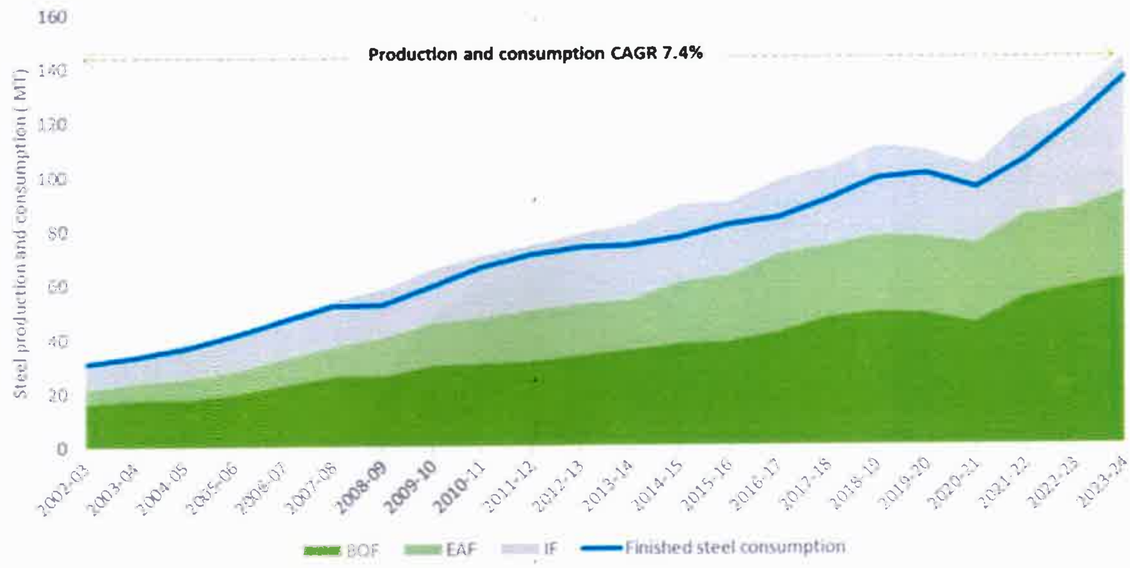

Figure 2: Growth in crude steel production and consumption in India[2]

5 CO_2 Emissions from the Steel Industry

This section provides an overview of the CO_2 emissions of various steel production process routes in India and globally. As shown in ***Figure 3***, the iron and steel sector is highly energy- and emissions-intensive, accounting for 8% of global final energy use and 7% of global direct energy-related CO_2 emissions[14].

Currently, the sector accounts for about 8% of global final energy demand and 7% of energy-related CO_2 emissions, including process emissions[4] and 25% of industrial CO_2 emissions. As per IEA 2023 data, the steel industry has 2.8 Gt CO_2e of scope 1+2 emissions, with 83% of fossil fuels in the fuel mix[4].

Figure 3: IEA - Key Performance Data 2023 - Steel Error! Bookmark not defined.

[13] https://jpcindiansteel.nic.in/writereaddata/files/TrendReportApril%202025.pdf
[14] Iron and Steel Technology Roadmap - Towards more sustainable steelmaking

According to the World Steel Association's 2024 Sustainability Indicators Report, the average CO_2 emissions intensity of global crude steel production was 1.91 t-CO_2/tcs in 2023 (**Table 1**) [15].

Table 1: Emission intensity of crude steel production by different processes - Global[15]

Sl No	Process Route	CO_2 emission intensity (t-CO_2 /tcs)
1	BF - BOF	2.33
2	Scrap – DRI (Gas-based)	0.68
3	DRI (Gas-Based) - EAF	1.37
	Average emission intensity	**1.91**

Steel production in India contributes to ~12% of CO_2 emissions[2], which is a major challenge for the country to progress towards its Net-Zero commitments. Further, given India's massive $1.3 trillion infrastructure plan[16], the demand for low-carbon emissions steel is only going to go up, and it thus becomes imperative to reduce emissions in order to tackle the adverse effects of climate change. In India, the steel sector is heavily dependent on coal, which makes up about 85% of its energy needs[17]. Currently, the BF-BOF route accounts for a 45% share in steel production, whereas EAF/IF routes account for the balance. As per the MoS, the Indian steel sector consumes approximately 75 MT of oil equivalent (Mtoe) of total energy (as of 2022), with an average emission intensity of 2.54 t-CO_2/tcs in 2023-24 (**Table 2**)[2] which is significantly higher than the global average of 1.91 t-CO_2/tcs.

Table 2: Emission intensity of crude steel production by different process routes in India[2]

Sl No	Process Route	CO_2 emission intensity range (t-CO_2 /tcs)
1	Coal-based DRI- EIF route*	3.2[18]
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 emission intensity for the coal-based DRI-EIF route is comparatively very high compared to the above production routes, as calculated in this study.

The **Green Steel Certificate** is part of India's ambitious initiative to decarbonize its steel sector and achieve net-zero emissions by 2070. India has become the first country in the world to introduce a Green Steel Taxonomy, which establishes clear guidelines for determining the CO_2 thresholds of steel production. The concept of **"Green Steel"** is defined by the amount of CO_2 emissions released during the steel production process, with a threshold of **2.2 t-CO_2 equivalent (t-CO_2e) per tonne of finished steel (tfs)**[19]. Steel plants with emissions lower than this threshold are eligible for green certification, and the level of certification is determined based on how much their emissions fall below this standard.

[15] Sustainability-indicators-report-2023.pdf
[16] https://www.ibef.org/industry/infrastructure-sector-india
[17] https://www.iitk.ac.in/JTRC/file/Steel%20Report%20Final-3.pdf
[18] https://globalenergymonitor.org/projects/global-iron-and-steel-tracker/electric-arc-furnace-analysis-tool/
[19] https://steel.gov.in/sites/default/files/2025-03/Taxonomy%20Brochure.pdf

To facilitate this process, the **MoS & the Ministry of Heavy Industries** have outlined a rating system for Green Steel. The rating is classified into three categories: five-star, four-star, and three-star, depending on the emission intensity. Five-star rated steel has emissions below 1.6 t-CO_2e/tfs, while four-star and three-star ratings are given for steel with emission intensities between 1.6-2.0 and 2.0-2.2 t-CO_2e/tfs, respectively[19]. Steel with emission levels exceeding 2.2 t-CO_2e/tfs is excluded from the green certification[19]. This rating system allows consumers and businesses to easily identify steel products that contribute to a cleaner and more sustainable environment.

6 India's Sponge Iron Production and CO_2 emissions

This section presents the landscape of Indian coal-based sponge iron/DRI production, growth, production processes and assessment of GHG emissions associated with the production of sponge iron and further steel production through the EAF/IF route. **The global sponge iron market is projected to maintain stable expansion, achieving a CAGR of around 6% between 2025 and 2030[20].** The Asia-Pacific region, spearheaded by India, stands as the global leader in the sponge iron industry. This dominance stems from its expansive coal-based DRI capacity and rising domestic steel consumption. **India is the world's leading producer of sponge iron through the DRI process, accounting for 36% of global production[1].**

This method involves the direct reduction of iron ore to produce metallic iron, using coal, natural gas, or hydrogen as reducing agents. India's sponge iron output for 2024-25 was 55.6 MT, with the majority of production coming from coal-based rotary kilns, around 46 MT[13]. The remaining 8.9 MT is produced through natural gas-based vertical shaft technology[13]. Raw materials used for the production of sponge iron through the coal route are non-coking coal, iron ore and dolomite. Non-coking coal should have high reactivity with high fusion temperature but low ash fusion temperature. Dolomite is mainly used as a desulphurizing agent. There are approximately 344 DRI plants across the country, of which 339 are coal-based rotary kilns[2]. **Sponge iron plants operate either as integrated units, stand-alone facilities, or within industrial clusters.** Most are located in regions characterized by forested landscapes, widespread poverty, and the presence of marginalized tribal populations. These areas are typically near mineral-rich mining zones, offering easy access to raw materials and infrastructure such as roads and utilities[21]. **Sponge iron plants are concentrated in states like Odisha, Karnataka, Chhattisgarh, Jharkhand, and West Bengal (*Figure 4*).**

[20] https://www.globalgrowthinsights.com/market-reports/sponge-iron-market-114958#:~:text=The%20global%20sponge%20iron%20market,period%20%5B2025%E2%80%932033%5D.
[21] https://cdn.cseindia.org/attachments/0.25223700_1499927364_sponge_iron_layout.pdf

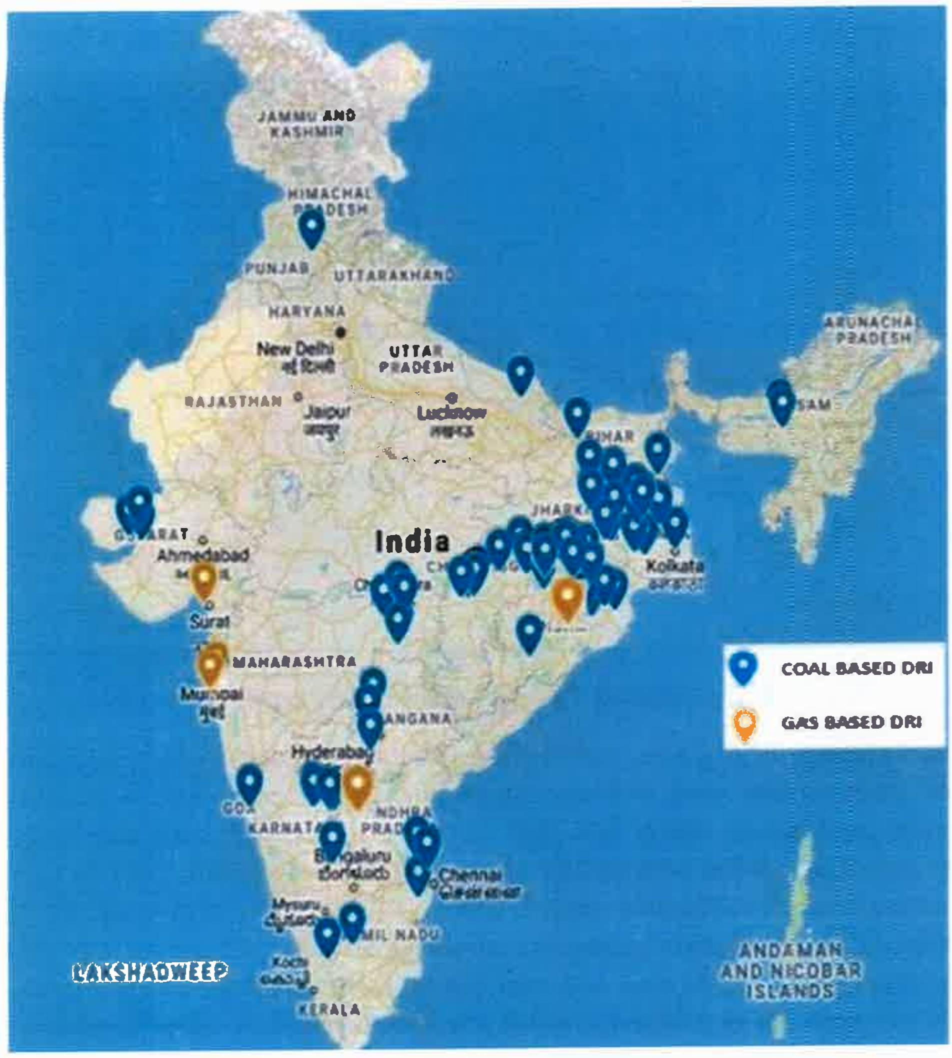

Figure 4: Sponge Iron Production in India[9]

6.1 Coal-based Sponge Iron Production using Rotary Kiln

India's coal-based sponge iron production involves horizontal rotary kilns lined with 150–200 mm of refractory material to protect the shell, set at a 2.5%–3.0% slope toward the discharge end[22]. Air blowers along the heating zone supply the necessary combustion air. Sponge iron production primarily relies on iron ore/ iron ore pellets, non-coking coal, and limestone/dolomite. Hematite, with an iron content of at least 65%, is preferred, and iron ore is used in the form of lumps or pellets. Most DRI plants in India operate with smaller rotary kilns, typically having capacities of 100 tonnes per day (tpd) or less, using iron ore lumps[22].

[22] https://www.teriin.org/sites/default/files/2021-08/Direct%20Reduction%20of%20Iron%20Process.pdf

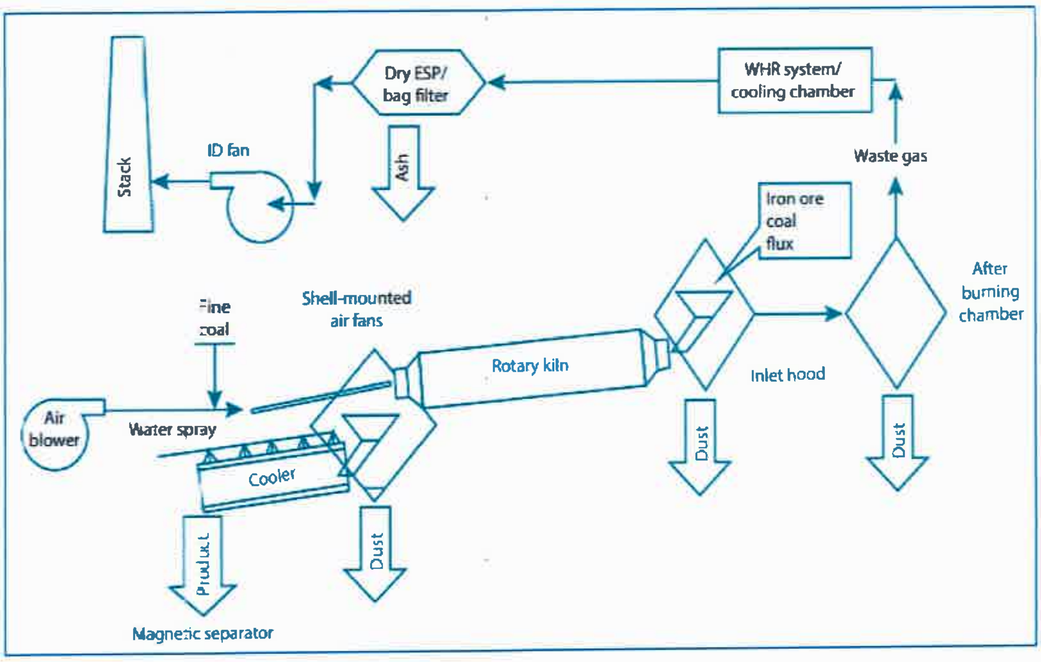

Figure 5: Coal-based Sponge Iron Production in Rotary Kiln

The coal-based sponge iron plants suffer from low production yields, significant operational inefficiencies, poor-quality coal, transportation losses, etc. The environmental challenges associated with coal-based rotary kiln DRI plants are complex and significant. A primary concern is air pollution, as the combustion of coal and the processing of raw materials lead to substantial emissions of particulate matter (PM), SO_2, and NO_x, which significantly degrade local air quality. Additionally, this production method is characterized by high CO_2 emissions, depending on the quality of the coal and iron ore utilized. Coal-based sponge iron industries are emitting significant amounts of pollutants, which are either directly or indirectly released into nearby land, water bodies such as streams and rivers, as well as into the atmosphere[23].

[23] https://rsisinternational.org/Issue20/93-105.pdf

6.2 Calculation of CO_2 emission from coal-based sponge iron production in India

The total direct CO_2 emission from sponge iron production has been calculated based on the mass balance approach of carbon dioxide. While indirect CO_2 emissions have been calculated using the upstream CO_2 emission factor of specific inputs, using the World Steel guidance.

The estimated CO_2 emission from coal-based sponge iron production (using iron ore lumps) is shown in **Table 3** below:

Table 3 Estimation of CO_2 emission from coal-based sponge iron production using iron ore lumps in India

Coal-based sponge iron using iron ore lumps										
Inventory Data							CO_2 Emissions Calculation			
Sl No	Input(s)	Unit	Range	Quantity	Remark	Reference	Carbon Content (%)	Direct Emissions (t-CO_2)	Upstream EF [t-CO_2e/t]	Indirect Emissions (t-CO_2e)
1	Iron ore lumps	t	1.6-1.8	1.7		*CEEW*[24]	-		0.003[25]	0.005
2	Dolomite	t	0.03-0.04	0.04		*MoS*[2]	13%	0.019	0.000	0.000
3	Domestic coal	t	1.4-1.6	1.5	*55% C [50%-65%]*	*CEEW*[24]	55%	3.025	0.045[26]	0.068
4	Electricity	kWh	90-100	100		*MoS*[2]	-		0.790	0.079
Sl No	Output(s)	Unit	Range	Quantity	Remark	Reference	Carbon Content (%)	Direct Emissions (t-CO_2)	Upstream EF [t-CO_2e/t]	Indirect Emissions (t-CO_2)
1	Sponge Iron	t	1	1			2%	-0.073		
2	Dolochar	t	0.28-0.30	0.3		*CSE*[21]	13%	-0.143		
3	Electricity	kWh	350-380	380		*CEEW*[24]			0.790	-0.300
Total CO_2 Emissions (Direct + Indirect) [t-CO_{2e}/t of sponge iron]									2.68	

As per the above estimation, total CO_2 emission from coal-based sponge iron production using iron ore lump is **2.68 t-CO_2/t of sponge iron**.

[24] https://www.ceew.in/sites/default/files/decarbonising-coal-based-dri-production.pdf
[25] https://www.nmdc.co.in/cms-admin/Upload/Environment_Sustenbility_Documents/f75fc58a07434cb6b33e1e10955adf65_20241130164302358.pdf
[26] https://d3u7ubx0okog7j.cloudfront.net/documents/Coal_India_BRSR_26_07_2024_V3.pdf

The estimated CO_2 emission from coal-based sponge iron production (using iron ore pellets) is shown in the **Table 4** below:

Table 4 Estimation of CO_2 emission from coal-based sponge iron production using iron ore pellets in India

Coal-based sponge iron using iron ore pellets										
Inventory Data							CO_2 Emissions Calculation			
Sl No	**Input(s)**	**Unit**	**Range**	**Quantity**	**Remark**	**Reference**	**Carbon Content (%)**	**Direct Emissions ($t\text{-}CO_2$)**	**Upstream EF [$t\text{-}CO_2e/t$]**	**Indirect Emissions ($t\text{-}CO_2e$)**
1	Iron ore Pellets	t	1.4-1.6	1.5		*CEEW*[24]	-		0.137[27]	0.206
2	Dolomite	t	0.03-0.04	0.04		*MoS*[2]	13%	0.019	0.000	0.000
3	Domestic coal	t	1.2-1.4	1.25	55% C [50%-65%]	*CEEW*[24]	55%	2.521	0.045[26]	0.056
4	Electricity	kWh	90-100	100		*MoS*[2]	-		0.790	0.079
Sl No	**Output(s)**	**Unit**	**Range**	**Quantity**	**Remark**	**Reference**	**Carbon Content (%)**	**Direct Emissions ($t\text{-}CO_2$)**	**Upstream EF [$t\text{-}CO_2e/t$]**	**Indirect Emissions ($t\text{-}CO_2$)**
1	Sponge Iron	t	1	1			2%	-0.073		
2	Dolochar	t	0.28-0.30	0.3		*CSE*[21]	13%	-0.143		
3	Electricity	kWh	350-380	380		*CEEW*[24]			0.790	-0.300
Total CO_2 Emissions (Direct + Indirect) [$t\text{-}CO_2/t$ of sponge iron]									**2.36**	

As per the above estimation, total CO_2 emission form coal-based sponge iron production using iron ore pellets is **2.36 $t\text{-}CO_2/t$ of sponge iron**.

[27] https://worldsteel.org/wp-content/uploads/CO2_User_Guide_V11.pdf

6.3 CO_2 Emissions from crude steel production via coal-based sponge iron – EIF route in India

The estimated CO_2 emission from crude steel production via coal-based sponge iron – electric induction furnace is shown in **Table 5** below. IF generally consumes 800-900 kWh of electricity per tcs production.

Table 5 Estimation of CO_2 emissions from crude steel production via coal-based sponge iron – EIF route in India

Crude steel production via coal-based sponge iron – EIF route										
Inventory Data							CO_2 Emissions Calculation			
Sl No	Input(s)	Unit	Range	Quantity	Remark	Reference	Carbon Content (%)	Direct Emissions ($t\text{-}CO_2$)	Upstream EF [$t\text{-}CO_2e/t$]	Indirect Emissions ($t\text{-}CO_2e$)
1	Sponge Iron	t	0.9-1.3	1.2			2%	0.088	2.68	3.215
2	Steel Scrap	t	0.1-0.2	0.1		*CEEW[24]*	0%	0.000	0.000	0.000
3	Ferro manganese	t	0.005	0.01			0%	0.000	6.500	0.065
4	Silico manganese	t	0.01	0.01			0%	0.000	8.500	0.085
5	Limestone	t	0.02	0.02			12%	0.009		
6	Electricity	kWh	800-900	850		*CEEW[24], MoS[2]*	-		0.790	0.672
Sl No	Output(s)	Unit	Range	Quantity	Remark	Reference	Carbon Content (%)	Direct Emissions ($t\text{-}CO_2$)	Upstream EF [$t\text{-}CO_2e/t$]	Indirect Emissions ($t\text{-}CO_2$)
1	Steel	t	1	1			0.2%	-0.007		
2	Slag	t	0.1-0.2	0.2		*CSE[21]*	0%	0.000		
Total CO_2 Emissions (Direct + Indirect) [$t\text{-}CO_2/tcs$]									**4.13**	

As per the above estimation, total CO_2 emission from crude steel production via coal-based sponge iron-EIF route is 4.13 $t\text{-}CO_2/tcs$.

Therefore, the CO_2 emissions intensity of crude steel production via coal-based sponge iron-EIF route (4.13 $t\text{-}CO_2/tcs$) is significantly higher than the BF-BOF route (2.5 $t\text{-}CO_2/tcs$) (Table 6).

Table 6: Crude Production and CO_2 Emissions in 2024

Sl No	Route	Crude Steel Production (MTPA)	CO_2 Emissions ($t\text{-}CO_2/tcs$)	Total CO_2 emissions ($MT\text{-}CO_2/year$)
1	Average BF-BOF Route	60	2.5	150
2	Coal Sponge Iron-EIF Route	40	4.1	164

Crude steel production of ~40 MTPA[2] through the coal-based sponge iron-EIF route results in annual CO_2 emissions of about **164 MT-CO_2/year**, with an emission intensity of 4.1 t-CO_2/tcs, a way higher contribution to national GHG emissions in comparison to the BF-BOF route despite reduced crude steel production by 33%. In contrast, the BF-BOF route produces around 60 MTPA[2] of crude steel, emitting approximately **150 MT-CO_2/year**, with a lower emission intensity of 2.5 t-CO_2/tcs. These high CO_2 emissions are caused by small and medium-sized sponge iron companies clustered around various states of India, unlike a smaller number of well-organized, large, integrated steel plants producing steel through the BF-BOF route.

According to the Gazette notification issued by MoEF &CC dated 23rd June 2025, related to the Carbon Credit Trading Scheme (CCTS), defining the Indian carbon market framework for trading carbon credit schemes to reduce, remove, or avoid GHG emissions measured as GHG emission intensity (GEI) in t-CO_2 equivalent per tonne of output or product. Baseline GHG emission intensity for sponge iron products varies in the range of 2 t-CO_2e/t sponge iron to 3 t-CO_2e/t sponge iron. Our study indicates on average 2.68 t CO_2e/t of sponge iron and 4.1 t-CO_2e/tcs, which is very high in comparison to the steel produced through the BF-BOF route, with an average 2.5 t-CO_2e/tcs in India.

Also, the emission intensity of **4.1 t-CO_2/tcs** is significantly higher than the **2.2 t-CO_2/tcs** threshold set by the MoEF&CC for a three-star rating under the Green Steel Taxonomy for steel production. It is evident that reaching the Green Steel Taxonomy by sponge iron-based producers will be a gigantic task and reflects a low probability of achieving this threshold in the next 10-20 years. There is also a lack of technology and strong barriers to investment for these companies to bring down the GHG emissions to the desired level. At present, India does not have any incentive schemes for supplying low-carbon-emission steel products in the market, while sponge iron-based steel producers conveniently sell high-carbon-emission steel products in the market without any penalty. The steel industry is under extreme pressure in India, being one of the significant contributors of industrial GHG emissions, to bring down its GHG emissions in line with the 1.5-degree target.

The EU's Carbon Border Adjustment Mechanism (CBAM) is a tool to put a fair price on the carbon emitted during the production of carbon-intensive goods that are entering the EU, and to encourage cleaner industrial production in non-EU countries. To comply with the reporting requirements during the transition period, the EU has provided default emission factors for various steel products. **The default values represent a 'world' average, weighted by production volumes and have set the default for the coal-based DRI (CN Code 7203 - Ferrous products obtained by direct reduction of iron ore and other spongy ferrous products) as 4.81 tCO_2/tcs[28]. These companies will have to pay a hefty sum to the buyers against the differential carbon price if they export in the European Union, becoming uncompetitive in the market.**

[28] https://taxation-customs.ec.europa.eu/system/files/2023-12/Default%20values%20transitional%20period.pdf

7 Key Challenges and Issues of Coal-based Rotary Kilns

Apart from high CO_2 emissions, coal-based sponge iron production has several other challenges, including high energy consumption, low quality domestic coal and iron ore, low yield, high waste generation and air pollution, etc. This section summarizes the major roadblocks towards the decarbonization of coal-based DRI production in India.

Air pollution

Air pollution is also a major concern in the sponge iron industry, with key pollutants including particulate matter (PM 2.5/PM10) and gaseous emissions such **as SO_2 and NO_x.** Dust, a significant issue for the sector, is released into the air from both fixed sources (like stacks) and fugitive emissions from material handling, storage, loading, unloading, and transportation. Other critical emission points include kilns, cooler discharge, and product houses.

The situation gets challenging due to the non-installation or non-operation of pollution control equipment. Medium and small-scale plants dominate the sector, and these do not have sufficient technical competence or the financial capacity to install pollution control equipment. Lack of maintenance, improper design, and non-operational pollution control equipment at night contribute towards increased emissions. Many small and medium-sized coal-based sponge iron plants intentionally keep pollution control equipment such as an electrostatic precipitator (ESP) and a bag filter **non-operational to reduce the high electricity cost.**

On average, sponge iron production results in SO_x emissions of approximately 596 g/t of sponge iron and NO_x emissions of around 1,637 g/t of sponge iron[29]. Since sponge iron manufacturers consume a significant quantity of coal in comparison to the BF-BOF route, this leads to higher SO_2 and NO_x emissions. While the BF-BOF route coal combustion goes through the gas cleaning systems in coke ovens and desulphurization during steel-making processes. Sponge iron industries contribute significantly to **air pollution**, with emissions **originating from kilns, raw material handling, and dust generated by trucks travelling** on unpaved roads. These pollutants negatively impact the health of nearby residents, leading to respiratory and other health issues. Additionally, pollution affects local livestock and forests, disrupting ecosystems and threatening the livelihoods of those dependent on agriculture and forest resources.

Photographs of high air pollution from coal-based sponge iron plants in India are shown below:

[29] https://www.diva-portal.org/smash/get/diva2:1507502/FULLTEXT01.pdf

Fugitive emissions

In India's coal-based sponge iron (or DRI) plants, fugitive emissions arise from multiple sources tied to material handling and processing. These include raw material, fuel and product movement, storage and stacking operations road transport activities, and discharge points at the rotary kiln and cooler. As per the CSE report, high fugitive emissions from cooler discharge and product separation houses were observed at the plant.

In small and medium-sized sponge iron plants, raw materials and coal are predominantly transported by uncovered trucks and unloaded through a truck tippler, resulting in significant fugitive emissions and material losses. On the other hand, fully integrated steel plants following the BF-BOF route typically rely more controlled system of dedicated rail networks for transporting raw materials and coal with lower emissions and reduced material wastage. Also, raw material storage in these plants is **mostly unpaved and without any cover, wind curtains, a dust suppression system, a proper green belt, a boundary wall and a run-off collection system. Also, in these plants, crushers and screeners are not equipped with proper enclosures, air suction with bag filters and dry fog dust systems[30].** These factors ultimately lead to higher fugitive emissions. **Photographs of high fugitive emissions from coal-based sponge iron plants in India are shown below.**

[30] Pollution in Sponge Iron Industry

Solid waste generation

Sponge iron production generates solid waste in various forms, **including char, dust from the settling chamber, kiln accretion, ESP residues**, and sludge from gas cleaning plants. A 0.033 MTPA sponge iron plant produces 29 tonnes of char daily, contributing to a total solid waste load of 47 tonnes per day[21].

Table 7 Solid Waste Generation from Coal-based Sponge Iron Production in India[Error! Bookmark not defined.]

Sl No	Waste	(tonnes/tonne of sponge iron produced)
1	Char	0.28 - 0.32
2	Dust from the settling chamber	0.20 – 0.24
3	ESP waste	0.17 – 0.19
4	Kiln accretion	0.015 – 0.02

The waste char is usually dumped in the factory premises or nearby agricultural fields, reused in a captive power plant or sold. Small-scale industrial plants often struggle with waste char disposal due to limited land and resources. **In Jharkhand, 60% of industries dump char, 26% reuse it, and 15% sell it**[21]**. Meanwhile, industries in West Bengal and Odisha dispose of char (100%) by dumping it within or outside their premises**[21].

Crude steel production via the **BF-BOF route** generates **300-500 kg of waste/tcs**, with **around 90% utilized** within steelmaking processes, while BF slag is utilized in cement making, and BOF slag is used for aggregates and internal recycling. In contrast, the **coal-based sponge iron – EIF route** produces **600-800 kg of waste/tcs**[21], but due to inadequate recycling, most of the waste leads to disposal in nearby areas and causes various **environmental and health risks**.

Health issues

The emissions of sulfur oxides, nitrogen oxides, and hydrocarbons into the air from sponge iron production can contribute to respiratory **health issues** in humans. These pollutants can lead to conditions such as chronic bronchitis, cough, phlegm buildup, and may worsen asthma symptoms, posing significant risks to nearby communities.

As per the CSE 2011 report[21], **in Odisha, nearly 2,00,000 people are adversely impacted by sponge iron plants, primarily due to pollution-related issues.** In Chhattisgarh, residents of areas like Siltara, Urla, and Borjhara are experiencing serious **health problems, including asthma, skin disorders, bronchitis, and even cases of tuberculosis**. In Bellary, Janakunte village has been suffering a steep rise in asthma cases over the last three to four years, profoundly affecting the health and daily lives of its residents. In the Durgapur-Asansol region, a significant number of schoolchildren are affected by upper and lower respiratory tract infections, highlighting the deteriorating air quality. The condition of sponge iron factory workers, who endure prolonged exposure to toxic emissions, is likely far worse. These workers often lack access to routine health check-ups, leaving them vulnerable and untreated. According to Nagarik Mancha, a West Bengal-based NGO, nearly **7,000 workers** employed across **42 sponge iron plants in** the state are reportedly suffering from various health disorders[21].

Residents living near sponge iron plants report a growing range of health concerns. Continuous exposure to toxic gas emissions has caused irritation in the respiratory tract, with many developing asthma-like symptoms and chronic respiratory illnesses.

The **CSE report** highlights severe pollution in Odisha's **Kuarmunda cluster**, particularly affecting villages such as **Kuarmunda, Kukundabahal, Klashirira,** and **Puturikham**. Environmental degradation has taken a heavy toll on local wildlife—species like **bears, foxes,** and **hyenas** have been forced to migrate from the **Chadri Reserve Forest** to **Mudra Pahad Reserve Forest** due to worsening air quality and habitat loss. Similarly, high pollution levels have been recorded in Baramusa and Kendrikala, situated just 0.5 km from the Bonai cluster[21]. Additional villages in Bonai facing environmental stress include Jareikala, Gobindpur, Purunapani, and Rajamunda, where residents are grappling with the consequences of industrial emissions[21]. In **many villages of West Bengal**, residents face persistent dust pollution that settles on homes, belongings, and even their bodies, severely affecting everyday life[21]. This environmental degradation has led to rising cases of **respiratory illnesses in children**, sparking public concern. The situation has grown so dire that many families have relocated to neighboring villages in search of cleaner, safer conditions[21].

Water pollution

Waste generated by the sponge iron industry significantly alters the physicochemical characteristics of water, contributing to its pollution. In the monsoon season, water pollution becomes a major concern in sponge iron plants. During rain, runoff from raw material stockpiles, as well as oil and chemical storage areas, which then contaminates nearby surface water sources, including ponds, rivers and agricultural canals[30]. The surface waters near sponge iron plants contain high levels of turbidity, TDS, TS, heavy metal impurities (such as Cu, Hg, Cd, and Pb), which are not within the desirable limits given by IS[23].

According to the CSE 2011 report[21], ponds near sponge iron plants in the Bonai cluster (Odisha) are heavily contaminated, their surfaces coated with thick layers of dust that render the water unusable for basic activities like bathing and washing. In **Kendrikala village**, the community pond is especially affected, worsened by **M/s Shiva Metallics**, which reportedly disposes of **char waste** directly into the water body relied on by locals. The situation is just as alarming in the surrounding natural ecosystems. Pollution has drastically altered the **Brahmani River**, turning the riverbed black and causing the disappearance of once-abundant **prawn species**, which were a vital part of the local catch. None of the sponge iron plants in either cluster treats their **liquid effluents**, with some reportedly releasing untreated wastewater directly into **agricultural fields**[21]. Villagers claim their land is now blanketed with a black residue, severely impacting soil health and crop viability. **Kendrikala** and **Baramosi** are among the worst-hit, suffering long-term damage from this unchecked discharge. During the rainy season, contamination of local water bodies worsens, leading to outbreaks of **gastrointestinal diseases** among villagers. Pollution has made basic resources like clean air and water a serious health hazard[21].

High energy consumption

The sponge iron production is recognized as a high-energy sector. The SEC coal-based sponge iron plants range from **17-23 GJ/t-sponge iron[1], which is higher than the gas-based DRI production (10-11 GJ/t). It has also been observed that very few companies are implementing waste heat recovery in their kilns, making them less efficient and highly carbon-intensive.** The small and medium-sized sponge iron plants also face the lack of adoption of energy efficiency through waste heat recovery.

The primary role of heat energy in a rotary kiln is to raise the feed material's temperature to drive the chemical reactions that reduce iron ore to metallic iron. However, several types of heat losses can occur during this process, including:

- Heat loss through off-gases comprising sensible heat and chemical heat (carbon monoxide and unburnt carbon)
- Heat loss due to moisture
- Heat loss due to char formation
- Sensible heat loss in kiln discharge consisting of sponge iron and coal–char
- Wall losses from kiln surfaces

It has also been observed that such companies lack energy management systems, and leakage/wastage of energy is observed at multiple locations. These facilities face severe variation in the feed quality, improper operational control, lack of maintenance of equipment, poor health of the rotary kiln, unskilled workers, etc. Causing a significant decline in productivity and lower energy efficiency.

Lack of good-quality coal

Indian coal typically contains a high ash content, ranging from 15% to 45%, with most domestic supply falling between 35%-45% whereas imported coal generally has much lower ash content, between 10%-20%[31, 32]. As a result, producing one tonne of DRI with domestic coal requires a greater volume of coal, which leads to lower energy efficiency and higher emission intensity. However, the elevated cost of imported coal forces the Indian steel industry to rely on domestic sources to remain cost-competitive, ultimately contributing to increased emissions[33]. These facilities are at the cost of high energy intensity, with significant GHG emissions, but are managing to be cost-competitive in comparison to the products produced through the BF-BOF route.

Also, sponge iron production requires **higher coal consumption** compared to steel production via the BF-BOF route. As for producing 1 t of crude steel, **1.5 t of coal is required for the sponge iron route, while in the Blast furnace route, overall coal consumption is well below 1 t**. It is also evident that steel produced through the BF route uses very high-quality coal in comparison to the sponge iron route, while utilising all the fractions of the coal product, such as Tar, BTX and Coke oven gas heat.

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[31] https://sansad.in/getFile/loksabhaquestions/annex/171/AU677.pdf?source=pqals#:~:text=(a):%20Ash%20content%20of,ii.

[32] https://www.pib.gov.in/PressReleasePage.aspx?PRID=1515278

[33] https://www.npcindia.gov.in/NPC/Uploads/Competencies/Manual%20Iron%20&%20Steel%20Final.pdf

Use of low-quality iron ore:

Despite the limited availability of high-quality iron ore lumps, most coal-based sponge iron plants in India use iron ore lumps in the rotary kiln. This results in resource scarcity as lump is a scarce material, and simultaneously, during the mining of lump, iron ore fines are also generated and generally kept unutilized. It has been noticed that very few companies are using pellets in their rotary kiln. There are very few instances wherein companies have installed a palletization plant to utilize the iron ore fines. Also, the use of iron ore/pellets by the small and medium-sized plants is decided purely on economic considerations and their local availability, so again, on the cost of high GHG emissions, sponge iron manufacturers try to be cost-competitive.

In contrast, these low-grade iron ore fines can be more efficiently used in sinter plants and pellet plants for crude steel production via the BF–BOF route, which typically leads to lower emissions and waste generation, resulting in the utilization of resources efficiently.

Low productivity

Small-scale coal-based sponge iron plants in India face operational challenges that result in low productivity, higher air emissions, and increased waste generation. Their limited scaling potential also makes it difficult to expand sponge iron production efficiently. **In contrast, the BF–BOF route offers a viable alternative to the sponge iron–EIF method, with demonstrated advantages in scalability, higher productivity, and lower waste generation.**

According to a CSE report, the majority of sponge iron plants in India operate at small or medium scale. Kilns with a capacity below 200 tpd are typically unable to adopt cleaner technologies such as AFBC boilers for utilizing kiln gases, or char-fired boilers due to economic and technical limitations.

Operational losses

Coal-based sponge iron production experiences several operational losses, including material spillages from feed and injection zones, yield losses, and emissions of flue gases through slip seals, cooler discharge points, and stack caps. Additionally, there are radiation losses that contribute to overall inefficiencies. These losses ultimately lead to lower energy efficiency, high coal consumption, air emissions and waste generation. Also, accretion built up during sponge iron production significantly hinders the material flows in rotary kilns, leading to shut down after every 3-4 days, reduced productivity, high wastage and lower efficiency.

Other issues

Villages near sponge iron plants have experienced reduced **agricultural** productivity due to dust and emissions settling on the soil. This pollution has negatively impacted both the quantity and quality of crops, affecting local farmers and their livelihoods.

These industries emit significant amounts of pollution into the atmosphere from the kiln, raw material handling and dust from the unpaved roads on which the trucks ply. This affects the health of the people residing in the nearby areas. It also affects the livestock and forests, in turn affecting the livelihood of the people dependent on these forests, agricultural yield, etc. The villages located on the periphery of sponge iron plants have their agricultural fields rendered unproductive with the accumulation of dust and emissions on the soil. The quality and quantity of agricultural produce have also been affected.

Coal-based sponge iron plants are mostly **located in clusters** across iron and coal-rich states like Chhattisgarh, Odisha and West Bengal. As these plants are highly polluting, the clusters' assault has colossal damage to the environment and natural resources[30].

According to a CSE report, **several illegal sponge iron plants** operate across various districts in Odisha, including Sundargarh, Keonjhar, Jharsuguda, Angul, Dhenkanal, Cuttack, and Jajpur[21]. **Odisha has the highest concentration of illegally operating sponge iron plants in India.** While official records report 108 such units in the state, unofficial estimates suggest the actual number could be as high as 1,502[21]. Beyond air pollution, **unauthorized groundwater withdrawal** has emerged as a serious issue in Odisha's **Sundargarh district**. Due to **illegal extraction by sponge iron plants**, the region has witnessed mounting **water scarcity**, affecting both ecosystems and local communities. Investigations revealed that **ten sponge iron units** were withdrawing groundwater without securing mandatory clearance from the **Central Ground Water Authority (CGWA)**[21]. In response, **police cases** were filed against these plants for operating without the required **No Objection Certificates (NOCs)**[21].

The sponge iron sector is one of the most unorganized and poorly regulated industries in the country, exhibiting a notably high rate of regulatory **non-compliance**. The ambient air quality within the factory premises and adjoining areas does not meet the prescribed standards. There have been several cases **of non-compliance in meeting the emission standards as reported from different parts of the country.**

According to the CSE report[21]**, the sponge iron industry continues to fall short of environmental compliance benchmarks**. Despite existing legal mandates, numerous plants operate without functioning ESPs or begin production altogether without installing essential pollution control systems. This not only violates statutory norms but also exacerbates unchecked emissions. The State Pollution Control Board (SPCB) has repeatedly issued **show-cause notices** to erring units, but enforcement has proven ineffective. **The persistence of violations suggests that operators view these notices as procedural formalities, with little risk of actual penalties that could disrupt production or profits**. This underscores a systemic issue where regulatory actions lack sufficient deterrence, and economic incentives continue to outweigh environmental responsibility[21].

In **March 2025**, the Odisha SPCB issued **closure notices to 11 industrial units**, including several sponge iron plants in **Kalunga, Kuanrmunda, and Bonai** industrial areas of Rourkela[34]. Odisha State Pollution Control Board has sealed five sponge iron plants in Kuanrmunda area of Odisha's Sundargarh district for repeatedly violating environmental norms[35].

Also, the State Pollution Control Board (SPCB) in Odisha issued show-cause notices to **78 industrial units**, primarily sponge iron plants, for violating environmental norms in **the Rourkela region, including Kalunga, Kuarmunda, and Bonai** industrial areas[21].

8 Implications of Coal-based Sponge Iron to India's Net-Zero Targets

Coal-based rotary kilns encounter significant obstacles in decarbonization efforts, including uncertainty about the effectiveness of alternative fuels in reducing emissions, financial constraints, the use of low-quality domestic coal, and limited access to competitively priced iron ore pellets. These challenges make it difficult for the industry to transition to more sustainable production methods.

The average CO_2 emissions intensity for crude steel production via the BF-BOF route is 2.5 t-CO_2/tcs. In comparison, coal-based sponge iron production using the EIF route has a higher emissions intensity of approximately 4.1 t-CO_2/tcs. These emissions present a significant challenge to India's climate goals, which aim for a 45% reduction in emissions by 2030 and net-zero emissions by 2070.

[34] https://www.orissapost.com/spcb-serves-closure-notice-to-11-polluting-industrial-units/

[35] https://sambadenglish.com/latest-news/five-sponge-iron-plants-sealed-in-odishas-kuanrmunda-for-pollution-norm-violations-9333244#google_vignette

In spite of the above challenges, about 22 Environmental Clearances have been issued to coal-based DRI plants, amounting to about 4647700 TPA of production in 2024 alone (MOEFCC – PARIVESH Portal). This could further exacerbate the existing issues of environmental pollution and impact the CO_2 emissions trajectory of India.

9 Potential Decarbonization Measures for Coal-based Sponge Iron Production in India

In this chapter, potential short-term, medium-term, and long-term decarbonization strategies for the coal-based rotary kiln DRI plan are explained for reducing CO_2 emissions and overall environmental performance improvements.

9.1 Short-term decarbonization strategies

Implementation of Waste Heat Recovery and Energy Management System

The coal-based DRI production has three major processes for implementing the associated BATs, namely, DRI, EAF & IF, and re-rolling. During DRI, the flue gases possess up to 1000 °C of high temperature, whose energy can be recovered by **employing a WHR system** for pre-heating of raw materials or power generation. Even though estimates suggest integration of WHR in DRI plants to reduce up to 40% of the total CO2 emissions from the DRI process (28960 t-CO_2/year), about only 50 such WHR-integrated plants exist in India till 2023[1]. In fact, WHR for scrap preheating can also prove to be an effective decarbonization strategy for the EAF & IF process.

It is essential to have an **ISO 50001 energy management system** deployed for such industries. It is recommended that small-sized sponge iron plants need to be phased out, and only large-sized sponge iron plants, 500 tpd, need to be given clearance with the mandate to install WHRB systems and state-of-the-art pollution control systems such as bag filters, ESPs, fugitive emission control systems, and continuous emission monitoring systems. Analysing thermal energy usage highlights significant potential for efficiency improvements through WHR systems.

Switching to Coal Gasification Systems

Additionally, even though **switching to coal gasification systems** can also offer a more environmentally benign alternative to coal firing, they also demand capital expenditure. As suggested by the Ministry of Coal, India needs to gain more experience by incorporating more coal gasification plants. The National Coal Gasification Mission, therefore, planned to adopt a phase-wise setup of gasification plants[36].

"In short team, the project based on low ash coal available in CIL will be taken up. CIL will take care of mining of coal and marketing of the product and the gasification and product conversion plant will be set up on BOO/BOM/LSTK contract basis. Considering the low availability of low ash coal, gasification plants will be set up based on high ash coal and with concessions given for commercial mining of coal it is expected to reach the goal of 100 MT gasification by 2030."

Integration of Carbon Capture, Utilization and Storage (CCUS)

Integration of green energy, carbon capture and utilization (CCU) & CCUS has also been encouraged by the MoS to reduce the CO2 emission from coal-based rotary kiln DRI and steel production[17].

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[36] https://coal.gov.in/sites/default/files/ncgm/ncgm21-09-21.pdf

However, CCUS technologies have not yet been fully developed for DRI rotary kiln technology, and it will take 10-15 years to have economically and technologically suitable CCUS for sponge iron production routes.

"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"[2].

Improvement in Operational Losses

Various initiatives can be taken to reduce the operational losses, such as:

- Enhanced sealing of stack caps to effectively contain fugitive emissions.
- Installation of pneumatic cylinders at slip seals to ensure proper sealing and minimize gas leakage.
- Thorough inspection and timely replacement of worn-out refractory linings using high-quality materials to reduce radiation losses.
- Monitoring and immediate rectification of material spillages in feed and discharge zones.
- Minimizing coal usage during shutdown and light-up periods by adhering to planned ramp-up procedures.
- Deployment of differential pressure valves at cooler discharge points to improve process control and reduce gas escape.

Improving Production Rate

This can be achieved by:

- Proper blending of imported & domestic coal to maintain the required carbon content.
- Utilization of high-quality pellets
- Fe balancing to analyse yield losses
- Fabrication of CB & coal injection trolley for fast operation.
- Restriction of undersized material

Coal Transport and Handling Losses

Covering the coal in transit (wagon and truck) and at the yard to reduce the losses. **Other various process changes can lead to a reduction in environmental impact** and lead to decarbonization of coal-based sponge iron production[33]. Some of the measures recommended for inclusion in the action plan are as follows:

- Overall revival and improvements of rotary kilns' health to have GHG emission reaching the 95th percentile best figure amongst the rotary kilns capacity categories.
- Monitoring and reporting of GHG emissions annually
- Use of better-quality coal in a phased manner
- Reduction of PM, SO_2, NO_x emissions.
- Implementation of a continuous monitoring system and regular upkeep of ESPs, bag filters and other pollution control equipment.
- Conducting third-party environmental and energy audits and reporting to SPCBs
- Iron ore preheating rotary kiln using waste heat recovery system
- WHR-based absorption chiller
- Transitioning towards more energy-efficient strategies/equipment (like pumps and motors) and installation of "decentralized VFDs for shell air fans"

9.2 Medium-term decarbonization strategies

Pelletization of Iron ore

Pelletization is the process of agglomerating fine iron ore concentrates into spherical pellets, making them suitable for use in BF or DRI processes. This transformation not only improves the handling and transport efficiency of iron ore but also reduces dust emissions significantly. By offering a uniform feedstock with controlled porosity and reactivity, pelletization enhances the efficiency of ironmaking operations. Additionally, pellets improve furnace permeability, promoting smoother gas flow and consistent descent of the ferrous burden—ultimately boosting energy efficiency.

Employing Renewable Energy

Use of renewable energy in DRI production will lead to a reduction in CO_2 emissions and other environmental impacts. Even though EAF and IF are considered to be relatively less energy-intensive than BOF, there is still scope for further reducing the associated carbon footprint by employing a renewable energy-dominated electricity mix. This is particularly required as currently 70% of the energy input in these processes is in the form of electricity, which is dominantly fossil-fuel-derived[1].

9.3 Long-term decarbonization strategies

Adoption of New Energy-Efficient Technologies:

The Sponge Iron Manufacturers Association (SIMA) projects that 27 MT of coal-based DRI capacity will be added by 2030[2]. The DRI sector must shift toward natural gas-based shaft furnaces to enhance sustainability and efficiency. It is also advantageous for meeting the DRI requirements of the Indian steel industry by adopting alternative production routes and advanced technologies.

- ✓ DRI production using gas route (MIDREX),
- ✓ Direct reduction of iron production using green hydrogen
- ✓ Direct reduction of iron production using COREX gas (HYL Reactor)
- ✓ DRI production process using COG in modern shaft furnaces

These technologies also have **lower CO_2 emissions** and waste generation compared to coal-based sponge iron production**Error! Bookmark not defined.**.

Transition towards Natural Gas

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 natural gas as an intermediary fuel[2]. Considering the high emissions intensity of coal-based DRI units when compared to gas-based DRI plants, the DRI sector must shift toward natural gas-based shaft furnaces to enhance sustainability and efficiency. Therefore, in the medium term, it will be necessary for the DRI sector to transition to natural gas-based shaft furnaces. However, the gas/syngas-based DRI process can be utilized as an entry point for H_2-direct reduction (H-DR).

The MoS may work with stakeholders to expand piped natural gas access across India's steel-producing regions. Natural gas should be made available to all integrated steel plants and clusters. A detailed, year-wise plan on gas availability and distribution should be documented and shared with the steel industry and associations. Encouraging indigenous equipment manufacturers of gas-based DRI to develop and provide smaller units for replacing coal-based DRIs.

Transition to Green Hydrogen with Shaft Furnace

The H-DR is most suited for shaft furnace (like Midrex and HYL), typically employing 55–85 vol.% H2 as the reductant, with the potential of using up to 100 vol.% Hydrogen[37]. Regarding the design and operation of direct reduction processes, the immediate focus should be on H_2-rich direct reduction shaft furnace technology, which partially replaces natural gas with low-carbon hydrogen. The transition to H-DR can be achieved incrementally by increasing the hydrogen proportion in the reducing gas. The anticipated future utilization of affordable green hydrogen in H-DR is likely to represent a significant milestone towards achieving carbon neutrality within the steel industry. Sourcing H_2-based power for EAF can also aid in decarbonizing DRI-derived steel production.

MoS, in coordination with the Ministry of Power (MoP) and the Ministry of New and Renewable Energy (MNRE), can promote and extend benefits provided to green hydrogen projects in the refinery and fertilizer sector to the steel industry as well, while replacing the rotary kiln with a shaft furnace fed by green hydrogen.

Transition Towards Biochar

Biomass, a renewable resource sourced from plant matter, offers significant potential for lowering carbon emissions in steel manufacturing. Utilization of biochar can solve two simultaneous issues, namely, substitution of coal and management of organic solid waste. Transforming the organic fraction of municipal solid waste, lignocellulosic agro-industrial waste and organic sludge into biochar also promotes circular economy models and prevents the waste disposal costs. Biochar has already proven to be a sustainable substitute for non-coking coal for DRI-based steel production. The physicochemical properties of biochar also hold remarkable similarities with coal and coke making it a suitable renewable fuel in the iron and steel industry. Combining iron ore fines with biochar or torrefied biomass to create pellets or briquettes results in carbon composite agglomerates (CCAs), commonly used for the in-situ reduction of ore. Such a strategy eliminates the need for external reducing agents (like natural gas, syngas or H_2) in the DRI process. The United Nations Framework Convention on Climate Change has also recognized the co-firing of biochar with coal to be a promising strategy for reducing the overall carbon footprint of steel production.

10 Conclusion & Recommendations

The coal-based sponge iron sector, while integral to India's steel production capacity and economic growth, contributing approximately 2% to GDP and positioning India as the global leader in sponge iron production, faces critical sustainability challenges. **With an average emission intensity of 4.1 t-CO_2/tcs, the coal-based DRI–EIF route significantly exceeds both the global average (1.91 t-CO_2/tcs) and the MOEF&CC's Green Steel Taxonomy threshold (2.2 t-CO_2/tfs). This high carbon footprint severely constrains the sector's alignment with India's national climate targets of a 45% emission reduction by 2030 and net-zero by 2070**.

Despite a production base of 344 DRI plants, of which 339 are coal-based rotary kilns[2], only a limited number are covered under the CCTS, leaving a substantial portion of high-emitting standalone units outside the compliance carbon market. Additionally, the sector suffers from high energy intensity, low product yield, poor quality feedstock, and severe air, water, and public health issues, many of which have seen little to no improvement since earlier assessments such as the CSE 2011 report.

[37] https://www.sciencedirect.com/science/article/abs/pii/S095965262103972X

This report provides an overview of CO_2 emissions and other environmental concerns related to coal-based sponge iron (or DRI) plants in India based on information available in secondary sources as referenced in this document. To provide a more comprehensive assessment of the current state of these facilities, it is recommended that the MoS consider funding a new, detailed study. This proposed study can have a similar scope and depth to the CSE's 2011 investigation[21], focusing on the present conditions of the nation-wide sponge iron plants, particularly in relation to the GHG emissions and air pollution. Also, India should ban providing environmental clearances to any new facility of coal-based sponge iron production that is carbon-intensive, visibly polluting, and poses serious health risks to both workers and surrounding communities. These approvals must be urgently re-evaluated in light of public health concerns and sustainability priorities.

As global steelmaking shifts toward gas-based and renewable-energy-integrated DRI, particularly in the Middle East and North America, India's reliance on coal-based technologies presents a competitive and environmental disadvantage. Unless urgent steps are taken to reform the coal-based DRI sector through technology transition, stringent compliance, and integration of cleaner energy sources, achieving green steel certification and long-term sustainability will remain out of reach.

The decarbonization of coal-based sponge iron production is very complex, practically impossible to retrofit cleaner technologies to the existing plants. Furthermore, such endeavors are hindered by financial constraints and technological incompatibility. The operational processes of these plants have largely remained unchanged for 14 years, following the last comprehensive report published by the CSE in 2011[21], which addressed the substantial emission challenges linked to coal-based sponge iron production. Additionally, issues pertaining to higher GHG emissions pose a serious threat to climate change, while significantly causing major roadblocks to the Indian steel industry's net-zero ambitions. Therefore, it is recommended that the government should direct the sponge iron industry to make significant investment in the deployment of new technologies such as natural gas-based shaft furnaces, hydrogen-DRI, etc. and phase out all the small & medium-scale sponge iron production plants and improve the functionality of large-scale sponge iron plants through suggested decarbonisation levers. Further, there should be an immediate ban on environmental clearance to install new coal-based sponge iron plants in the country. It is also suggested that all the sponge iron plants need to be assessed and evaluated critically, and an action plan for phasing out should be prepared. Large-sized plants where decarbonisation projects are feasible to install and have GHG emissions comparable to BF-BOF and have the potential to reach Green Steel certification may only be allowed to operate.

Recommendations

Considering the wide spectrum of strategies for decarbonizing the Indian DRI sector, appropriate recommendations have been provided to support their commercial feasibility and scalability. Some of the necessary directions that should be explored are highlighted below.

- Coal-based DRI units with a capacity of at least 500 TPD generally exhibit greater energy efficiency compared to those with a capacity of 350 TPD or less. **Therefore, the expansion of small and medium-sized DRI operations should be restricted, while existing smaller/mid-sized facilities should be phased out.**
- **Improving the production efficiency** of existing large-scale coal-based sponge iron plants of at least 500 T in India is critical to reducing CO_2 emissions, other harmful air pollutants, waste generation, and associated health risks. Therefore, to pave the way towards a more sustainable

and environmentally responsible steel industry, India must decisively **phase out the lower-capacity coal-based rotary kiln DRI units.**

- **There is limited potential to reduce the CO_2 emission due to technological constraints and financial viability in coal-based rotary kiln technology for DRI production. This is the high time that India should ban providing further environmental clearances to any new greenfield or Brownfield facility of coal-based sponge iron production through Rotary Kiln that are carbon-intensive, visibly polluting, and pose serious health risks to both workers and surrounding communities. These approvals must be urgently re-evaluated in light of public health concerns and sustainability priorities.**
- The existing large-scale coal-based DRI plants should be given short-term, mid-term and long-term goals of reducing CO_2 emissions and improving their overall environmental performance.
- It is essential to have an ISO 50001 energy management system deployed to improve the energy performance.
- The larger units should be mandated to install WHR and state-of-the-art pollution control systems such as bag filters, electrostatic precipitators, fugitive emission control systems, and continuous emission monitoring systems.
- It is recommended to transition from using lump ore with domestic coal to pellet-based production with imported coal. By adopting this change, carbon intensity could be decreased by 25%, contributing to more environmentally friendly production practices[24].
- Incorporation of biochar can also be a good strategy due to its significantly lower ash content than domestic coal, necessitating further research in this direction.
- Initiatives should be taken to reduce the operational losses.
- Iron ore preheating rotary kiln using waste heat recovery system. All the DRI plants should have a dust arrester in the ESP installed as per the SPCB requirements.
- Third-party environmental and energy audit and reporting to SPCBs
- The DRI sector must shift toward natural gas-based shaft furnaces to enhance sustainability and efficiency in the medium term and toward green hydrogen in the long term. The MoS may work with stakeholders to expand piped natural gas access across India's steel-producing regions.
- Encouraging collaboration between the MoS and Ministry of Power (MoP) and the Ministry of New and Renewable Energy (MNRE) to apply the advantages offered to green hydrogen initiatives in the refinery and fertilizer sectors to the steel industry as well[2].
- The MoS might collaborate with other government agencies to enhance CO_2 storage capabilities and conduct risk assessment studies for the safe storage of CO_2, utilizing the existing geological and geophysical data in India. These studies on CO_2 storage capacities and risk assessment could be based on the available geological and geophysical information[2].
- To align with global efforts, the MoS might collaborate with other ministries to create policy guidelines that favour the procurement of CCU products produced in steel plants, aiming to enhance technology advancement and implementation in India[2].
- To align with global efforts, the MoS might collaborate with other ministries to create policy guidelines that favour the procurement of CCU products produced in steel plants, aiming to enhance technology advancement and implementation in India.
- To enhance local capabilities in CCUS, the MoS could support the development and expansion of domestic technology providers and Original Equipment Manufacturers in the CCUS sector[2].
- Carbon-credits-based framework may be leveraged to enact and operationalize carbon credit transactions.

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