

Final Report

Evaluation of the Scheme

“Promotion of Research & Development in Iron and Steel Sector”

Submitted to



Ministry of Steel
Government of India

By



Indian Institute of Public Administration

I.P. Estate, New Delhi

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Acknowledgement

The Ministry of Steel's "Promotion of Research & Development in Iron and Steel Sector" scheme is aimed at playing a pivotal role in the development of the steel industry, driving innovation, technological advancements, and contributing to India's economic progress. This sector is integral to the national growth, particularly by fostering research and development (R&D), which is essential for enhancing productivity, ensuring sustainability, and maintaining global competitiveness.

We are pleased to present the evaluation report of the Ministry of Steel's R&D scheme. This comprehensive evaluation study was entrusted to us by the Ministry of Steel, Government of India, and we express our sincere gratitude for the opportunity to carry out this evaluation.

We would like to acknowledge the cooperation and invaluable support extended by various stakeholders throughout the project. Special thanks are due to the officials from the Ministry of Steel, including Shri Abhijit Narendra, Joint Secretary, Mr. G. Sarathy Raja, Dy. Secretary, Mr. Yogendra Rishishwar, Dy. Director, Ms. Vaishali Verma and Shri Gaurav Verma, for their timely guidance, constructive feedback, and support in collecting the necessary data and documentation.

We are deeply grateful to all the institutions, research organizations, and industry experts who contributed to the success of this evaluation. Their insights, information, and cooperation have been crucial in compiling a comprehensive and well-informed report.

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Finally, we express our gratitude to all those who, directly or indirectly, helped in making this evaluation a success. We look forward to continuing our work with the Ministry of Steel in the future as well.

New Delhi

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EXECUTIVE SUMMARY

India's steel industry has emerged as a global powerhouse. As of 2024, India stands as the second-largest producer of crude steel globally. It is also the third-largest consumer of finished steel worldwide, following China and the United States. It contributes about 2% to India's GDP.

Modern steel making in India is rapidly adopting green technologies such as hydrogen-based steel production, and extensive recycling programs.

1. Terms of Reference for the Study

The terms of the assignment as given by the Ministry for this study are given as below:

- i. Analysis of objectives of the scheme vis-à-vis the national perspective.
- ii. To evaluate the Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis of the Scheme.
- iii. To study and evaluate the performance of the scheme by taking into consideration all objectives of the scheme and interventions/support measures provided, so as to bring in further improvements in implementation of the scheme.
- iv. To study and assess to what extent the various R&D projects under the scheme have yielded results vis-à-vis the objectives of the individual R&D projects as well as the overall objectives of the scheme.
- v. To study the utilization of funds by the institutions vis-à-vis sanctioned projects/scheme guidelines and whether the funds have been utilized for the purpose for which it has been given.
- vi. Few case studies to be prepared while evaluating the scheme, in terms of the success and failure and analysis of the reasons for failure & success.
- vii. To give suggestions and recommendations for further improvement in the scheme.
- viii. To recommend justification for continuation of the scheme or otherwise.

2. Methodology

This study is both descriptive and analytical in nature, designed to thoroughly evaluate the "Promotion of Research & Development in Iron & Steel Sector" scheme. The aim is to assess the effectiveness, efficiency, and impact of the scheme, with a focus on both ongoing and completed projects. Relevance, Efficiency, Effectiveness, Impact, Sustainability, and Equity framework has been used for analysis and evaluation.

The evaluation has been carried out in two parts. The first part focuses on the overall objectives, design, implementation and performance of the scheme. This includes the analysis of the scheme's alignment with national priorities such as the National Steel Policy. Similar R&D initiatives in other leading steel-producing countries have been studied to identify best practices and their usefulness for our context.

The second part involves an assessment of individual projects, including both completed and ongoing projects but more so the ongoing projects, as the earlier evaluation of R&D scheme was done in 2020, which covered the earlier projects. The study covers 3 completed projects initiated before the agreed timeline to assess their impact and 28 of the remaining 35 for in-depth investigations. Field visits were undertaken to a sample of projects, and interactions were held with Principal Investigators, project teams, and other stakeholders.

The evaluation also assesses the contribution of projects to knowledge generation, skill development, and capacity building within the Indian steel sector. The primary data has been supplemented with secondary information from Ministry Annual Reports, project proposals, monitoring committee reports like Project Review Committee, and other relevant documents.

3. Findings

3.1 The Sector

- National Steel Policy (NSP) 2017 was introduced with an ambitious vision of achieving 300 million tonnes (MT) of crude steel production capacity and 255 MT of production by 2030–31, while increasing per capita steel consumption from 97.7 kg to 158 kg.
- The production of each type of steel is continuously increasing. Private sector producers make up most of the output. The overall steel production for the country grew from 103,545 in 2020-21 to a peak of 144,299 in 2023-24.
- India's steel consumption has been growing at an impressive compound annual growth rate (CAGR) of 14% over the last four years. However, per capita finished steel consumption is very low in India. It was 214.7 kg for World and 601.1 kg for China in 2024 25. The same for India was 108 kilogram.
- The steel sector currently contributes to 7 – 10% of India's total CO₂ emissions. the average emission intensity of steel production in 2023-24 in India was 2.54 tonne of CO₂ per tonne of crude steel, whereas the global average for the same

is 1.85 – 1.91. Similarly, the energy intensity of India’s steel sector is approximately 6-6.5 Gigacalories (Gcal) per tonne of crude steel, which is significantly higher than the global average of 4.5-5 Gcal/tonne.

- Key initiatives such as the “Greening the Steel Sector in India: Roadmap and Action Plan” and the newly announced Green Steel Taxonomy aim to promote low-carbon steel production through process innovations, technological advancements, and investment in cleaner alternatives.
- Equally crucial is the issue of raw material security, it remains heavily dependent on imported coking coal. To mitigate this strategic vulnerability, the Ministry of Steel is aggressively pursuing initiatives such as increasing domestic production through Mission Coking Coal, beneficiation of iron ore, optimizing coking coal blends, and expanding the use of pellets.
- In parallel, India is making significant strides in specialty steel development, a crucial segment that underpins high-tech applications in defence, automotive, electronics, and other strategic industries.

3.2 R&D in the Steel Sector

- World Steel Association reports that in 2023, the steel industry invested 7.25% of its revenue in new products and processes which includes capital expenditure and R&D investment.
- Research and development in the steel industry globally encompass a wide array of activities aimed at improving processes, enhancing product quality, and reducing environmental impact. From exploring new alloys to refining manufacturing techniques, R&D initiatives drive innovation across every facet of steel production.

3.3 R&D in Steel in other countries

- In China, there’s an increase of 3.37% in R&D expenditure from 2024 to 2025. China’s steel R&D is linked to its “dual-carbon” goals: to peak CO₂ emissions before 2030 and reach neutrality by 2060. The plan includes raising electric arc furnace (EAF) share from about 10% to 15% by 2025 and 20% by 2030. The government funds hydrogen steelmaking, direct reduction iron (DRI), and CCS

projects. It also gives subsidies for early-stage research. Companies, universities, and institutes are encouraged to form alliances, supported by green credit, low-interest loans, and innovation grants.

- The Technology Roadmap Program (TRP) in the United States set a 20-year vision for the steel sector, identifying the main research challenges and opportunities. The researches are carried out by the universities, national labs, and private firms. Only projects with industry cost-sharing are funded. Normally, Department of Energy covers about half the cost, while steel companies provide the rest through money, facilities, or staff. **The** Industrial Demonstrations Program is investing US\$6 billion in 33 large projects, including several for clean steel.
- The European Commission (EC) funds steel research through the Research Fund for Coal and Steel (RFCS), which provides about €111 million per year. In 2025, an additional €175 million was allocated: €100m for breakthrough steel technologies, €35m for coal transition, and €40m for the annual call.
- Japan's New Energy and Industrial Technology Development Organization (NEDO) runs major steel R&D programs as part of its 2050 carbon-neutral goal. Its Green Innovation Fund (2021–2030) supports hydrogen steelmaking, EAF development, and CO₂ capture. NEDO also backs international research.
- ULCOS (Ultra-Low CO₂ Steelmaking) began in 2004 with 47 partners from 15 countries. Its target is to reduce steel CO₂ emissions by 50%. It tested new processes like Hisarna smelting reduction, Top Gas Recycling Blast Furnace (TGR-BF), ULCORED DRI, and electrolysis routes.

3.3 ***R&D in Iron and Steel in India***

- Expenditure on R&D in steel is very low in India, which is less than 1%, far below the global average of nearly 2%.
- The Ministry launched the Scheme “Promotion of Research & Development in Iron and Steel Sector” to address the need.
- The Ministry provides funding under the R&D Scheme for research in green steel technologies, waste utilization, and energy efficiency to support innovation.

- A key focus of the NSP 2017 is on Research & Development (R&D), recognizing that innovation is essential for India to achieve global efficiency benchmarks, develop high-end steel products, and reduce its dependence on imports for specialty steels.
- As of 2024-25, out of 70 projects funded under this scheme, 35 have been completed and 35 remain ongoing.
- Ministry of Steel prefers R&D project proposals in joint collaborative mode, made by reputed academic institutions, research laboratories and steel companies for pursuing R&D projects for development of new alternate processes and technologies.
- The thrust areas have been identified in consultation with the stakeholders for providing support under the scheme.

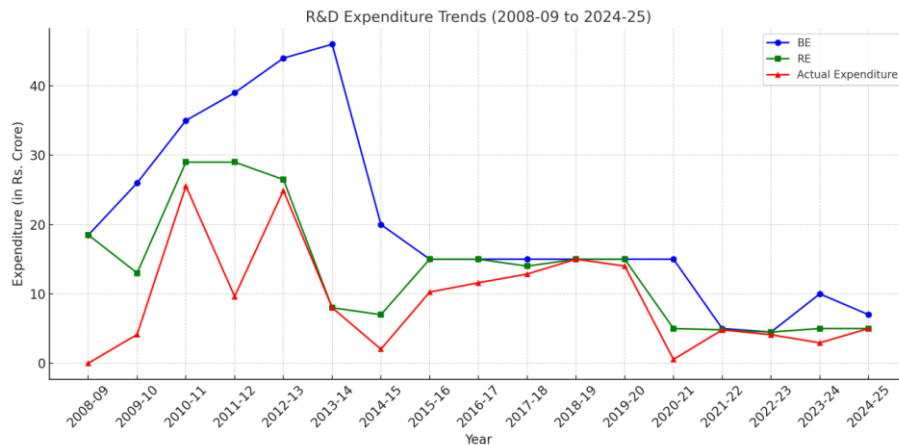
3.4 Implementation of the Scheme

- Researchers from premier institutions like IMMT, NML, IITs etc. are invited to submit the proposal for R&D in the iron and steel sector.
- An Evaluation Group comprising members from Principal Scientific Adviser to the Government of India, DRDO, DST, Premiere Academic Institutions and Industry, carry out evaluation of the R&D proposals received for funding under the scheme.
- A Project Approval and Monitoring Committee (PAMC) under the Chairmanship of Additional Secretary and Financial Adviser and Joint Secretary, Ministry of Steel, Director IIT Kharagpur, Director IMMT, Director NML are the 2nd Stage approving body for the R&D proposals recommended by Evaluation Group.
- Final approval is accorded by the designated authority based on the cost of the project as per the guidelines issued by Department of Expenditure.
- A Project Review Committee monitors the progress of the on-going projects on a regular basis.

3.5 Performance Assessment

- While the Ministry demonstrated effective fund utilization in the initial years, the recent under-utilization of R&D budgets signals a need for stronger execution mechanisms.

- From 2015-16 to 2019-20, the Ministry consistently allocated around 15 crore rupees annually, however, it became less there onwards.
- In the years 2021–22, 2022–23 and 2024–25, the money spent under the R&D Scheme was almost the same as what was planned in the revised budget. However, in 2023–24, less money was used than originally planned.



Source: Ministry of Steel

3.6 Overall Assessment

i. Relevance

- The Scheme supports the development of innovative, cost-effective, and sustainable technologies to address challenges such as climate change, energy efficiency, waste utilization, and raw material conservation.
- Advanced techniques are being applied in materials and structural design, including steel-masonry buildings, ceramic tiles from industrial residues, and enhanced binders for cement.
- Some projects integrate modern technologies like machine learning and AI for online monitoring of industrial processes.
- The projects funded under the Scheme emphasize resource efficiency, eco-friendly solutions, cost reduction, and improved performance, addressing gaps in conventional processes while promoting innovation in the steel and related sectors.
- The projects outcomes are likely to be highly valuable both for industry as well as academia.

ii. **Effectiveness**

- a. 18 projects (58.10%) reported collaborations with external agencies, while 13 projects (41.9%) had none, while the private organizations were the the most common partners. It may be noted that the Scheme stipulates that collaborative projects would be preferred.
- b. Government research institutes were involved in 5 collaborations, such as CSIR-CIMFR (Dhanbad) and RDCIS-SAIL (Ranchi).
- c. Most projects have duration of 24 months with 51.6 percent share. 18-month projects come next with 25.8 percent. 36-month projects account for 12.9 percent. Only 1 project each are of 17 months, 12 months and 7 months duration (3.2 percent).
- d. Out of 31 responses, most PIs (77.43%) reported that they did not have to modify their project after PRC suggestions.

iii. **Efficiency**

- a. Most of the researchers who completed their projects indicated that they have achieved the results that they had attempted.
- b. Some projects were delayed, because often they could not procure the equipment in time. Sometimes the funds were received by them at a later date than they expected.
- c. As per the survey responses, most of the PIs (about 87.1 percent) reported that the budget allocated for the research was sufficient. Only 6.45 percent stated that the budget was not enough, while around 6.45 percent felt it could be increased.

iv. **Impact**

- a. 83.9% Projects have not yet reached the commercialization stage, while only a small proportion (16.1%) have successfully transitioned towards commercialization.
- b. Soon to be commercialized projects focus mainly on industrial and agricultural applications.
- c. Out of the 31 responses received during the survey, most PIs, about 68%, reported that their projects did not result in any patents.
- d. Majority of projects, about 74.19 %, have not led to publications or working papers.

- e. Out of 31 responses, about 20 projects (65%) reported papers or talks presented externally, while the remaining 11 projects (35%) have either not presented their work yet, were awaiting patent clearance, or marked as “No/NIL/NA.”
 - f. Most PIs (77.4%) do not receive any honorarium or royalty in IPR / project’s commercial use, while a very small fraction (3.2%) reported receiving honorarium / royalty.
- v. Sustainability**
- a. Several of the 31 projects contribute in achieving multiple SDG goals.
 - b. 1 project working on safer handling of toxic wastes relates to SDG 3 goals.
 - c. 3 projects working on Reduced water consumption in beneficiation, effluent management relate to SDG 6 goals.
 - d. 6 projects working on Hydrogen, renewable energy in steel, syngas substitution relate to SDG 7 goals.
 - e. 12 projects working on New tech for beneficiation, AI-based automation, electrolyzers, innovation in steelmaking relate to SDG 9 goals.
 - f. 2 projects working on Structural steel in resilient, low-cost buildings relate to SDG 11 goals.
 - g. 8 projects working on Recycling waste, efficient resource use, sustainable production relate to SDG 12 goals.
 - h. 15 projects working on CO2 reduction, decarbonization, hydrogen-based DRI, cleaner production relate to SDG 13 goals.
 - i. 2 projects working on Safe sludge disposal, reduced land degradation relate to SDG 15 goals.
 - j. 1 project working on Public-private collaborations in R&D relates to SDG 17 goals.
- vi. Equity**
- a. Few institutes (IMMT, IIT Bombay, NML) have received multiple projects, while many others have limited participation.
 - b. Government sponsored organizations, while doing few projects, command a significant share of grants.
 - c. Majority of respondent Principal Investigators (PI) (83.83%) have not undertaken more than one project under the same scheme, while smaller portions (16.12%), primarily from CSIR-National Metallurgical Laboratory and IIT Bombay have managed multiple projects.

vii. Coherence

Presently, there is no active collaboration for resource pooling, either financial or human, with other government schemes, while there is scope for the same with many.

4. Recommendations

- i. The scheme is needed to help increase the R&D in Iron and Steel Sector.
- ii. The Mission / goal(s) of the scheme may be specifically spelt out.
- iii. The Ministry may include one more objective of 'creating and facilitating enabling environment for R&D'.
- iv. The Ministry may consider bringing at least one multidimensional team together of researchers from different institutions to prepare a futuristic proposal and fund it under the scheme.
- v. The Ministry may modify the condition of finding industrial partner for the submission of the project proposal.
- vi. The Ministry needs to take care of the procedural problems being faced by the scientists, conducting the research under this scheme.
- vii. The detailed and complete process of monitoring and funds release needs to be documented and provided to the scientists after a project is awarded to him or her.
- viii. Incentivizing R&D for the scientists may improve the quality of researches.
- ix. Some measures need to be put in place for non-performance as well.
- x. The Ministry needs to include MSMEs in the process.
- xi. A pool of money can be created at the scheme level, with contributions coming from industry, including the MSMEs.
- xii. In view of the significance of the MSMEs for the economy, the Ministry may consider incorporating one or two representatives from their associations in the Project Approval Committee.
- xiii. An inventory at the national level of equipment purchased under the scheme needs to be maintained and the facility thus created be made available to all the researchers who want to work on those equipment.

- xiv. Strong linkages should be developed between the scheme with the Steel Research and Technology Mission of India.
- xv. The scheme needs to be aligned with R&D initiatives and related activities of other ministries as well.
- xvi. The Ministry may also explore establishing linkages with Global Capability Centres relevant to steel industry.
- xvii. The Ministry may establish linkages with the startup ecosystem and invite individuals to take up their innovative ideas in the steel sector under this scheme.
- xviii. There has been greater focus on the process development through R&D in the scheme. The Ministry may think of funding product development projects more.

Part A

1. Introduction

India's steel industry has emerged as a global powerhouse, underpinned by policy support and a dynamic production landscape. As of 2024, India stands as the second-largest producer of crude steel globally, surpassed only by China, and maintains its position as the largest producer of sponge iron (Direct Reduced Iron, DRI). It is also the third-largest consumer of finished steel worldwide, following China and the United States.

The steel industry stands as a fundamental pillar supporting the economic progress of India. It is the backbone on which the country's infrastructure, industries, and everyday life depend. Steel is used in building homes, schools, hospitals, bridges, roads, railways, factories, and machinery, making it one of the most essential materials for development. This close connection means that the health of the steel industry directly mirrors the health of the nation's economy.

Currently, the steel sector contributes about 2% to India's GDP, but its impact goes beyond this direct figure. It provides millions of jobs, both directly within steel production plants and indirectly in related areas such as mining, transportation, equipment manufacturing, and services. For every one job in steel production, many more jobs are created in supporting industries, leading to a significant multiplier effect on employment. This extensive job creation helps improve livelihoods and supports families across rural and urban India, contributing to social stability and economic inclusion.

Steel consumption is widely regarded as an indicator of a country's industrial and economic development. As India urbanizes rapidly and its population grows, the demand for steel rises in parallel with the construction of new homes, highways, metro lines, railways, and power supply systems. These are the foundations of modern living and economic productivity. The growth in steel-use signifies improved living standards as infrastructure becomes modern and accessible to more people. Moreover, industries such as automobiles, defence, shipping, and consumer goods rely heavily on steel, highlighting its role in not only infrastructure but also manufacturing and innovation.

India's steel industry has shown remarkable growth in the past decade and has positioned the country as the world's second-largest producer of crude steel. To achieve this, modern policies promote production-linked incentives (PLIs), encourage investment in specialty steel, reduce

dependency on imports, and support 'Make in India' campaigns. These efforts help make the steel sector globally competitive while supporting the country's self-reliance.

The domestic steel sector not only meets local demand but also contributes to international markets through exports. In recent years, India has exported millions of tonnes of steel, earning valuable foreign exchange and strengthening its position in global trade. At the same time, India carefully manages imports to protect domestic producers, ensuring a balanced trade environment. This mix of import management and export promotion drives the sector's sustainable growth in a highly competitive global market.

In today's world, the steel industry is also embracing sustainability and environmental responsibility. Modern steel making in India is rapidly adopting green technologies such as hydrogen-based steel production, and extensive recycling programs. These clean technologies reduce carbon emissions and make the steel sector more energy-efficient, aligning with India's commitments to climate change goals. Investments in automation and digital technologies improve production quality and efficiency, attracting both domestic and foreign investment.

The steel industry is not just an economic engine but a barometer for national development. When steel production and consumption rise, it signals healthy investments in infrastructure, urban development, manufacturing, and innovation. These improvements reflect on an enhanced quality of life for citizens, more jobs, and broader economic stability. The industry supports projects in both rural and urban areas, helping build schools, bridges, hospitals, freight corridors, and power stations, thereby driving inclusive growth.

In summary, the steel industry's role in India's economy is fundamental and multifaceted. It drives industrialization, creates employment, supports exports, and helps build the infrastructure necessary for long-term development. As India aims to become a \$5 trillion economy and a global manufacturing hub, the steel sector will continue to be a vital enabler of these ambitions, transforming the country today and securing its prosperous future for the generations to come.

2. Objectives of the Assignment

The terms of the assignment as given by the Ministry for this study are as given below:

- ix. Analysis of objectives of the scheme vis-à-vis the national perspective.
- x. To evaluate the Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis of the Scheme.

- xi. To study and evaluate the performance of the scheme by taking into consideration all objectives of the scheme and interventions/support measures provided, so as to bring in further improvements in implementation of the scheme.
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- xiv. Few case studies to be prepared while evaluating the scheme, in terms of the success and failure and analysis of the reasons for failure & success.
- xv. To give suggestions and recommendations for further improvement in the scheme.
- xvi. To recommend justification for continuation of the scheme or otherwise.

3. Methodology

This study is both descriptive and analytical in nature, designed to thoroughly evaluate the “Promotion of Research & Development in Iron & Steel Sector” scheme. The aim is to assess the effectiveness, efficiency, and impact of the scheme, with a focus on both ongoing and completed projects. Relevance, Efficiency, Effectiveness, Impact, Sustainability, and Equity framework has been used for analysis and evaluation.

The evaluation has been carried out in two parts. The first part focuses on the overall objectives, design, implementation and performance of the scheme. This includes the analysis of the scheme’s alignment with national priorities such as the National Steel Policy. Similar R&D initiatives in other leading steel-producing countries have been studied to identify best practices and their usefulness for our context.

The second part involves an assessment of individual projects, including both completed and ongoing projects but more so the ongoing projects. As the earlier evaluation of R&D scheme was done in 2020, it was finalized in consultation with the officials in the Ministry that 35 ongoing projects would be considered for analysis, some of which have now been completed. After deliberation it was discussed to take those projects started/Completed from 2020-21. However, finally the study team covered 3 completed projects initiated before the agreed timeline to assess their impact and 28 of the remaining 35 have been covered. Some projects which have

just started have not been included, as they are in their initial phases and no remarkable finding would have been feasible.

To ensure comprehensive and standardized data collection, a data sheet was prepared and circulated among all project coordinators through the Ministry. Each coordinator was requested to fill out the data sheet with detailed information about the projects sanctioned to them by the Ministry of Steel. The study team received 31 responses which is sufficient to analyse the current R&D efforts and various issues under consideration. Each project has been evaluated against approved indicators and targets, including physical outputs and financial utilization. The evaluation also assesses the contribution of projects to knowledge generation, skill development, and capacity building within the Indian steel sector. Detailed case studies have been prepared for selected projects to highlight success stories, challenges faced, and lessons learnt.

Field visits were undertaken to a sample of projects, and interactions were held with Principal Investigators, project teams, and other stakeholders such as industry representatives, academic experts, and government officials. The primary data has been supplemented with secondary information from Ministry Annual Reports, project proposals, monitoring committee reports like Project Review Committee, and other relevant documents.

4. The Steel Sector in India

The steel industry is often considered the backbone of a nation's industrial and economic strength, serving as a vital enabler of infrastructure, manufacturing, transportation, and national defence. In India's case, the steel sector is not only a reflection of its accelerating economic development but also a strategic pillar for the realization of long-term national goals such as infrastructure modernization, industrial self-reliance, and sustainable growth. As India positions itself to become a \$5 trillion economy and a global manufacturing hub, the development of a robust, innovative, and self-sufficient steel industry is indispensable.

India's steel consumption, which has been growing at an impressive compound annual growth rate (CAGR) of 14% over the last four years—compared to the global average of less than 1%—stands as a testament to the sector's growing importance in the national economy. The country has already emerged as the second-largest crude steel producer in the world, and with rising demand in construction, automobiles, defence, and large-scale infrastructure projects, it seems to be poised for exponential growth well beyond 2030.

To harness this momentum, the National Steel Policy (NSP) 2017 was introduced with an ambitious vision of achieving 300 million tonnes (MT) of crude steel production capacity and 255 MT of production by 2030–31, while increasing per capita steel consumption from 97.7 kg to 158 kg. The policy underscores the government’s commitment to not only meet domestic demand—including high-grade automotive and strategic steel—but also to position India as a competitive player in the global steel value chain.

The significance of India’s steel sector extends beyond capacity building and economic metrics. In the era of climate consciousness, the global steel industry faces growing scrutiny for its high carbon emissions and energy-intensive production processes. India has embraced this challenge. In alignment with its international commitments made at COP26, including the goal to reduce the carbon intensity of its economy by 45% by 2030 and to achieve net-zero emissions by 2070, the Ministry of Steel has launched a green transition journey for the sector. Key initiatives such as the “Greening the Steel Sector in India: Roadmap and Action Plan” and the newly announced Green Steel Taxonomy aim to promote low-carbon steel production through process innovations, technological advancements, and investment in cleaner alternatives like hydrogen-based steelmaking and carbon capture utilization and storage (CCUS).

Equally crucial is the issue of raw material security, which continues to pose both short-term and long-term challenges. While India has ample reserves of iron ore and non-coking coal, it remains heavily dependent on imported coking coal, primarily due to the limited availability of high-quality domestic reserves. To mitigate this strategic vulnerability and reduce the manufacturing cost burden, the Ministry of Steel is aggressively pursuing initiatives such as diversifying coking coal imports, increasing domestic production through Mission Coking Coal, beneficiation of iron ore, optimizing coking coal blends, and expanding the use of pellets.

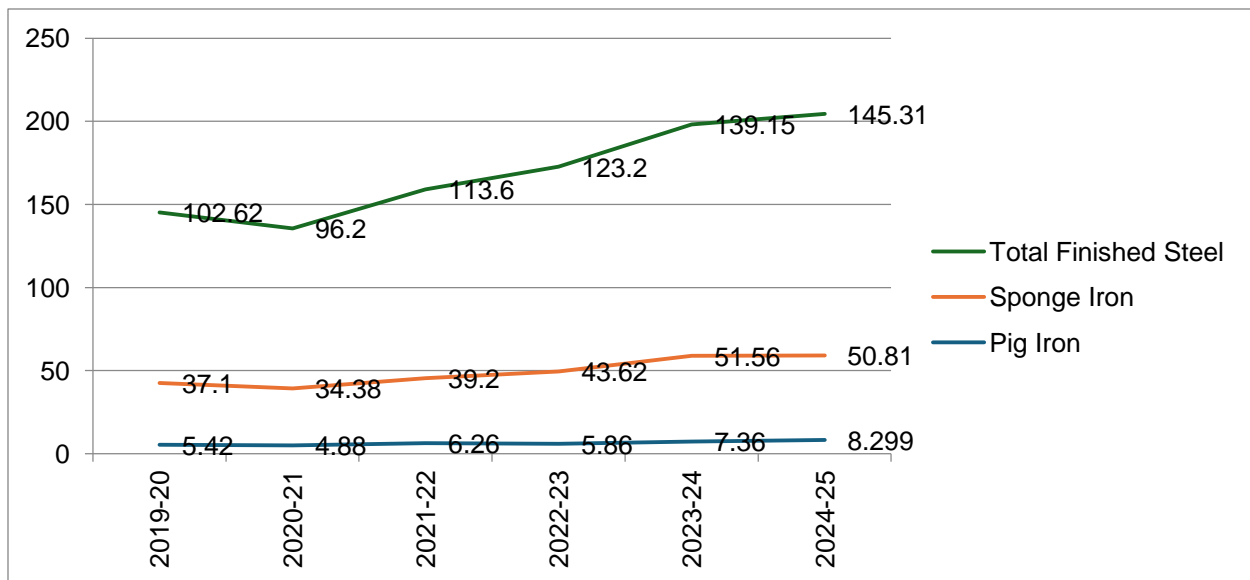
In parallel, India is making significant strides in specialty steel development, a crucial segment that underpins high-tech applications in defence, automotive, electronics, and other strategic industries. The Production Linked Incentive (PLI) Scheme for Specialty Steel, launched in 2021, aims to foster indigenous manufacturing capabilities and reduce dependency on imports. With 44 projects already underway and a second phase of the scheme launched in 2025, the initiative aligns strongly with the vision of Atmanirbhar Bharat (self-reliant India), promising to add substantial value to downstream capacity and promote high-grade innovation in the steel value chain.

Table -1: Total Production of Iron category wise (in Million Tonnes)

Category	Production of Iron (MT)					
	2019-20	2020-21	2021-22	2022-23	2023-24	2024-25
Pig Iron	5.42	4.88	6.26	5.86	7.36	8.299
Sponge Iron	37.1	34.38	39.2	43.62	51.56	50.81
Total Finished Steel	102.62	96.2	113.6	123.2	139.15	145.31

Source: Joint Plant Committee (April 2025)

Figure 1: Total Production of Iron Category wise (in Million tonnes)



As can be seen that the production of each type of steel is continuously increasing. The same can be said about the crude steel and finished steel production.

Table 2: Production, consumption, import and export of Finished Steel and production of crude steel for the last five years (2020-21 to 2024-25)

(In MT)

Item	2020-21	2021-22	2022-23	2023-24	2024-2025
Crude Steel Production	103.545	120.293	127.197	144.299	152.18
Finished Steel Production	96.204	113.597	123.196	139.153	146.69
Consumption	94.891	105.752	119.893	136.291	152.13
Import	4.752	4.669	6.022	8.32	9.55
Export	10.784	13.494	6.716	7.487	4.86

Source: JPC, 2024-25

It can be seen that the import of finished steel is increasing in India over the years. While there are other factors, it is a fact that India's steel industry does not have adequate capacity for certain advanced or specialty steel products, leading to more imports in these categories for sectors like automotive, defence and high-end construction.

Figure 2: Consumption and production of crude steel

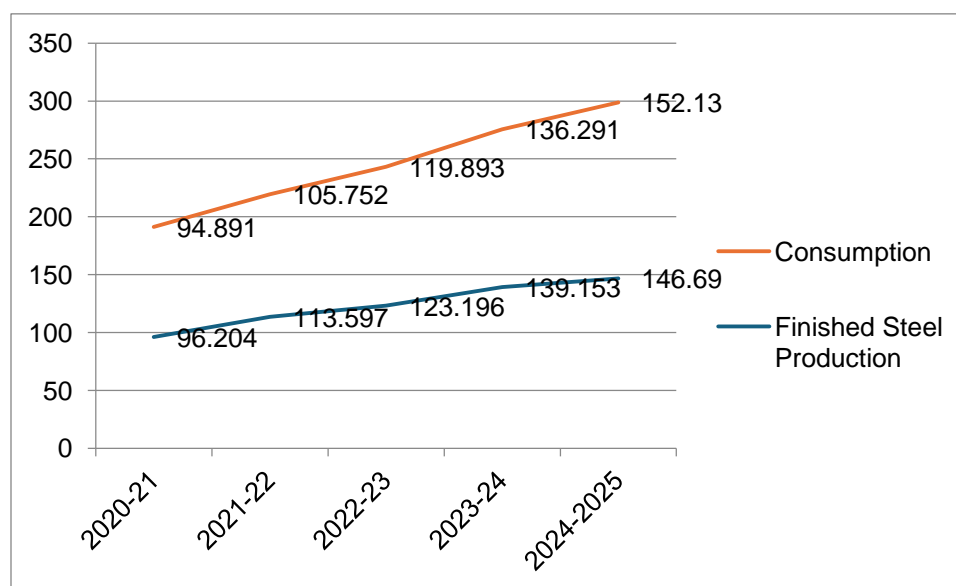


Figure 3: Import and Export of Finished Steel Production

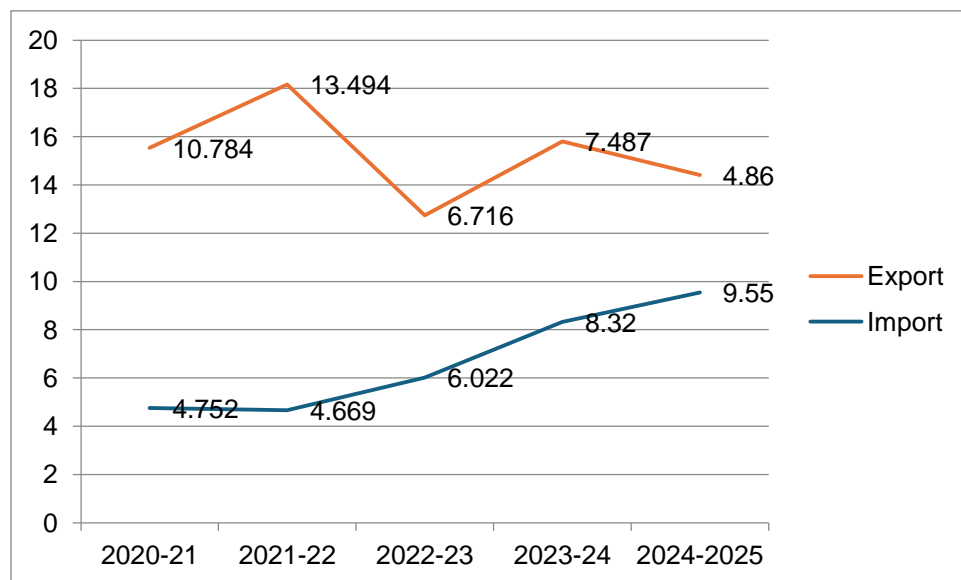


Table 3: Major producers of Steel in India

(in ,000 tonnes)

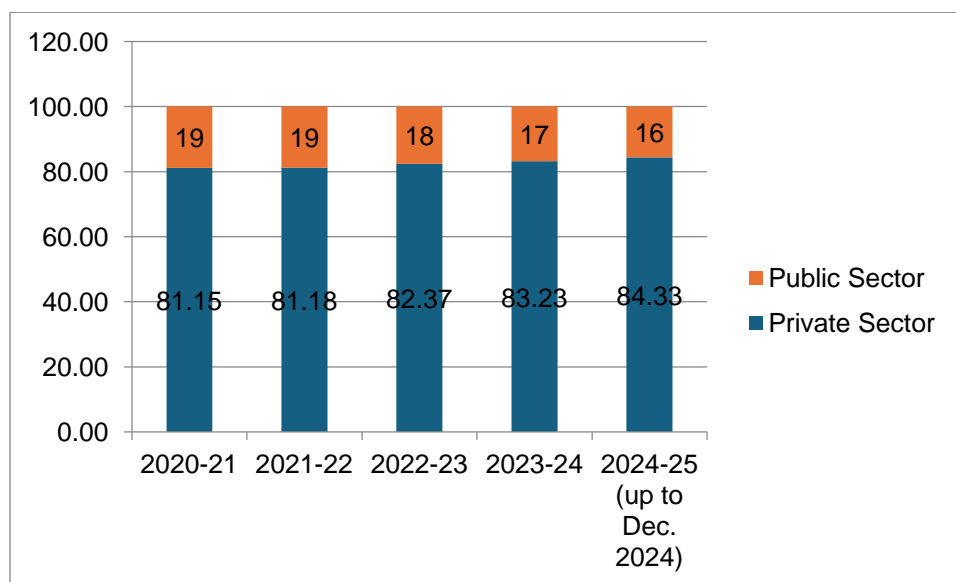
Producer	2020-21	2021-22	2022-23	2023-24	2024-25 (up to Dec. 2024)
SAIL	15,213	17,363	18,292	19,240	14,081
RINL	4,302	5,272	4,137	4,411	2,455
NMDC Steel Ltd.	-	-	-	540	1,018
Total Public Sector	19,515	22,636	22,429	24,192	17,552
TSL Group	17,204	19,464	19,805	20,783	16,234
AM/NS (Essar Steel Ltd.)	6,696	7,295	6,688	7,683	5,508
Jindal Steel and Power Ltd.	6,859	7,458	7,509	7,645	5,023
JSW Steel Ltd.	14,780	18,023	-	-	-
JSWL Group	-	-	23,623	25,608	19,438
Other BOF	1,786	2,070	2,127	2,185	1,515

Other EAF	7,653	8,138	4,815	5,121	4,332
Other IF	29,052	35,211	40,201	51,081	42,408
Total Private Sector	84,030	97,658	104,768	120,107	94,459
Total (Public + Private)	103,545	120,293	127,197	144,299	112,011
Share of Public Sector (%)	19	17	18	17	15.7

Source: Annual Report 2024-25, Ministry of Steel

This table shows how much steel was produced by major producers in India from 2020-21 to 2024-25. Figures for 2024-25 are provisional up to December 2024. Public sector companies like SAIL, RINL, and NMDC contributed a steady share, with SAIL's production peaking at 19.240 MT in 2023-24. RINL's and NMDC's output fluctuated. Private sector producers, including TSL Group, AM/NS, Jindal Steel, JSW Steel, and others, consistently made up most of the output, with total private sector production reaching its highest in 2023-24 at 120.107 MT. The overall steel production for the country grew from 103.545 MT in 2020-21 to a peak of 144.299 MT in 2023-24. Projections indicate that the productions are likely to increase further.

Figure 4: Percentage of Public and Private sector contributions in production



The share of the public sector in total production is rather steady. In simple terms, India's steel production is on a strong upward trend.

However, per capita finished steel consumption is very low in India. If the country has to become a developed nation by 2047, different sectors would be needing much more Steel. Per capita finished steel consumption in 2024 was 214.7 kg for World and 601.1 kg for China, as per provisional data released by World Steel Association. The same for India was 108 kilogram in 2024 25.

In conclusion, the Indian steel sector stands at a pivotal juncture—poised for rapid growth, yet navigating a complex landscape of global competitiveness, environmental accountability, and raw material constraints. Through progressive policies, sustainability commitments, strategic investments, and technological innovation, the Government of India is not only laying the foundation for a globally competitive and self-reliant steel industry but also ensuring that it plays a central role in the country's journey towards sustainable and inclusive economic development.

4.1. Steel Policy in India

During the last few years The Ministry of Steel, Government of India, has launched several key policies and initiatives to promote the growth, modernization, and sustainability of the steel sector. The National Steel Policy (NSP) 2017 aims to increase crude steel capacity to 300 million tonnes by 2030–31 and build a globally competitive, self-reliant steel industry. To boost high-value steel production, the Production Linked Incentive (PLI) Scheme for Specialty Steel was introduced in 2021, attracting significant private investment and enhancing domestic capacity. The Steel Quality Control Order (QCO) ensures that only BIS-certified, high-quality steel is produced and imported, safeguarding users and industries.

To ensure the use of high-quality steel, the Ministry of Steel has implemented the Steel Quality Control Order (QCO), which mandates that only steel conforming to Bureau of Indian Standards (BIS) can be manufactured, sold, or imported in India. As of now, 151 Indian Standards covering carbon steel, alloy steel, and stainless steel have been notified under the QCO, with more standards being added to further enhance quality. In 2025, two important orders were issued to extend BIS compliance to intermediate steel materials used in manufacturing final products. However, exemptions have been provided for imports shipped on or before 15 July 2025, and Integrated Steel Plants (ISPs) may also receive exemption upon verification of their BIS licenses.

Similarly, to support innovation, the Ministry provides funding under the R&D Scheme for research in green steel technologies, waste utilization, and energy efficiency. The Steel Import Monitoring System (SIMS) enables real-time monitoring of steel imports, helping to control surges and guide policy decisions. Additionally, the Ministry is driving efforts toward decarbonising the steel sector, in line with India’s climate goals, through the “Greening the Steel Sector in India: Roadmap and Action Plan” and the recently introduced Green Steel Taxonomy, encouraging investment in sustainable production technologies.

5. Global R&D in Steel Sector

Global steel production was around 1.84 billion tons in 2024, a slight decrease from 2023, with China remaining the largest producer by a significant margin, followed by India. While overall production experienced a minor dip, many individual countries saw production increases, such as Germany, Turkey, and Brazil, highlighting regional variations within the global market.

World Steel Association reports that in 2023, the steel industry invested 7.25% of its revenue in new products and processes which includes capital expenditure and R&D investment. This investment reflects a strategic pivot within the sector, aiming to enhance productivity, sustainability, and competitiveness in response to shifting global demands¹.

Table 4 below outlines the top 10 steel-producing countries in the world for the years 2023 and 2024, reflecting both consistency in leadership and slight fluctuations in production volumes:

Table 4: Top 10 steel producer countries globally

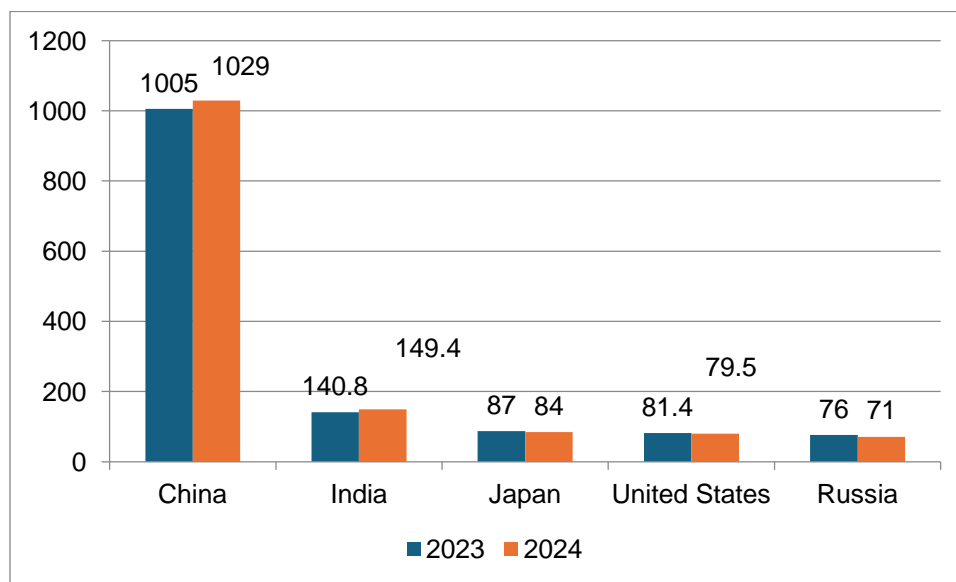
Country	Top 10 steel producer countries internationally			
	2024		2023	
	Rank	Tonnage	Rank	Tonnage
China	1	1 005.1	1	1 028.9
India	2	149.4	2	140.8
Japan	3	84	3	87
United States	4	79.5	4	81.4
Russia	5	71	5	76

¹ <https://worldsteel.org/data/world-steel-in-figures/world-steel-in-figures-2025/>

South Korea	6	63.6	6	66.7
Germany	7	37.2	7	35.4
Türkiye	8	36.9	8	33.7
Brazil	9	33.8	9	32
Iran	10	31.4	10	30.7

Source: World steel Association

Figure 5: Top 5 steel producer countries globally



Source: World steel Association

Research and development in the steel industry globally encompass a wide array of activities aimed at improving processes, enhancing product quality, and reducing environmental impact. From exploring new alloys to refining manufacturing techniques, R&D initiatives drive innovation across every facet of steel production.

China remains the leading investor in R&D, as far as the steel sector is concerned. Global R&D expenditure is growing, and countries like Japan, Germany, and South Korea are leaders in overall R&D. They invest substantially in their industrial sectors, including steel.

In 2023, the business enterprise R&D expenditure in China's manufacture of basic iron and steel, as well as the casting of iron and steel, stood at 95.5 billion Yuan Renminbi. The

forecasted expenditure shows a steady growth from 2024 to 2028, indicating a positive annual compound growth rate (CAGR). For instance, from 2024 to 2025, there's an increase of 3.37%, while from 2025 to 2026, the growth is 3.20%. This trend continues with slight variations, leading to a CAGR of approximately 3.77% over the forecasted period.

Expenditure on R&D in steel is very low in India, which is less than 1%, far below the global average of nearly 2%.

R&D Landscape across Major Steel Producers

i. United States

The Technology Roadmap Program (TRP) was launched by the U.S. Department of Energy (DOE) in the late 1990s. It set a 20-year vision for the steel sector, identifying the main research challenges and opportunities. The goal was to ensure that new research benefits the whole industry, not just one company. Proposals came from universities, national labs, and private firms, and were reviewed by experts. Only projects with industry cost-sharing were funded. Normally, DOE covered about half the cost, while steel companies provided the rest through money, facilities, or staff.²

Today, DOE continues this style of support. The Industrial Demonstrations Program is investing US\$6 billion in 33 large projects, including several for clean steel. Examples are SSAB's hydrogen-based direct reduction plant in Mississippi and Cleveland-Cliffs' hydrogen furnace projects in Ohio and Pennsylvania.³

In 2025, DOE and AIST (Association for Iron & Steel Technology) also released a new Iron & Steel Roadmap. It highlights long-term priorities like hydrogen steelmaking, electric furnaces, carbon capture.⁴

² <https://www.energy.gov/eere/iedo/steel>

³ <https://www.breakthroughenergy.org/newsroom/articles/industrial-demonstrations-program/>

⁴ <https://www.aist.org/getmedia/472f52ae-417f-487b-a2a4-dba9403b755c/AIST-NIST-Grant-spreads.pdf>

ii. European Union

The European Commission (EC) funds steel research through the Research Fund for Coal and Steel (RFCS), which provides about €111 million per year. In 2025, an additional €175 million was allocated: €100m for breakthrough steel technologies, €35m for coal transition, and €40m for the annual call.⁵

Another big initiative is the Clean Steel Partnership, run with ESTEP. It uses RFCS and Horizon Europe funds to support hydrogen-based reduction, electrified furnaces, CCUS, and circular steelmaking. The target is to reduce CO₂ emissions by 55% by 2030.⁶

Projects are open to companies, SMEs, universities, and research institutes. They require cost-sharing and are reviewed by expert panels to make sure results benefit the whole industry.⁷

In addition, the EU approved nearly €9 billion (2022–2025) in state aid for steel decarbonization, through the Innovation Fund and LIFE Programme.⁸

iii. China

China's steel R&D is linked to its “dual-carbon” goals: to peak CO₂ emissions before 2030 and reach neutrality by 2060. The plan includes raising electric arc furnace (EAF) share from about 10% to 15% by 2025 and 20% by 2030. A capacity swap policy is also in place, where old blast furnaces are replaced with newer, cleaner ones.⁹

The government funds hydrogen steelmaking, direct reduction iron (DRI), and CCS projects. It also gives subsidies for early-stage research. Companies, universities, and institutes are

⁵ https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/eu-provides-eu175-million-support-research-innovation-and-just-transition-steel-and-coal-sectors-2025-01-20_en

⁶ <https://www.estep.eu/assets/Publications/CSP-SRIA-Oct2021-clean.pdf>

⁷ https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/research-fund-coal-and-steel-rfcs_en

⁸ <https://www.haptic.ro/steel-and-metals-strategy-charting-a-resilient-and-green-future-for-europe/>

⁹ https://eta-publications.lbl.gov/sites/default/files/china_steel_roadmap-2mar2023.pdf

encouraged to form alliances, supported by green credit, low-interest loans, and innovation grants.¹⁰

Other measures support energy efficiency, like pulverized coal injection, low-temperature sintering, and coke dry quenching. Policies such as emissions trading (ETS), green finance, and public funding are used to reduce risks.¹¹

Still, most advanced technologies remain at pilot or demo stage, facing barriers like cost and hydrogen supply. China is responding with funding, strict policies, and carbon markets to scale them up.¹²

iv. Japan (NEDO)

Japan's New Energy and Industrial Technology Development Organization (NEDO) runs major steel R&D programs as part of its 2050 carbon-neutral goal. Its Green Innovation Fund (2021–2030) supports hydrogen steelmaking, EAF development, and CO₂ capture. The COURSE50 and Super COURSE50 projects test hydrogen injection in blast furnaces and carbon recovery, aiming for 30–50% emission cuts.¹³

Other NEDO projects include using hydrogen-rich coke oven gas, CO₂ recovery with waste heat, and ferrocake for efficiency. These are moving from 12 m³ test furnaces toward large demonstration plants.¹⁴

NEDO also backs international research. For example, JFE Steel and Kyushu University are developing hydrogen-resistant pipeline steels. Meanwhile, Nippon Steel invests in high-strength steels, AI-based digital tools, and CCUS.¹⁵

¹⁰ <https://rmi.org/insight/clean-hydrogen-based-steel-in-china-and-europe/>

¹¹ <https://www.oaepublish.com/articles/cf.2024.55>

¹² <https://rmi.org/insight/unlocking-the-first-wave-of-breakthrough-steel-investments-in-china/>

¹³ https://worldsteel.org/wp-content/uploads/Presentation_Hideki-MURAKAMI-Nippon-Steel-Corporation.pdf

¹⁴ https://www.nedo.go.jp/english/activities/activities_ZZJP_100050.html

¹⁵ <https://www.jfe-steel.co.jp/en/release/2024/07/240717.html>

v. ULCOS

ULCOS (Ultra-Low CO₂ Steelmaking) began in 2004 with 47 partners from 15 countries. Its target is to reduce steel CO₂ emissions by 50%. It tested new processes like Hisarna smelting reduction, Top Gas Recycling Blast Furnace (TGR-BF), ULCORED DRI, and electrolysis routes.¹⁶

The Hisarna pilot plant at Tata Steel Ijmuiden has run since 2011. It proved flexible and stable, showing 20–35% CO₂ cuts without CCS and higher reductions with capture.¹⁷

Most ULCOS technologies are still at pilot or early commercial stage. A full Hisarna plant (0.5–1 Mt/year) would cost several hundred million euros. Other methods like TGR-BF also need CCS networks and further trials.¹⁸

ULCOS laid the base for newer programs like the Clean Steel Partnership.

6.1 Thrust to R&D in Steel in India

The National Steel Policy (NSP) 2017 provides the current strategic framework for the sector. This policy aims to enhance India's steel production capacity to 300 million tonnes by 2030-31 and emphasizes the need for technological advancement, resource efficiency, and sustainability. A key focus of the NSP 2017 is on Research & Development (R&D), recognizing that innovation is essential for India to achieve global efficiency benchmarks, develop high-end steel products, and reduce its dependence on imports for specialty steels.

Thus there is need to focus on R&D. However, despite the presence of major private and public sector players, investment in R&D within the Indian steel industry has historically been limited.

¹⁶ <https://cordis.europa.eu/project/id/515960>

¹⁷ https://www.gem.wiki/Hisarna_process

¹⁸ https://www.estep.eu/assets/Projects/GreenSteel4Europe/GreenSteel_Publication/D2.2-Investment-Needs.pdf

Table. 5: Research and Development spending of Top 3 steel manufacturers in India

Name of the companies	Research and Development spending of Major steel manufacturers in India (in million Indian rupees)						
	2018	2019	2020	2021	2022	2023	2024
Nippon Steel	72.8	77.69	65.34	66.43	70.56	72.74	
JSW Steel	410	450	560	380	390	440	450
Tata Steel	1,816.4	2,160	2,590	2,310	2,130	8,590	2,850

Ministry of Steel: Annual reports: <https://steel.gov.in/annual-reports>

The Ministry of Steel is actively promoting research and development (R&D) through government-funded projects aimed at creating new processes and technologies that enhance efficiency, address environmental concerns, and promote waste utilization and resource conservation.

The government has prioritized indigenous R&D efforts, as reflected in both the National Steel Policy 2005 and 2017. To address the gap, the Ministry of Steel launched the “Promotion of Research & Development in Iron & Steel Sector” scheme during the 11th Five Year Plan. The scheme’s objectives include:

- Development of innovative technologies for utilizing iron ore fines and non-coking coal.
- Beneficiation and agglomeration of raw materials such as iron ore and coal.
- Improvement in the quality of steel produced via induction furnaces.
- Development of technology for Cold Rolled Grain Oriented (CRGO) electrical steel sheets and other value-added products.
- Pursuit of R&D on topics of national importance related to the iron and steel sector.

As of 2024-25, out of 70 projects funded under this scheme, 35 have been completed and 35 remain ongoing (some of these have also been completed as told to the study team, but are categorized as ongoing because their closure report has yet not been submitted), reflecting a significant shift towards project completion compared to previous cycles. This evaluation, therefore, places special emphasis on assessing the outcomes and impacts of both completed and ongoing projects.

The Ministry of Steel has entrusted the evaluation of this scheme to Indian Institute of Public Administration, with the aim of ensuring that R&D efforts are aligned with national goals and global best practices.

6.2 Implementation of the Scheme

Ministry of Steel prefers R&D project proposals in joint collaborative mode, made by reputed academic institutions, research laboratories and steel companies for pursuing R&D projects for development of new alternate processes and technologies.

The thrust areas have been identified in consultation with the stakeholders for providing support under the scheme, which include¹⁹:

- i. Heat Recovery and Dry Slag Granulation Plant for Blast Furnace and Steel Slag
- ii. Carbon Capture & Utilisation
- iii. Hydrogen Recovery, utilization of Coke Oven gas, plastic/polymer injection, charcoal etc in BF
- iv. Integrated Slag utilization Project in Cement, Agriculture, Road, Insulation material, Fertilizer, etc.
- v. Advanced Coal Washery System using Dry and wet washing system.
- vi. Beneficiation of low grade iron ore & fines and agglomeration
- vii. Use of Green Hydrogen in DRI process
- viii. Use of Green Hydrogen in Blast Furnace process
- ix. Alternate Ironmaking Technology with Green Hydrogen
- x. Water Consumption & Effluent treatment
- xi. R&D to address Challenges & Issues specific to the Secondary Steel Sector
- xii. Conversion of coal based DRI into gas based DRI

The approval process starts with an Evaluation Group comprising members from Principal Scientific Adviser to the Government of India, DRDO, DST, Premiere Academic Institutions and Industry, carry out evaluation of the R&D proposals received for funding under the scheme.

A Project Approval and Monitoring Committee (PAMC) under the Chairmanship of Additional Secretary and Financial Adviser and Joint Secretary, Ministry of Steel, Director IIT Kharagpur, Director IMMT, Director NML are the 2nd Stage approving body for the R&D proposals recommended by Evaluation Group.

Final approval is accorded by the designated authority based on the cost of the project as per the guidelines issued by Department of Expenditure.

A Project Review Committee monitors the progress of the on-going projects on a regular basis.

¹⁹ <https://steel.gov.in/sites/default/files/2025-02/Annexure-2.pdf>

6.3 Areas of Concern

As per experts, the steel sector currently contributes to 7 – 10% of India’s total CO2 emissions. A rapid growth in output would result in a steep increase in emissions from the sector, which are expected to double by 2030 in a business-as-usual scenario. A PIB release in Dec. 2024 mentioned that the average emission intensity of steel production in 2023-24 in India was 2.54 tonne of CO2 per tonne of crude steel, whereas the global average for the same is 1.85 – 1.91. As per current plans, nearly all of the new production capacity that is expected to be added is fossil-based (i.e., via. BF – BOF and DRI – EAF/IF route. Only a small share of the same is through scrap-based EAF units).

Similarly, the energy intensity of India’s steel sector is approximately 6-6.5 Giga calories (Gcal) per tonne of crude steel, which is significantly higher than the global average of 4.5-5 Gcal/tonne. This higher energy intensity is attributed to the use of obsolete technologies, operational inefficiencies, and reliance on lower-quality raw materials like high-ash coal.

7 Performance Assessment of the Scheme

There is no fixed number of projects to be approved. In fact, at the screening stage itself, a lot of project proposals are rejected, as they are not found to be addressing the thrust areas.

Table 6: Year wise Number of projects approved under the Scheme

Years	No. of Projects Approved
2010	8
2014	5
2016	10
2017	3
2018	9
2019	2
2020	2
2021	6
2022	4
2023	9
2024	12
Total	70

Source: Ministry of Steel

The table given below reveals a mixed picture: while the Ministry demonstrated effective fund utilization in the initial years, the recent under-utilization of R&D budgets signals a need for stronger execution mechanisms. If the Ministry aims to drive innovation and sustainability in the steel sector, better planning, monitoring, and implementation of R&D initiatives will be crucial going forward.

Table 6: Budget for Research and Development

Year	Budget Estimate (Rs. Crores)	Revised Estimate (Rs. Crores)	Actual Expenditure (Rs. Crores)	Utilisation % over RE
2020-21	15	5	0.54	11%
2021-22	5	4.81	4.81	100%
2022-23	4.49	4.49	4.49	100%
2023-24	10	5	2.94	59%
2024-25	7	5	4.99	99.8%

Source: Ministry of Steel

Over the past decade, the Ministry of Steel's budget for the Scheme has shown some distinct patterns. From 2015-16 to 2019-20, the Ministry consistently allocated around 15 crore rupees annually as both budget estimates (BE) and revised estimates (RE), reflecting stable planning and commitment to R&D. Actual utilization during these years was relatively strong, improving from 68% in 2015-16 to a high of 100% in 2018-19, indicating efficient use of allocated funds and steady progress in funded projects.

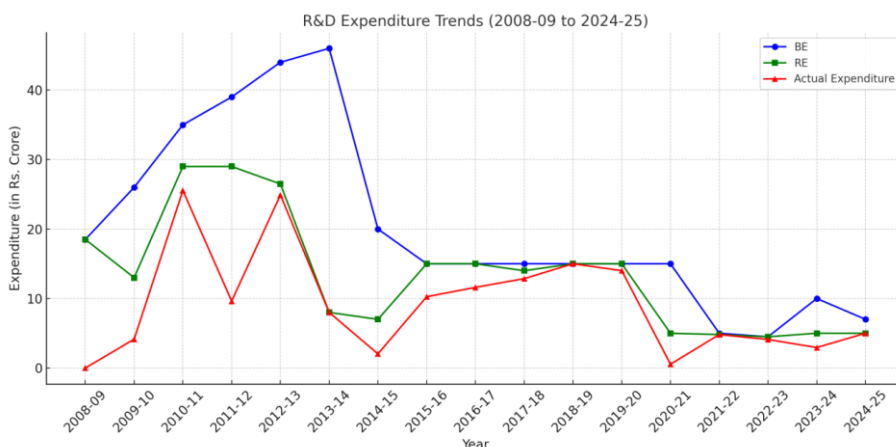
In the years 2021–22, 2022–23 and 2024–25, the money spent under the R&D Scheme was almost the same as what was planned in the Revised Budget. This shows that the Ministry of Steel used its funds well and made practical plans. The spending was well-aligned with what was estimated, which indicates efficient management and smooth execution of R&D projects during these years.

However, there have been significant reductions in the budget estimates and revised estimates in the past two financial years. This reduction may indicate shifting priorities, resource constraints, or a re-evaluation of ongoing projects. Despite the lower figures, utilization rates varied widely: a very low 11% in 2021-22 probably because of the COVID-induced delays, whereas other years like 2022-23 saw full utilization of allocated funds, showing efficient project selection and fund deployment.

However, in 2023–24 and 2024–25, there was a clear gap between the money that was allocated and the money actually spent. For example, in 2023–24, only ₹2.94 crore was used out of the ₹10 crore that was originally planned. In 2024–25, ₹4.99 crore was spent from the ₹7 crore budget.

The budget estimate for 2023–24 was increased to ₹10 crore, possibly because the Ministry wanted to support more research work or bigger projects. Since the actual spending was very low, it may mean that the budget was too high or that there were challenges in carrying out the planned work. In both 2023–24 and 2024–25, the government had to revise the budget down midway through the year, which shows that adjustments were made based on the real situation. This also highlights the need for better planning from the beginning.

The graph below shows the BE, RE, and Actual Expenditure on R&D from 2008-09 to 2024-25.



While the Ministry did well in the earlier years, the drop in spending in later years is a concern. It can slow down the progress of the R&D Scheme, especially at a time when the steel sector needs innovation, cleaner technologies, and global competitiveness.

Overall, the Ministry of Steel’s 10-year R&D budget reflects a balance between steady funding in earlier years and more fluctuating, sometimes reduced, budget allocations in recent years. This trend may highlight challenges in project execution or changing focus areas, but overall, it shows continued financial support for innovation and research critical to advancing steel production technologies in India.

8 Overall Assessment

8.1 Relevance

The R&D Scheme of the Ministry of Steel, Government of India, plays a crucial role in strengthening the technological foundation of the steel industry. It supports the development of innovative, cost-effective, and sustainable technologies to address challenges such as climate change, energy efficiency, waste utilization, and raw material conservation. By funding collaborative research projects with academic institutions and industry, the scheme promotes indigenous solutions and reduces dependence on foreign technology. As India moves towards green steel and global competitiveness, the R&D Scheme is vital for driving innovation, enhancing productivity, and supporting the transition to a low-carbon, self-reliant steel sector.

8.1.1 Novelty and Advancements in Current Projects

As per the Principal Investigators (PIs) responses, most of the projects under this scheme differ from existing technologies in several important ways. Many projects focus on using industrial wastes, such as chemically activated LD slag, red mud, steel pickling liquor, and spent graphite, as raw materials to improve sustainability and reduce environmental impact. Several projects aim to reduce water and energy consumption, for example by developing dry beneficiation processes for iron ore and hybrid wet-dry processing for coking coal. Some projects are developing indigenous technologies, such as H₂-based direct reduced iron reactors and low-carbon ferroalloy production, to reduce dependence on imports and lower carbon emissions. Others focus on innovative carbon capture and utilization, converting industrial CO₂ into stable minerals or chemicals.

Advanced techniques are being applied in materials and structural design, including steel-masonry buildings, ceramic tiles from industrial residues, and enhanced binders for cement. Some projects integrate modern technologies like machine learning and AI for online monitoring of industrial processes. Overall, these projects emphasize resource efficiency, eco-friendly solutions, cost reduction, and improved performance, addressing gaps in conventional processes while promoting innovation in the steel and related sectors.

8.1.2 Usefulness of the research projects for the iron and steel industry

The responses received from the PIs indicate that the research projects are highly useful to industry across multiple sectors, particularly steel, cement, coal, and iron ore processing. Many projects focus on converting industrial waste into value-added products, such as cementitious materials from Linz-Donawitz (LD) slag, CO₂ mineralization into carbonates, and magnetite nanoparticles for toner production. These innovations contribute to cost savings, enhanced resource utilization, reduced energy consumption, and improved sustainability, aligning with industry goals for greener operations and regulatory compliance. In addition, techniques like dry and hybrid beneficiation of coal, low-grade iron ore processing, and hydrogen-based reduction methods help optimize raw material use, reduce water consumption, and lower carbon footprints, which is critical given environmental and resource challenges in India. Several projects also address specific operational issues, such as sludge recycling, oil recovery, and catalytic conversion processes, offering practical solutions that can be directly implemented in existing industrial setups.

8.1.3 Usefulness of the research projects for the academics

The interaction with experts suggests that the researches are highly valuable for academics, offering both theoretical and practical contributions across multiple fields such as materials science, environmental engineering, civil engineering, and chemical engineering. Many projects provide opportunities to study novel material properties, sustainable construction techniques, advanced beneficiation methods, and waste utilization, creating a rich platform for interdisciplinary collaboration. Graduate and postdoctoral students gain hands-on experience in complex experimental setups, reactor operation, and process optimization, while also learning about transport phenomena, thermodynamics, and reaction kinetics. Several studies, such as LD slag-based cementitious materials, low-grade iron ore dry beneficiation, and CO₂-based decarburization, provide fresh experimental data and insights that can be integrated into teaching, laboratory work, dissertations, and case studies, bridging the gap between theory and industrial practice. Additionally, publications, conference presentations, and knowledge generated through these projects contribute to the wider academic knowledge base and offer guidance for future research initiatives.

Furthermore, the research outcomes provide strategic decision-support tools, performance data, and design guidance for industry stakeholders, including structural designers, contractors, and

EPC firms. Projects on steel framework fabrication, bridge construction, and DRI/H₂-based processes aim to enhance technical knowledge, improve safety, and increase production efficiency. Many projects also include pilot-scale trials, field validations, and collaborations with industry partners, ensuring that the solutions are not only theoretically sound but also commercially viable. Collectively, the responses suggest that over 90% of the research outputs have direct industrial relevance, with potential for large-scale adoption, economic benefits, and environmental improvements. Some limitations were noted, such as the need for further testing, patent-related restrictions on dissemination, and dependency on specialized facilities for certain experimental validations, but overall the research is well-aligned with industry needs and sustainability goals.

Moreover, the research fosters innovation and skill development by introducing novel methodologies and technologies that have been underexplored, such as hydrogen-based reduction roasting, CO₂ mineralization, plasma-based operations, and magnetite nanoparticle synthesis. Academics benefit from understanding complex industrial processes, experimental setups, and mechanistic insights, which can inspire further studies in green steelmaking, resource utilization, carbon capture, and sustainable metallurgy. The projects also support joint PhDs, manpower development, and interdisciplinary collaborations, strengthening academic-industrial linkages. Overall, the research equips students, researchers, and faculty with technical expertise, practical knowledge, and innovative approaches, enhancing both academic scholarship and the capacity to address sustainability and resource management challenges in real-world industrial contexts.

8.2 Effectiveness

8.2.1 Project Collaborations with External Agencies/Companies

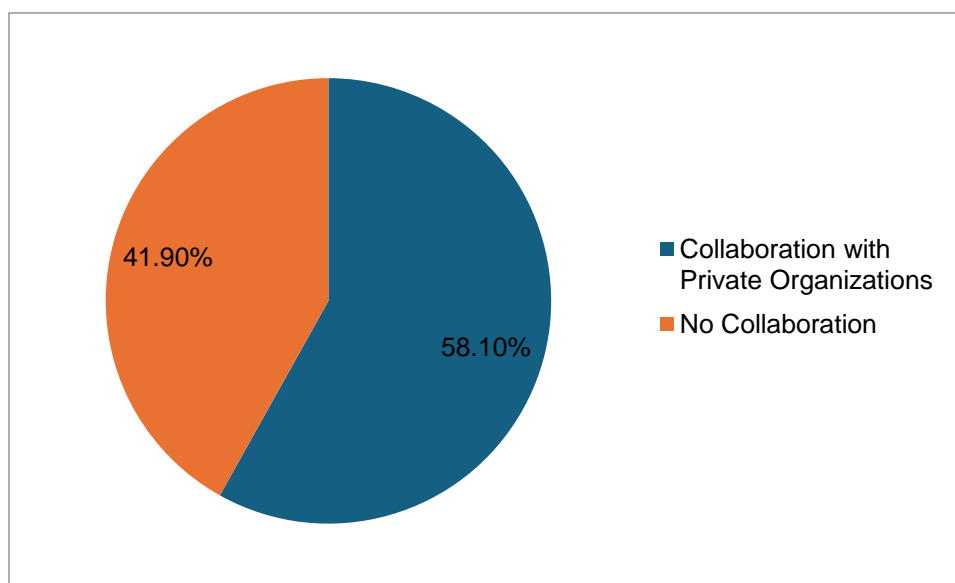
The analysis of project collaborations shows that out of 31 projects, 18 projects (58.10%) reported collaborations, while 13 projects (41.9%) had none. Among the collaborative projects, private organizations were the most common partners (13 cases), including Tata Steel Ltd. And ACME Cleantech Solutions Pvt. Ltd., along with several generic mentions of "Private/Organization." Government research institutes were involved in 5 collaborations, such as CSIR-CIMFR (Dhanbad) and RDCIS-SAIL (Ranchi). A few projects also reflected joint collaborations between government and private partners, showing efforts to combine research strengths with industrial application. This indicates that the Ministry of Steel's R&D ecosystem is leaning more towards industry-driven collaborations, but government institutes still play a

significant supporting role. Overall, the data suggests that private partnerships are slightly more dominant, reflecting the sector’s need for industry-oriented solutions and technology transfer.

Table 7. Project Collaborations with External Agencies/Companies

Response	Frequency	Percentage	Collaboration with Private Organizations	Collaboration with Government Organisations Organizations
Yes	18	58.10%	13	5
No	13	41.9%		
Total	31	100%		

Figure 6: Project Collaborations with External Agencies/Companies



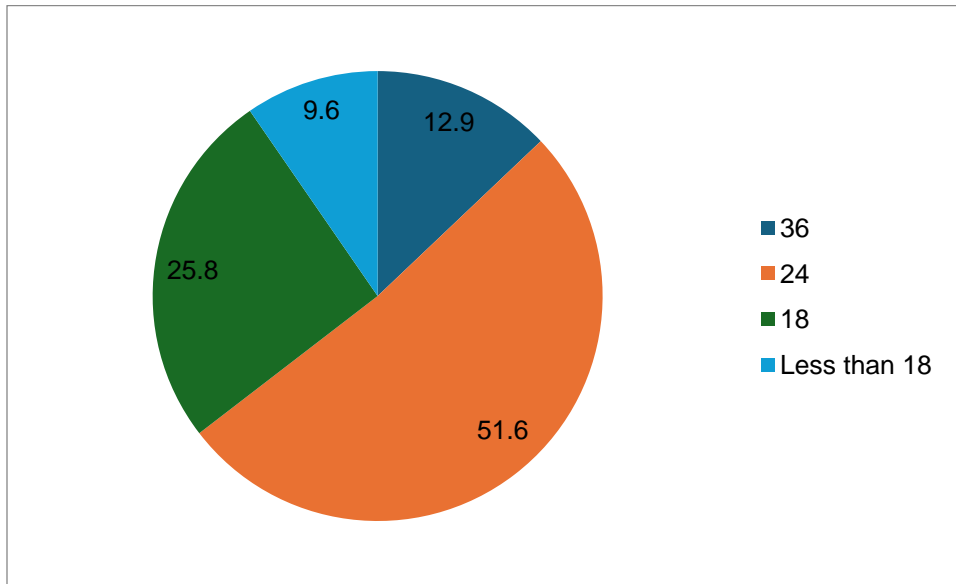
8.2.2 Project Duration

Most projects have duration of 24 months with 51.6 percent share. 18-month projects come next with 25.8 percent. 36-month projects account for 12.9 percent. Only 1 project each are of 17 months, 12 months and 7 months duration (3.2 percent). Overall, the projects largely have two-year time period. The Minutes of the Meetings of PAC indicate that often the PIs were asked to reduce the time period of the projects from the proposed duration.

Table 8: Project Duration (Months)

Duration (Months)	Frequency	Percentage
36	4	12.90%
24	16	51.6%
18	8	25.8%
17	1	3.2%
12	1	3.2%
7	1	3.2%
Total	31	100%

Figure 7: Project Duration (months)



8.3 Efficiency

Most of the researchers who completed their projects indicated that they have achieved the results that they had attempted. The acceptance of their reports also suggests that the project objectives were achieved in most cases. But in terms of outcomes, these statistics are abysmal. 2 to 3 projects can be said to be very useful. For example, use of steel in rural housing being done by SPA, Bhopal and MNIT, Jaipur can lead to greater consumption of steel if adopted. Commercialization as a result of research outputs is very low. In some cases, the studies have led to processes reaching lab scale, but they are nowhere near the stage of commercialization. Some projects did lead to suggested processes being adopted. However, they can be

categorized as incremental improvements. There are three other important factors affecting efficiency:

i. Delays in the project

Some projects were delayed and two projects were stalled. The PIs attributed delays to procedural problems. Often they could not procure the equipment in time. Sometimes the funds were received by them at a later date than they expected. However, it may be mentioned here that many of them were not aware that CNA model has been put into effect. CNA (Central Nodal Agency) refers to the designated body responsible for implementing central sector schemes and managing the flow of funds through a single account with the CSIR-NML, ensuring 'Just in Time' (JIT) fund release and utilization to enhance financial transparency and prevent idle cash balances.

ii. Adequacy of budget for research projects

As per the survey responses, most of the PIs (about 87.1 percent) reported that the budget allocated for the research was sufficient. Only 6.45 percent stated that the budget was not enough, while around 6.45 percent felt it could be increased. One PI gave no response. The main issues of insufficiency were delays in fund release and higher costs of equipment and consumables than planned. The insufficiency of budget in the projects mainly arises due to delays in fund release and higher-than-expected costs. In one case, although the project began with the first-quarter fund of Rs. 5.775 lakhs, the second and third-quarter funds were released only in the fourth quarter on 12.01.2024, causing financial gaps. Additionally, the cost of procuring equipment often exceeded the projected estimates at the proposal stage, while the need for more consumables to conduct experiments with the lab-scale rotary kiln reactor further increased expenses. These factors together highlight the necessity of increasing the project budget to meet actual requirements.

Table 9: Sufficiency of budget for the study

Response	No. of Projects	Percentage
Yes	27	87.10%
No	2	6.45%
Can be increased	2	6.45%
Total	31	100%

iii. Retention of the last installment

Many PIs complained about the retention of 10% of the project cost at the end of the project, which is released after the acceptance of their Project Report. The scientists' grouse was that if the money is not given before, how they will spend it. If not spent, then the money has to be returned to the Ministry.

8.4 Impact

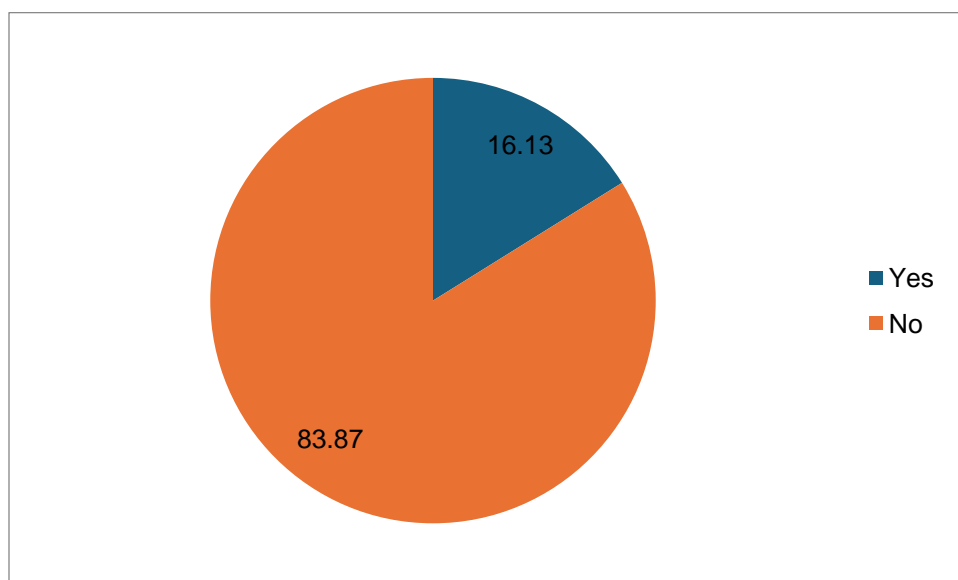
The table shows that most projects (83.9%) have not yet reached the commercialization stage, while only a small proportion (16.1%) have successfully transitioned towards commercialization. This indicates that the majority of projects are still in the research or development phase, suggesting that commercialization remains a challenge or is not yet the focus for most projects.

Out of all the surveyed institutes, only a few have reported that their projects have reached the commercialization stage. These include CSIR-Central Building Research Institute, Roorkee, CSIR-Institute of Minerals and Materials Technology, ICAR-Indian Agricultural Research Institute (IARI), and the National Institute of Secondary Steel Technology.

Table 10: Status of project in terms of its commercialization

Response	Frequency	Percentage
Yes	5	16.13%
No	26	83.87%
Total	31	100%

Figure 8: Status of Project in terms of commercialization



The commercialized projects focus mainly on industrial and agricultural applications, such as:

- Developing new cementitious materials using chemically activated steel slag for construction purposes.
- Creating a dry beneficiation process to extract iron from low-grade ores efficiently.
- Producing eco-friendly fertilizers from steel slag to support sustainable agriculture.
- Developing cost-effective refractory lining materials for quality steel production, including industrial trials.

This indicates that institutes that have achieved commercialization are primarily working on projects with high practical utility and industrial relevance, showing a clear transition from research to application.

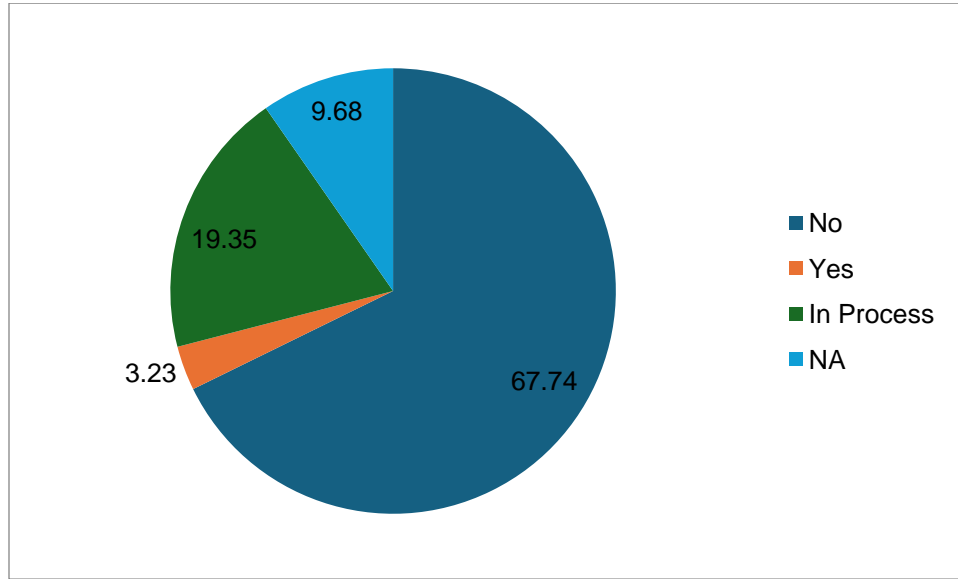
8.4.1 Patents out of the Projects

Out of the 31 responses received during the survey, most PIs, about 68%, reported that their projects did not result in any patents. This shows that the majority of projects did not lead to patentable outcomes. Only one project, which is about 3%, successfully obtained a patent. Six projects, around 19%, have patents that are still in process, meaning the applications are ongoing or awaiting approval. Additionally, three PIs, about 10%, did not provide relevant information. Overall, this indicates that patenting is not very common among these projects, and only a small number have either secured or are pursuing patents.

Table 11 : Patents out of the Projects

Sr. No.	Answers	Frequency
1	No	21
2	Yes	1
3	In Process	6
4	NA	3

Figure 9: Patents out of Projects



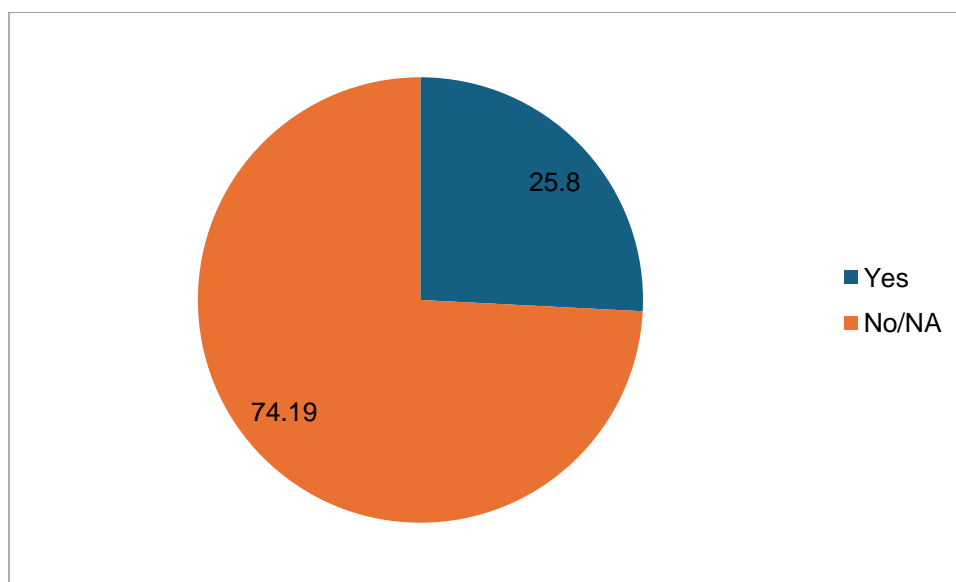
8.4.2 Research Publications

The table shows that a majority of projects, about 74.19 %, have not led to publications or working papers. 8 publications are either journal articles, conference papers, or manuscripts currently under review. Examples include comparative studies on bridge design and life-cycle assessment, research on steel slag use in agriculture published in journals like *Journal of Environmental Biotechnology* and *Sustainable Chemistry for the Environment*, and studies on iron ore beneficiation, H₂-based reduction, and carbon capture published in *Acta Materialia* and *Materials and Structures*. Other notable contributions include advanced friction stir welding techniques for industrial steel pipes and machine learning applications for iron ore pellet monitoring published in IEEE journals.

Table 12: Publications related with research projects

Response	Frequency	Percentage
Yes	8	25.80%
No / NA	23	74.19%
Total	31	100%

Figure 10: Research Publications



The “Yes” responses show that these projects are actively adding to the scientific knowledge base and helping share research findings beyond the project itself. About 26% of projects are still in progress, with manuscripts under preparation. This suggests that some more publications can be expected in the near future when projects are completed and finalized.

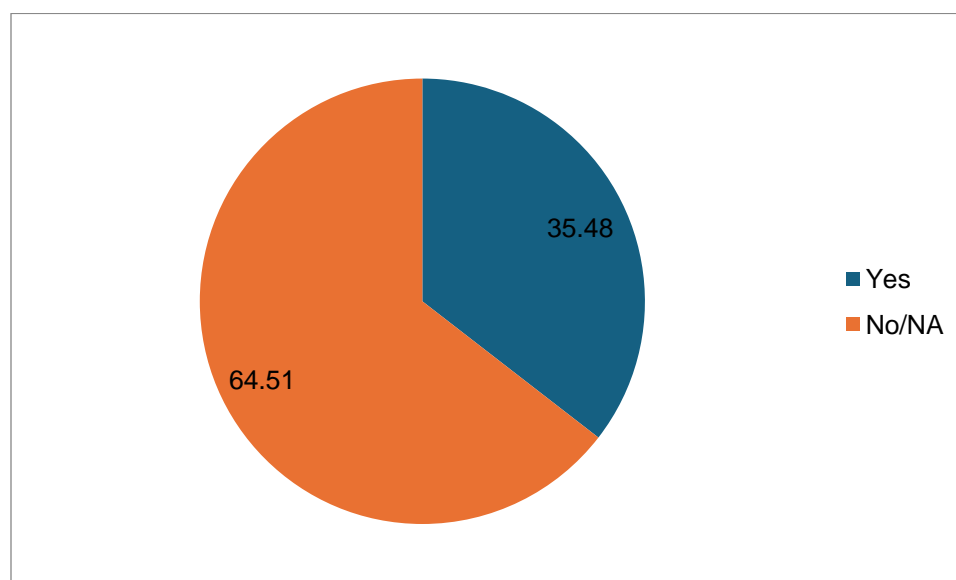
8.4.3 Paper presentations

The table 13 shows that a majority of projects have actively contributed to knowledge dissemination through presentations in seminars, workshops, and conferences, in addition to publications. Out of 31 responses, about 11 projects (35%) reported papers or talks presented externally, while the remaining 20 projects (65%) have either not presented their work yet, were awaiting patent clearance, or marked as “No/NIL/NA.” Notable presentations include Linz-Donawitz (LD) slag research presented at international conferences such as the *Steel & Metallurgy International Conference on Resource Efficiency and Circular Economy 2022*, the *NCB International Conference on Cement, Concrete and Building Materials (2022 & 2024)*, and *Innovative World of Concrete 2024 (Kolkata)*. Other examples include presentations on hybrid beneficiation of coking coal, chromium recovery from spent pickling solutions, and sustainable waste management for steel industries, shared in workshops and national conferences such as CSIR-CIMFR Dhanbad, STIS-V IISc Bengaluru, and Big Mint Ferrous Week.

Table 13: Conference and Seminar Presentations Resulting from the Project

Response Type	Frequency	Percentage
Yes	11	35.48%
No/NA	20	64.51%
Total	31	100%

Figure 11: Conference and Seminar Presentations



The “Yes” responses indicate that these projects are not only generating valuable research outputs but also actively sharing insights with the wider scientific and industrial community. Presenting in seminars and conferences helps establish collaboration, exchange ideas, and enhances the visibility of the projects’ outcomes. There could be additional presentations as the projects progress and results are finalized.

8.4.4 Honorarium / Royalty from the commercialization of the project

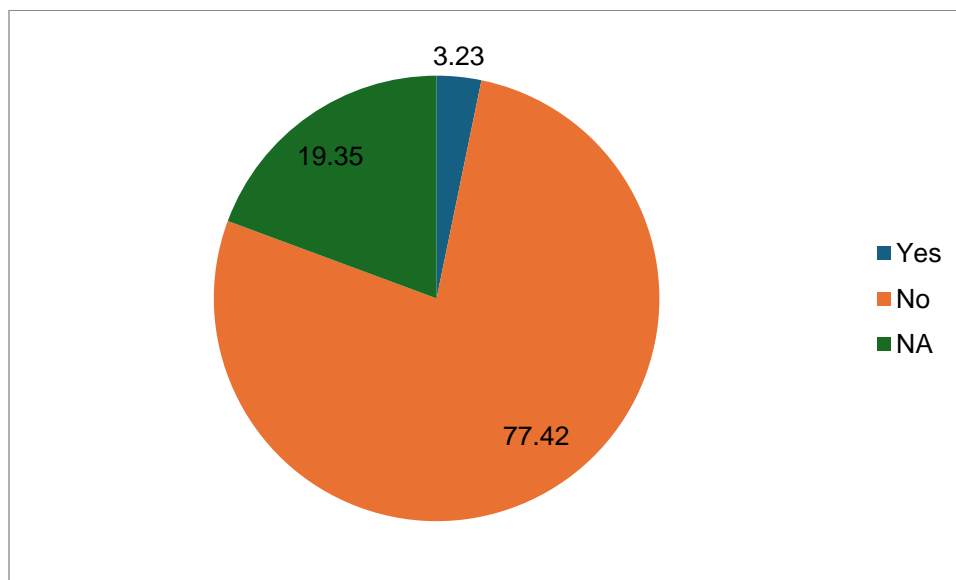
The table below shows that Most PIs (77.4%) do not receive any honorarium or royalty in IPR / project’s commercial use, while a very small fraction (3.2%) reported receiving honorarium / royalty. About 19.4% of PIs marked NA, indicating that the question may either not be applicable to them or project is under completion, therefore the projects are not eligible for royalties. This suggests that royalty benefits in IPR are very limited or not widely accessible

among the surveyed institutes. Only CSIR-NML, which have worked upon the project namely, “Processing of tin slag and technological extraction of critical elements for high strength low alloy steels the PI said that they are getting royalty for their work.

Table14 : Getting Honorarium / Royalty from the project

Response	Frequency	Percentage
Yes	1	3.23%
No	24	77.42%
NA	6	19.35%
Total	31	100%

Figure 12: Honorarium /Royalty from the Project



8.5 Sustainability and Adherence to the SDG Goals

While analyzing the responses from R&D projects supported under the Scheme regarding of which of the Sustainable Development Goals (SDGs) these projects are aligned with, it was found that the following SDGs were referred by the institutes most frequently;

Table 15 : Project Adherence to the SDG Goals

SDG No.	SDG Goal	Frequency of SDGs mentioned in the project	Themes from Projects
SDG 3	Good Health & Wellbeing	1	Safer handling of toxic wastes.
SDG 6	Clean Water & Sanitation	3	Reduced water consumption in beneficiation, effluent management.
SDG 7	Affordable & Clean Energy	6	Hydrogen, renewable energy in steel, syngas substitution.
SDG 9	Industry, Innovation & Infrastructure	12	New tech for beneficiation, AI-based automation, electrolyzers, innovation in steelmaking.
SDG 11	Sustainable Cities & Communities	2	Structural steel in resilient, low-cost buildings.
SDG 12	Responsible Consumption & Production	8	Recycling waste, efficient resource use, sustainable production.
SDG 13	Climate Action	15	CO ₂ reduction, decarbonization, hydrogen-based DRI, cleaner production.
SDG 15	Life on Land	2	Safe sludge disposal, reduced land degradation.
SDG 17	Partnerships for Goals	1	Public-private collaborations in R&D.

Several of the 31 projects contribute in achieving multiple SDG goals. The above analysis shows that the R&D projects supported by the Ministry of Steel align most strongly with SDG 13: Climate Action, as the majority focus on reducing carbon emissions through hydrogen-based steel-making, CO₂ mitigation, and cleaner technologies. Alongside this, SDG 9: Industry, Innovation & Infrastructure is a key area, reflecting the Ministry's emphasis on technological advancement and modernization of the steel sector. Significant contributions are also made toward SDG 12: Responsible Consumption & Production, highlighting efforts to promote circular economy practices, waste recycling, and efficient resource use. Energy transition initiatives link these projects with SDG 7: Affordable & Clean Energy, while a smaller number address SDG 6: Clean Water and SDG 15: Life on Land by reducing water consumption and preventing land degradation. Socially relevant goals such as SDG 11, SDG 3, and SDG 17 feature less prominently but indicate broader benefits through resilient infrastructure, safer industrial practices, and collaborative partnerships.

8.6 Equity

Overall, the distribution shows that a few institutes (IMMT, IIT Bombay, NML) have been able to get more projects, while many others have limited participation.

Table 16: Research Grant to Various institutions

Organization	No. of Projects Approve	Projects Percentage (%) out of 70	Grants Released	Grants Percentage (%) out of 15836.12
ICAR-IARI	1	1.43	311.88	1.97
NML	15	21.43	4,465.60	28.20
IMMT	15	21.43	3,522.93	22.25
CGCRI	2	2.86	165	1.04
CBRI	1	1.43	120	0.76
CRRRI	1	1.43	286.5	1.81
CIMFR	1	1.43	23.24	0.15
Total CSIR	36	51.43	8,895.15	56.17
IIT Bombay	7	10.00	398.22	2.51
IIT Kharagpur	3	4.29	351.81	2.22
IIT Madras	2	2.86	207.13	1.31
IIT BHU	2	2.86	284.45	1.80
IIT Kanpur	1	1.43	154.63	0.98
MNIT Jaipur	2	2.86	325.82	2.06
JU	1	1.43	481.1	3.04
BITS Pilani	1	1.43	34.241	0.22
PEC	1	1.43	137	0.87
IIT (ISM) Dhanbad	1	1.43	51.223	0.32
IIT Hyderabad	2	2.86	198.191	1.25
IIT Roorkee	2	2.86	0.00004	0.00
Total Academic	25	35.71	2,623.81	16.57
RDCIS SAIL	4	5.71	2,836.45	17.91
MECON	1	1.43	154	0.97
KIOCL	1	1.43	11.2	0.07
MIDHANI	1	1.43	800	5.05
NISST	2	2.86	515.5	3.26
Total PSOs	9	12.86	4,317.15	27.26

It is clear from the table above that a few organizations have been able to get the majority of projects and grants, suggesting a skewed distribution. Government sponsored organizations, while doing few projects, received a significant share of grants.

8.7.1 Undertaken more than one project under the same scheme over the years?

From the table, it is clear that the majority of respondents (83.83%) have not undertaken more than one project under the same scheme, while smaller portions (16.12%) have managed multiple projects. The "Yes" responses indicate repeat involvement by a few key researchers, primarily from CSIR-National Metallurgical Laboratory and IIT Bombay, suggesting that some experienced PIs have maintained continuity in similar projects over the years. This continuity may reflect their expertise in specific research areas and their capacity to handle multiple projects under the same scheme, contributing to sustained progress and knowledge development in their respective fields.

Table17: Undertaken more than one Project

Response	Frequency	Percentage
Yes	5	16.12%
No	26	83.83%
Total	31	100%

8.7 Need for modification in the project as suggested by PRC Committee

Out of 31 responses, most PIs (77.43%) reported that they did not have to modify their project after PRC suggestions. About 22.5% of the PIs indicated that they did make modifications based on PRC recommendations. This suggests that while a majority of projects were acceptable without changes, a notable portion of projects required fine-tuning at the project proposal formulation stage.

Table 18: Need for modification in the project as suggested by PRC Committee

Response	Frequency	Percentage
Yes	7	22.57%
No	24	77.43%
Total	31	100%

Overall, there are some notable achievements under the scheme and many areas to improve the various aspects of this scheme. For example, a broader vision for the R&D in view of the ambitious sectoral plans, project proposal preparation, industrial contribution to researches, incentivizing research to improve the quality of researchers, etc.

PART B

Brief Notes on the Projects Sanctioned Under the Scheme

PART B: BRIEF NOTES ON THE PROJECTS SANCTIONED UNDER THE SCHEME

B.1.1: Project Title: Development of Newer Cementitious Materials using Chemically Activated Linz Donawitz (LD) Slag

B1.2: Project objectives:

1. To develop a process technology for the utilization of high-volume LD/ steel slag for making cementitious binders / blended cement/ concrete.
2. Performance and durability assessment of developed cementitious binders/ blended cement for mortars/ concrete under aggressive environment

B1.3: Duration of the Project: 36 months

B1.4: Project starting date: 01/10/2018

B1.5: Project Completion date: 31-03-2024

B1.5: Status of the Project: Completed (On-time)

B1.6: Project cost:

Total Project Cost: Rs. 1,95,00,000/

ii. Scheme's funding: Rs. 1,20,00, 000/- (Released)

iii. Organization's own contribution: Scientific manpower, institution facilities etc.

B1. 7: Principal Investigator: Prof. S. K. Singh

B1.8: Name of the Institute: CSIR-Central Building Research Institute, Roorkee

B1.9: Achievements: Developed a process for utilization of LD slag for making cementitious binders / blended cement via: Mechano-chemical activation study:

Mechanical activation of LD slag through grinding for different time intervals followed by particle size optimization. Further, chemical activation using four different activator solutions i.e., sodium silicate, sodium sulphate, sodium hydroxide and sodium carbonate. Preparation of blended paste cubes incorporating 70% OPC and 30% milled LD slag with different activator solutions. Thereafter, mechanical strength testing, mineralogical and morphological studies of 28 days aged specimens of paste was conducted. Here mechano-chemical activation process and 30% processed LD slag were optimised for the development of sustainable binder. Durability studies on the developed binders in concrete with different test methods were also established. Conduct of modelling of the developed LD slag-cement for measuring the degree of reaction and also experimental validations. In this context, novel test methods have been developed for evaluating reactivity of OPC-LD slag composite binder. Test included acid dissolution combined with XRD and BSE image analysis.

B.11: Observations: LD or BOF process is one of the methods used to produce steel from liquid cast iron. In this process, slag is an essential by-product, with about 120–150 kg generated per ton of crude steel. Earlier, this slag was dumped as waste, but nowadays it is processed, cured, and utilized in road construction, railway ballast, as a cement and clinker substitute, and for soil conditioning. Moreover, there is a significant opportunity for metal recovery, particularly for iron (Fe) and manganese (Mn).

B.2.1: Project Title: Eco-friendly solution with metal recovery and value-added products from stainless steel spent pickle liquor: A zero waste business model

B.2.2: Project objectives:

- Development a flow-sheet for recovery of Ni, Cr, Mn from spent stainless steel pickling liquor in the form of saleable products
- Fixing of toxic component of process residue and assessment of environmental impact using Life Cycle Assessment (LCA)

B.2.3: Duration of the Project: 24 Months

B.2.4: Project starting date: 01/04/2023

B.2.5: Project Completion date: 01/03/2025

B.2.5: Status of the Project: Completed (On-time)

B.2.6: Project cost: i.

Total Project Cost: 125.124 L

ii. Scheme's funding: 67.724 L

iii. Organization's own contribution: : 22.40 L

iv. Any other source: 35.00 L (Jindal Stainless Ltd, JSL)

B.2.7: Principal Investigator: Dr. K. K. Sahu

B.2.8: Name of the Institute: National Metallurgical laboratory, Jamshedpur

B.2.9: Achievements: The research and developments carried out under this project contributes towards developing a complete solution to take care of highly toxic spent pickle liquor through value addition. The findings propose some simple methods for key consideration to get rid of the present unscientific practice and improve the sustainability of the stainless-steel industries.

B.2.11: Observations:

Stainless steel pickling liquor is a hazardous but resource rich waste stream generated during pickling (acid cleaning) of stainless-steel surfaces.

It mainly contains spent acids and dissolved metals such as Fe, Cr., Ni, Mo depending on the steel grade.

Instead of disposal good industries recover value-added metals and re-Cycle acids.

There are huge opportunities in improving the recovery methods for metals and acid re-generation to reduce the processing costs.

B.3.1: Project Title: Selective Removal of CO₂ from the Gas Produced from Coal/Biomass Using Suitable Media for Gas Enrichment

B.3.2: Project objectives:

1. Preparation of media for selective removal of CO₂ from input gas stream.
2. Development of indigenous media cartridge for effective use in laboratory scale

B.3.3: Duration of the Project: 12 months

B.3.4: Project starting date: 01-04-2023

B.3.5: Project Completion date: 31-03-2024

B.3.5: Status of the Project: Completed On-time

B.3.6: Project cost:

Total Project Cost: Rs.33,00,000/-

ii. Scheme's funding: Rs.16,67,943/-

iii. Organization's own contribution: Rs.9,90,000/-

B.3.7: Principal Investigator: Dr. Pallishree Prusti

B.3.8: Name of the Institute: CSIR Institute of Minerals & Materials Technology, Bhubaneswar

B.3.9: Achievements:

Preparation of media for selective removal of CO₂ from input gas stream

Development of indigenous media cartridge for effective use in laboratory scale

B.3.11: Observations:

When coal or bio-mass is gasified the product gas (Syn Gas or producer gas) contain a mix of CO, H₂, CH₄, CO₂, N₂ & H₂O.

For gas enrichment, we often remove CO₂ selectively without losing calorific components.

High CO₂ lowers calorific values and reactivity.

Enrichment aims to increase CO+ hydrogen (Syn gas) and improve fuel gas quality.

This technology was developed by Lurgi- South Africa.

The only plant in India is 2.1 million Tonn DRI plant bast on Coal gasification technology at JSPL Angul.

The biggest strength is use of non-coking coal.

There is huge opportunity in use of this technology. Now a days Ministry of Coal GOI is giving huge subsidy to use this, that's why Jindal Steel Limited is setting up another 2.0-million-ton plant at Angul.

B.4.1: Project Title: Development of process for Beneficiation of Lean grade iron ores with less than 45% Fe content

B.4.2: Project objectives:

1. Upgrading the quality of lean grade iron ore to produce pellet grade concentrate.
2. Development of process flowsheet for iron ore upgradation via physical/chemical beneficiation

B.4.3: Duration of the Project: 18 months

B.4.4: Project starting date: 28-03-2024

B.4.5: Project Completion date: 28-09-2025

B.4.5: Status of the Project: Completed (on-time)

B.4.6: Project cost:

- i. Total Project Cost: Rs. 52.23
- ii, Lakhs Scheme's funding: Rs. 36.56 Lakhs (Received 32.904 lakhs)
- iii. Organization's own contribution: Rs. 15.67 Lakhs

B.4.7: Principal Investigator: Abhishek Kumar

B.4.8: Name of the Institute: CSIR-National Metallurgical Laboratory

B.4.9: Achievements:

1. Lean grade iron ore with assay < 45% has been successfully beneficiated to produce pellet grade concentrate.
2. A process flowsheet has been developed for utilization of this type of lean grade iron ore.

B.4.11: Observations:

Developing process of beneficiation of low-grade iron ore is a major challenge not only in India but other countries also having iron ore mines

Low grade iron ore (Fe 45-55%) contain goethite, silica, alumina and other impurities.

Process involves various separation technicism with a goal of pellet grade concentrate.

With depleting Fe content there is huge scope of opportunity to develop this process.

Only threat is the disposal of waste material

B.5.1: Project Title: Strategic Recycling of Cold Rolling Mill oil sludge of Jindal stainless Ltd. to recover the valuables

B.5.2: Project objectives: Development of state-of-art technology for efficient recovery of pure oil and metal values from cold rolling mill oil sludge.

Optimization of process parameters in laboratory scale, bench scale, and replication in 50 kg scale (batch wise).

Arriving at the mass balance and energy calculations; techno-economics

Immediate implementation of the technology by M/S Jindal stainless Ltd., in Jaipur, Odisha

B.5.3: Duration of the Project: 18 months

B.5.4: Project starting date: 09/11/2023

B.5.5: Project Completion date: 13/02/2025

B.5.5: Status of the Project: Completed (On- time)

B.5.6: Project cost:

i. Total Project Cost: 63.28 lakhs

ii. Scheme's funding: 31.64 lakhs.

iii. Organization's own contribution:

iv. Any other source: 31.64 lakhs by Jindal Stainless Ltd, Jajpur.

B.5.7: Principal Investigator: Dr. Pravas Ranjan Behera

B.5.8: Name of the Institute: CSIR-Institute of Minerals and Materials Technology

B.5.9: Achievements: Process flow-sheet developed in laboratory scale and bench scale.

B.5.11: Observations:

Jindal Stainless Ltd. (JSL) is operating a cold rolling complex and Combo lines at Jajpur, Odisha.

Cold rolling sludge (CRS) is a significant waste stream in stainless steel units, generated from rolling oils, coolants, metallic fines and oxides. It is a hazardous waste but contains valuable metals also viz. Fe, Cr, Ni, Mo that can be recovered.

CRS is an environmental issue and disposal in landfills risks soil & water contamination.

There is a huge scope of oil recovery and de-oiling and increase uses of biological treatment.

There is a great opportunity in metal recovery and charge it as a sinter/pellet feed.

After recovery these can be used in cement & pigment production units.

Only threat is disposal of recovered waste in a safe manner

B.6.1: Project Title: Decarburization of High Carbon Ferro Manganese for Preparation of Low Carbon Ferro Manganese

B.6.2: Project objectives:

The object of the proposed study is as follows.

- Decarburization of high carbon Fe- Mn to achieve below 1.5wt% in a 20-50 kg electric arc furnace/ Induction furnace/suitable reactor by blowing Co₂ in the presence of MnO-rich slag.
- Feasibility study of decarburization with CO₂ with Oxygen enrichment in CO₂ gas to achieve carbon content below 1.5% on a 20-50 kg scale.
- Upscaling of the developed process up to 200-250 kg/ batch.
- Techno- economic assessment for using CO₂ with oxygen enrichment in CO₂ gas to achieve carbon content below 1.5% on a 20-50 kg scale.

B.6.3: Duration of the Project: 24 months

B.6.4: Project starting date: 06-03-2025

B.6.5: Project Completion date: 05-03-2027

B.6.5: Status of the Project: Completed (on-time)

B.6.6: Project cost:

i. Total Project Cost: 90 Lakhs

ii. Scheme's funding: 63 Lakhs

iii. Organization's own contribution: Nil

iv. Any other source: 27 Lakhs from RDCIS

B.6.7: Principal Investigator: DR AMMASI A

B.6.8: Name of the Institute: CSIR- National Metallurgical Laboratory, Jamshedpur

B.6.9: Achievements: The project work activities are in progress as it is recently approved project. Preliminary experiments were performed.

B.6.11: Observations:

This is a process of metal recovery.

Carbon is inducted during production via coke and then must be removed in downstream refining.

High carbon ferro manganese is used in normal crude steel production. But Low Carbon Ferro Manganese is used in special steel and stainless-steel production.

To decarbonise HC Fe Mn into LC FeMn, the silicothermic route using FeSi/Si Mn is the main method while oxygen refining and Si reduction is also practiced for special steel electrolytic manganese is the only way.

Ferro-manganese alloy is a must for steel production from hot metal.

But now a days considering the growth in automobile industry and latest changes in roofing sector there is a great demand of low carbon ferro manganese.

Considering the emphasis on production of green steel hydrogen base refining, replacing c with H₂ is getting priority, there are great opportunity in this process only threat is the recovery and re-use the processed product. Because we cannot burn carbon

B.7.1: Project Title: Development of Steel Slag Based Cost Effective Eco Inclusive Growth Development of Steel Slag Based Cost Effective Eco-Friendly Fertilizers for Sustainable Agriculture and inclusive growth.

B.7.2: Project objectives: 1)To study the influence of steel slag application on soil physical, chemical & biological properties as well as heavy metal build up in soil / ground water in order to understand its positive andnegative impact. (2)To study the efficiency of steel slag application as soil amendment for acid soil reclamation, mitigation of Green House Gases (GHG) and reduce the heavy metal contamination.. (3)To study the effect of steel slag as a source of plant nutrients and its impact on available nutrients, growth, yield, quality and economics of major crops. (4) techniques to enrich the steel slag by blending with other agricultural inputs for and its impact on available nutrients, growth, yield, quality and economics of major crops. 5) Post project intervention: Introduce interventions to improve the soil physical, chemical and biological status, if the experimental site is observed for any negative soil and its impact on available nutrients, growth, yield, quality and economics of major crops.

B.7.3: Duration of the Project: 36 months

B.7.4: Project starting date: 06/07/2021

B.7.5: Project Completion date: 30/09/2024

B.7.5: Status of the Project: Completed (on- Time)

B.7.6: Project cost:

- i. Total Project Cost: Rs.8.66 Cr.
- ii. Scheme's funding: Rs 3.464 Cr
- iii. Organization's own contribution: .in kind, scientific manpower and resources
- iv. Any other source: Rs. 5.196 Cr (Industry)

B.7.7: Principal Investigator: Bhupinder Singh

B.7.8: Name of the Institute: ICAR-Indian Agricultural Research Institute (IARI)

B.7.9: Achievements:

Objective 1: Steel slag supplied by the Industry partners did not vary significantly in terms of their chemical composition, but were rich in plant essential and beneficial mineral nutrients. Cr content in different lots varied between 600-800 ppm). Application of raw slag in field and in potted soil caused an increase in soil pH and heavy metals particularly Ni and Cr. Objective 2: Steel slag ameliorated soil acidity and improved the soil available minerals for plant uptake. Experiments conducted with HM contaminated acidic soils clearly reveal a reduced availability of HM for plant uptake and accumulation in presence of steel slag. Steel slag application in acidic soil, even with 80% NPK, improved the vegetative and economic yield of green gram and rice, when later was raised on heavy metal contaminated acidic soil. A significant reduction in cumulative N₂O emissions was recorded when steel slag was applied either alone or with biochar in wheat. Bio-sorption of Cr on biochar applied together with steel slag reduced the total concentration of toxic heavy metals in the soil under rice. Objective 3: Steel slag application alone, in general, did not increase the produce and the biomass yield of cereal, vegetable and oil seed crops. However, with 80% RDF the biomass and produce yield were bettered significantly in vegetables. Slag application as such improved the Fe content of economic produce across crops. Objective 4: Not only the steel slag-based value-added products were developed and characterized but also their performance in respect of the crop response was evaluated under pot/ field culture condition across crops and regions. Out of a total of 51 amended products thirteen promising products were identified and were given to the industry partners @ 20 kg of each of 13 products per partner for independent validation of their performance in field crops. Mean increase in yield across crops varied from 10 to 15% even with 80% crop specific recommended NPK use and was accompanied by an improved nutritional quality of the economic produce. Objective 5: These products are likely to improve crop yield without causing any phyto toxicological and eco-toxicological impact on plant and soil health on normal acidic and degraded sandy and heavy metal contaminated soils, in comparison to raw slag usage in agriculture. Following salient results were obtained: *TF values >1 indicates efficient metal transport system from soil to shoots Page 5 of 9 (Raw slag) , TF < HQ ≤ 10 = medium risk; HQ > 10 = high risk of heavy metal for the consumer health;

***HI values ≤ 1 , Acceptable level of risk (Amended enriched slag), HI values > 1 , Unacceptable risk (Raw slag).

B.7.11: Observations: Steel slags from Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) routes contain valuable oxides that can be converted into cost effective fertiliser.

Steel slag composition is Cao (30-50%), MgO (10-20%), SiO₂ (10-20%), FeO/Fe₂O₃ (10-30%)

Fertiliser conversion from slag needs weathering, grinding and value addition by adding phosphorus.

Strength of this process is cost effectiveness because slag is waste material so cost is very low.

This is also environment friendly and gives protection from hazardous waste disposal.

This grade of fertiliser is very good for cultivation of rice, wheat and sugarcane.

There is always shortage of fertiliser in the country hence converted fertiliser from slag has very good potential to grow in the fertiliser market.

B.8.1: Project Title: Development of Cost effective refractory lining materials for induction melting Furnace suitable for production of quality of steel: Phase II(Industrial Trials)

B.8.2: Project objectives:

- a) Suitability of the basic lining mass under basic and oxidizing flux.
- (b) To assess the lining erosion pattern during refining.
- (c) economic feasibility of the lining material

B.8.3: Duration of the Project: 18 months

B.8.4: Project starting date: 01.11.2019

B.8.5: Project Completion date: 01/09/2023

B.8.5: Status of the Project: Completed (on-time)

B.8.6: Project cost:

- i. Total Project Cost: 154.30 Lakhs
- ii. Scheme's funding: Scheme for promotion of Research & Development in Iron & Steel Sector (1008)

B.8.7: Principal Investigator: Sandeep pal Singh

B.8.8: Name of the Institute: CGCRI&NISST

B.8.9: Achievements: The basic ramming mass tried in industrial trial could not sustain the industrial environment due to higher ferro static pressure and cracked during initial stages of heat itself.

B.8.11: Observations: This is the cheapest route to produce steel compared to BOF and EAF.

Major key performance indices (KPIs) of refractory lining are:

- Lining life

- Cost per ton
- Tap to Tap energy
- Contamination PPM
- Downtime hours per year.

Most of the steel producers outsource the changing of refractory lining.

If there is only one furnace then production is stopped during lining life, then the strength is to select good quality refractory material and contractors.

Weakness is lower lining life due to use of high eddy current electric flow.

Threat is non-environment friendly; hence this method is used only in India

B.9.1: Project Title: Developing a facile electrocatalytic CO₂ to CO conversion to CO conversion

B.9.2: Project objectives: This project, developed at IIT Bombay with support from the Ministry of Steel, Government of India, focuses on establishing a robust and energy electrocatalytic system for the neutral strategies in industrial sectors, particularly in steel manufacturing, this initiative addresses the urgent need for scalable and sustainable C lies in the design of a low-cost, stable electrocatalyst capable of converting CO Faradaic efficiency under ambient conditions

B.9.3: Duration of the Project: 17 months

B.9.4: Project starting date: 01/04/2023

B.9.5: Project Completion date: 30/09/2024

B.9.5: Status of the Project: Completed (On-time)

B.9.6: Project cost:

i. Total Project Cost: Rs. 1,53,75,000.00

ii. Scheme's funding: DST

B.9.7: Principal Investigator: Dr. Arnab Dutta

B.9.8: Name of the Institute: IIT Mumbai

B.9.9: Achievements: The project has delivered all envisaged objectives with significant scientific and technological outcomes: We have developed an active modular CO₂ capture and conversion prototype (Capacity 10.0 100.0 kg per day).

B.9.11: Observations: There are many processes to convert CO₂ to Co mainly:

- Electro-chemical CO₂ to Co
- Thermocatalytic Reverse Water -Gas shift
- Photochemical/Photocatalytic/ solar driven routes

Basic reaction is $\text{CO}_2 + \text{H}_2 = \text{CO} + \text{H}_2\text{O}$

CO is treated as Syn gas which many advantages as compared to Coke Oven and BF gas.

It is a very good R& d project

Strength of CO is that it is a reducing gas while CO₂ is fully oxidized.

Co is far more useful as a chemical feedstock and has more commercial value. Only weakness and threat is that it is more dangerous than CO₂

B.10.1: Project Title: Development of nanosized magnetite from mill scale for printing application

B.10.2: Project objectives: To produce magnetite nanoparticles from mill scale, To make toner from the obtained magnetite nanoparticles, To compare the quality of the produced toner.

B.10.3: Duration of the Project: 24 months

B.10.4: Project starting date: 28-03-2022

B.10.5: Project Completion date: 27-03-2024

B.10.5: Status of the Project: Completed

B.10.6: Project cost:

1. Total Project Cost: .52,80,300
2. Scheme's funding: 36,96,300
3. Grant released: 33,26,670, pending is 3,69,630
4. Organization's own contribution: 15,84,000.

B.10.7: Principal Investigator: Dr. R. Sakthivel

B.10.8: Name of the Institute: CSIR- IIT Bhuvneshwar

B.10.9: Achievements: Magnetite nanoparticles are successfully synthesized by using mill scale as raw material. Gram to kg scale of production of magnetite is achieved at room temperature. The magnetite nanoparticles derived from the mill scale are comparable to the imported magnetite. Toner has been prepared successfully from magnetite nanoparticles

B.10.11: Observations: Mill scale waste from rolling mills can be valuable feed stock nanosized magnetic materials, having high potential in printing inks, magnetic toners, sensors and and electronic devices.

Mill scale is a by-product of hot rolling 92-45 of input steel.

It is low cost, abundant, underutilized waste.

Mill scale is pretreated, converted to nano-magnetics and ground to powder form.

Major strength is conversion to nano materials, low cost and support circular economy in steel industry

Weakness tight particle size control, removal of heavy materials

B.11.1: Project Title: Development of an Integrated Design, Optimization and Life-Cycle Cost Calculation Software for Steel Girder Bridges

B.11.2: Project objectives: 1. To construction by providing designers with an easy-to-use integrated software.

2. To reduce carbon footprint by promoting steel bridges as an alternative to concrete.

3.To develop a comprehensive life-cycle cost (LCC) assessment framework tailored for Indian conditions.

B.11.3: Duration of the Project: 24 months

B.11.4: Project starting date: 01 /06/2025

B.11.5: Project Completion date: 31/12/2026

B.11.5: Status of the Project: Ongoing

B.11.6: Project cost:

Total Project Cost: 2,41,58,352

Scheme's funding: 1, 69,10,846

Organization's own contributions: 0

Any Other Source: 72,47506

B.11.7: Principal Investigator: Siddhartha Ghosh

B.11.8: Name of the Institute: Indian Institute of Technology Bombay

B.11.9: Achievements:

Developed 3PS-LCC framework for bridges.

Generated benchmark designs of steel and PSC girder bridges.

Built foundation for integrated open-source software under Osdag.

B.11.11: Observations: Now a days to increase road connectivity there is very vast network of NH & SH and there is huge consumption of steel in bride construction.

Roughly 0.6-0.8 Metric Ton steel is used in per span per KM.

If steel girder bridges is designed properly then there is huge scope in cost reduction and longer life in steel bridges.

Several software has been developed for calculating and optimization of life cycle cost.

If design and quality of steel used are not proper and there are chances of pre-mature failure, which has been observed in many states in recent days.

Several software have been developed Life Cycle Cost (LCC) by National Institute of Standard Technology (NIST) and National Cooperative Highways Research Programme (NCHRP).

There is huge scope for further improve LCC of bridges.

Improper design and use of sub-standard quality material may lead to early failure.

B.12.1: Project Title: Development of Dry Beneficiation Process to Recover Iron Values from the Low-grade Iron Ores and Fines

B.12.2: Project objectives: The prime objective of the project is to develop a complete dry beneficiation process to recover iron values of the required grade from the low-grade iron ores and fines.

B.12.3: Duration of the Project: 18 months

B.12.4: Project starting date: 01/04/2024

B.12.5: Project Completion date: 30/09/2025

B.12.5: Status of the Project: Ongoing (On-time)

B.12.6: Project cost:

- i. Total Project Cost: ₹ 55.15 Lakhs
- ii. Scheme's funding: ₹ 35.65 Lakhs
- iii. Organization's own contribution: ₹ 19.50 Lakhs

B.12.7: Principal Investigator: Prasanta Kumar Baskey

B.12.8: Name of the Institute: CSIR-Institute of Minerals and Materials Technology

B.12.9: Achievements: The primary objective of the project was to develop a dry beneficiation process for the recovery of iron values from low-grade iron ore and fines.

b) For this study, a low-grade iron ore sample and an iron ore fines sample were collected from Joda Mines. The low-grade ore assayed 50.12% Fe (T), 8.00% SiO₂, and 9.06% Al₂O₃, while the fines sample assayed 60.30% Fe (T), 2.72% SiO₂, and 3.66% Al₂O₃.

c) Detailed laboratory-scale beneficiation studies were carried out, leading to the development of a process flow sheet for both the low-grade iron ore and fines samples from Joda Mines.

d) Using the developed dry beneficiation flow sheet for the low-grade ore, an iron ore concentrate assaying 62.09% Fe was produced from a feed grade of 50.12% Fe, with a yield of 47%. The final concentrate contained 3.16% SiO₂ and 2.59% Al₂O₃.

e) For the fines sample, the iron content was upgraded to 65.06% Fe from a feed grade of 60.30% Fe, with a yield of 63%. The corresponding SiO₂ and Al₂O₃ contents in the final concentrate were 2.43% and 2.56%, respectively.

B.12.11: Observations:

Total iron ore deposit in India is about 15 billion ton.

As the mining progress and we go deeper the Fe content goes on decreasing. This is why the Indian Bureau of Mines (IBM) has reduced the cut-off point of Fe content from 60% to 45%.

Recovery of iron values from low grade ore is done by different processes viz.

- Gravity + Magnetic separation for coarser particles
- Floatation for fines/slimes
- Palletisation agglomeration.

These upgrade Fe from 45-55% to 62-64%. Making it suitable for steel making.

As per one estimate approx. 2 million tone low grade iron ore is lying with SAIL & NMDC iron ore mines,

After the introduction of new MMDRA act-2015 the use of low-grade iron ore has increased and iron ore beneficiation capacity has also increased.

Bigger threat is accumulation of low-grade iron ore at mines head.

There is huge opportunity for increasing the agglomeration capacity. Pellet capacity in India has gone up to 70 million ton and there is further scope to increase it

B.13.1: Project Title: Development of sustainable technology for efficient utilization of goethitic ore through Magnetizing Roasting using Biochar

B.13.2: Project objectives: To optimize the magnetizing roasting process using biochar to maximize the recovery of iron and minimize the environmental impact. To evaluate the environmental benefits of utilizing biochar as a green energy source in ore beneficiation

B.13.3: Duration of the Project: 18 months

B.13.4: Project starting date: 1.03.2024

B.13.5: Project Completion date: 30.09.2025

B.13.5: Status of the Project: Ongoing (On-time)

B.13.6: Project cost:

Total Project Cost: Rs. 85,31,600/-

Scheme's funding: Rs. 56,91,400/-

Organization's own contribution: Rs. 28,40,200/-

B.13.7: Principal Investigator: Dr. Shatrughan Soren

B.13.8: Name of the Institute: Indian Institute of Technology (ISM) Dhanbad

B.13.9: Achievements: The project objectives were to (i) utilize low-grade iron ore (goethitic ore), (ii) optimize process parameters for efficiency, (iii) validate performance through experimental studies, and (iv) assess environmental sustainability. In line with these, significant achievements have been made. The beneficiation and processing of low-grade iron ore has been successfully demonstrated, with Fe recovery improving by around 80% compared to the baseline. Process optimization studies identified the most favorable operating conditions, leading to a measurable reduction in energy consumption and cost. Laboratory trials confirmed the technical feasibility. On the sustainability front, it is expected that the process will show a clear potential for CO₂ reduction through biomass utilization, thereby contributing to green steel initiatives.

Additionally, the project has generated academic outcomes in the form of conference publications and student training. Thus, the achievements are strongly aligned with the envisaged project objectives.

B.13.11: Observations:

Project is utilisation of goethitic ore ($\text{FeO} \cdot \text{OH}$), a low-grade iron ore by using bio-char as a reductant.

Bio-char is a carbon rich product from biomass. Bio-char blended yields DRI with high metallization.

The process improves reducibility and costs effective also.

It is in use in very low scale once established it will give boost to Dri process.

weakness is that it will take time in commercial production.

B.14.1: Project Title: Technology development for utilization of spent EAF graphite electrode to prepare high commercial value graphene products

B.14.2: Project objectives: To prepare a process for preparing high value graphene products from spent EAF electrodes for possible use in energy devices

B.14.3: Duration of the Project: 24 months

B.14.4: Project starting date: 01/11/2023

B.14.5: Project Completion date: 01/11/2025

B.14.5: Status of the Project: On-time

B.14.6: Project cost:

i. Total Project Cost: .66,70,000.

ii. Scheme's funding: 46,70,000.

ii. Organization's own contribution: 13,00,000

B.14.7: Principal Investigator: Dr Balaji Umapathi

B.14.8: Name of the Institute: CSIR IMMT Bhubaneswar

B.14.9: Achievements: A novel process has been developed for preparing a graphite-graphene mixture for use as electrodes in batteries. Process evaluation underway. Comprehensive understanding of utilization feasibility has been carried out in the course of the project.

B.14.11: Observations:

Spent graphite electrodes from EAF in steel making, are a waste stream rich in high purity carbon and can be upcycled into graphene.

Processing for graphene production:

- Mechanical cleaning
- Acid/alkali washing

- Thermal purification
- Liquid phase exfoliation
- Chemical oxidation

Graphene is used in conductive inks and coatings, energy storage, sensors and electronic devices.

Strength is creating wealth from waste, low-cost raw material.

With emphasis on green steel making there is huge scope in increasing the use of graphene.

There are no risks in using it.

Biggest strength is recycling steel industry waste and supporting circular economy.

B.15.1: Project Title: Upgradation of lean grade ore/ slimes through reduction roasting to develop

B.15.2: Project objectives:

Development of reduction roasting process for utilizing the very lean grade iron ore lumps and fines (<55% Fe) in different roasting process such as rotary kin (for lumps) and fluidized bed reactor (for fines) and its optimization in laboratory scale.

To beneficiate 48% Fe low-grade iron ore/fines to 60–62% Fe beneficiated ore suitable for making BF-grade pellets.

56–58% Fe iron ore fines (used in sinter making) may also be attempted to achieve 66% Fe, making them suitable for making DRI-grade pellets.

Optimization of grinding and magnetic separation to maximise recovery.

Process optimisation for pelletisation of magnetite concentrates to prepare the blast furnace (BF) grade pellets.

Techno-economic assessment for different reduction roasting processes for utilising lean grade lump and fines/slimes followed by pelletisation process

B.15.3: Duration of the Project: 18 months

B.15.4: Project starting date: 12-03-2024

B.15.5: Project Completion date: 30.09.2025

B.15.5: Status of the Project: On- time

B.15.6: Project cost:

i. Total Project Cost: 67 Lakhs

ii. Scheme's funding: 47 Lakhs

iii. Organization's own contribution:20 Lakhs

B.15.7: Principal Investigator: DR AMMASI A

B.15.8: Name of the Institute: CSIR- National Metallurgical Laboratory, Jamshedpur
National Metallurgical Laboratory, Jamshedpur

B.15.9: Achievements: The followings are the achievements vis-à-vis the project objectives

- 56 - 58% Fe iron ore fines have been concentrated to 66% Fe, making it suitable for making DRI-grade pellets.
- Process optimisation to beneficiate 48% Fe low-grade iron ore fines to 60-62% Fe is achieved

B.15.11: Observations: The process converts weak magnetic oxides to magnetite by controlled reduction roasting, low intensity magnetic separation, then pelletise and indurate to BF grade pellet quality.

Reduction roasting transform Fe_2O_3 to Fe_3O_4 previously non-magnetic iron minerals recoverable by magnetic separation.

Various steps involved are- crushing & grinding, mix with reductant, roasting, cooling & magnetic separation, pellet feed blending, disc/drum palletisation and induration to achieve desired quality and chemistry.

Major strength is lower carbon footprint and achieve desired quality.

Lower Fe content is giving good opportunity to increase iron ore beneficiation and palletisation.

During the last 10 years pellet capacity has doubled in India.

Major weaknesses are over-reduction, gangue carry-over carbon emission.

B.1.16.1: Project Title: Development of Solid Oxide Electrolyzer Cell & Short Stack for Blast Furnace Top Gas Utilization to Reduce CO₂ Footprint in the Iron Making Process

B.16.2: Project objectives:

- To study the kinetics of iron ore reduction using hydrogen gas at lab scale rotary kiln. Further, the study will be verified by simulation using CFD-DEM software.
- To simulate the industrial scale rotary kiln to use hydrogen as a reductant along with coal considering complete mechanism i.e. preheating and reduction.
- To develop geometry of the rotary kiln as per its actual dimensions, collected from the plant, in CFD DEM software.
- To solve the model in CFD-DEM software and to validate the results with that of existing kiln.
- To optimize % metallization in rotary kiln by varying operating parameters and modifying design of kiln.

To validate the results of the simulation study in the rotary kiln at the plant site

B.16.3: Duration of the Project: 24 months

B.16.4: Project starting date: 17.01.2025

B.16.5: Project Completion date: 16.01.2027

B.16.5: Status of the Project: On- time

B.16.6: Project cost:

i. Total Project Cost: .98.96.

ii. Scheme's funding: .69.27.

.iii. Organization's own contribution: Nil.

iv. Any other source: ...29. 69..

B.16.7: Principal Investigator: Shabina Khanam

B.16.8: Name of the Institute: CSIR-CGCRI, Kolkata

B.16.9: Achievements:

For 1st objective, lab set-up to study the reduction in static bed is fabricated and installed. The experiments will be starting soon. Further, design of rotary kiln set-up with hydrogen injection is completed and fabrication of the same is in progress. This part is taken care by industry partner. Once it is completed, kinetic study will be conducted.

For conducting simulation study in 1st and 2nd objective, purchase and installation of software and hardware is completed

B.16.11: Observations: Solid Oxide Electrolyser Cell (SOEC) can reduce the carbon footprint of iron making.

SOEC use high temperature heat + electricity to split H₂O and CO₂ into H₂ and CO, producing low-carbon hydrogen/Syngas more efficiently than low temperature electrolysis when useful waste heat is available.

Major strength is conversion BF top gas CO/CO₂/H₂O into CO/H₂ that can be recycled to the BF and reduce net carbon emission.

Produce high temperature H₂ for PCI coal injection and recover Oxygen.

Net effect of all this is lower coke consumption.

Major weakness is generation of contaminants viz. Sulphur, Tar and particulates which need proper treatment like filters, condensers etc.

B.17.1: Project Title: Decarbonization of DRI process in rotary kiln using hydrogen as reductant

B.17.2: Project objectives:

To study the kinetics of iron ore reduction using hydrogen gas at lab scale rotary kiln. Further, the study will be verified by simulation using CFD-DEM software.

- To simulate the industrial scale rotary kiln to use hydrogen as a reductant along with coal considering complete mechanism i.e. preheating and reduction.
- To develop geometry of the rotary kiln as per its actual dimensions, collected from the plant, in CFD DEM software.
- To solve the model in CFD-DEM software and to validate the results with that of existing kiln.
- To optimize % metallization in rotary kiln by varying operating parameters and modifying design of kiln.
- To validate the results of the simulation study in the rotary kiln at the plant site

B.17.3: Duration of the Project: 24 months

B.17.4: Project starting date: 17.01.2025

B.17.5: Project Completion date: 16.01.2027

B.17.5: Status of the Project: On- Time

B.17.6: Project cost:

i. Total Project Cost: 1,90,67000.00.

ii. Scheme's funding: 1,32,67000.00

iii. Organization's own contribution:

iv. Any other source: 58,00000. 00

B.17.7: Principal Investigator: Shabina Khanam

B.17.8: Name of the Institute: IIT Roorkee

B.17.9: Achievements: For 1st objective, lab set-up to study the reduction in static bed is fabricated and installed. The experiments will be starting soon. Further, design of rotary kiln set-up with hydrogen injection is completed and fabrication of the same is in progress. This part is taken care by industry partner. Once it is completed, kinetic study will be conducted.

For conducting simulation study in 1st and 2nd objective, purchase and installation of software and hardware is completed

B.17.11: Observations:

Hydrogen is used as a reductant in rotary kiln because hydrogen works quickly and reduce iron oxide to iron and produce steam instead of CO₂.

Rotary kiln operation to produce solid DRI is one of the important process apart from pellet and sinter.

Most of the secondary steel producer use this process.

Strength of this process is low carbon emission.

Only weakness is availability of low carbon H₂ gas.

B.18.1: Project Title: Melting and Refining of gas based DRI and hydrogen based DRI

B.18.2: Project objectives: Understand the melting behavior of HDRI/gas based DRI with variation of properties such as porosity, carbon content, ore type etc

B.18.3: Duration of the Project: 18 months

B.18.4: Project starting date: 01/03/2025

B.18.5: Project Completion date: 01/09/2026

B.18.5: Status of the Project: On-time

B.18.6: Project cost:

i. Total Project Cost: 77.8 lakhs.

ii. Scheme's funding: .42.9 lakhs

iii. Organization's own contribution: 25 lakhs

iv. Any other sources: 9.9 lakhs

B.18.7: Principal Investigator: Jayasree Biswas

B.18.8: Name of the Institute: IIT Mumbai

B.18.9: Achievements: We have developed a model. We already presented the model results in an international conference in South Korea in last June, ICS 2025. We will also present this in coming December in STIS 2025 at IISc Bangalore.

B.18.11: Observations: Gas based DRI and hydrogen based Dri are both low carbon alternative to coal based DRI (Rotary Kiln Process), but they differ in fuel gas, carbon footprint and techno-economics.

Gas based DRI e.g. Midrex (JSPL-Angul) natural gas reformed into H₂+ CO (Syn Gas), where as Hydrogen based DRI uses pure hydrogen.

Gas based DRI emits 1.2-1.4 Ton Co₂ per ton of steel where as H₂ based DRI emits 0.2-0.4 Ton co₂ per ton of steel

Gas based Dri needs natural gas where as h2 based DRI needs 50-55 Kg h2 per ton of steel.

Gas based DRI is cheaper because availability of natural gas, whereas h2 based Dri is expensive because of green H2.

Strength of gas based DRI is techno-economics but H2 based DRI is the need of future considering the importance of green steel.

There are no threats in both but there is huge opportunity to increase production from both methods.

B.19.1: Project Title: Investigation on coal-biomass blends as reductant and fuel in rotary kiln DRI making towards CO₂ mitigation

B.19.2: Project objectives: • Investigation on the co-firing of coal-biomass/biochar blends in the burner of the lab-scale rotary kiln furnace to understand the performance and emission characteristics towards CO₂ mitigation in the DRI process.

• Study on the coal-biochar blends as a reductant of iron ore in the co-fired lab-scale rotary kiln furnace to understand the overall DRI process efficiency

• Sustainability assessment of the modified rotary kiln DRI making with biochar/biomass as co reductant and fuel

B.19.3: Duration of the Project: 24 months

B.19.4: Project starting date: 17/01/2025

B.19.5: Project Completion date: 16/01/2027

B.19.5: Status of the Project: On- Time

B.19.6: Project cost:

i. Total Project Cost:

ii. Scheme's funding: ₹161.44 lakhs ₹112.72 lakhs

iii. Organization's own contribution:

iv. Any other source: ₹13.72 lakhs ₹35.00 lakhs of Industry support – in-kind mode (Specify the source also)

B.19.7: Principal Investigator: Dr. Gnanaprakash K

B.19.8: Name of the Institute: Indian Institute of Technology Hyderabad

B.19.9: Achievements: The literature review on combustion and reduction processes of coal/bio-char blends is almost completed. A review of the study on such blends shall be communicated to a journal for publication in the future. • Purchase of two major equipments for this project is completed and of other equipment is under process. •

Characterization of raw materials such as iron ore, biochar and coal are ongoing, for their proximate and ultimate analysis, calorific value, thermal decomposition behaviour, etc.

B.19.11: Observations:

Hydrogen is used as a reductant in rotary kiln because hydrogen works quickly and reduce iron oxide to iron and produce steam instead of CO₂.

Rotary kiln operation to produce solid DRI is one of the important process apart from pellet and sinter.

Most of the secondary steel producer use this process.

Strength of this process is low carbon emission.

Only weakness is availability of low carbon H₂ gas

B.20.1: Project Title: Large-scale electrocatalytic conversion of CO₂ to CO and scale electrocatalytic conversion of CO₂ to CO and its further valorization

B.20.2: Project objectives: Optimizing an energy-efficient and sustainable CO₂/CO converting electrolyser operating at 1.0 kg CO₂/day conversion capacity, fabricating a 1.0-ton-per-day CO₂ to CO converting electrolyser assembly and operating the electrolyser prototype (1.0 kg/day and 1.0 ton/day capacity) at the industrial site and finetuning them for appropriate application.

B.20.3: Duration of the Project: 24 months

B.20.4: Project starting date: 01/03/2025

B.20.5: Project Completion date: 01/03/2027

B.20.5: Status of the Project: On- time

B.20.6: Project cost:

i Total Project Cost: 5,15,00,000.

ii.Scheme's funding:2,45,00,000.

iii. Organization's own contribution

iv.. Any other source: .2,70,00,000 (JSPL)..

B.20.7: Principal Investigator: Arnab Dutta...

B.20.8: Name of the Institute: Institute of Technology Bombay Indian Institute of Technology Bombay

B.20.11: Observations:

For converting hydrothermal oxidation of industrial effluent to H₂ enriched fuel gas there are two routes:

- Supercritical water gasification
- Supercritical water oxidation

This converts most organics 9Sewage sludge, oily sludge, black liquor , distillery waste water to gases

This can achieve high carbon conversion and produce H₂-rich gases.

Major operational weakness is presence of salts, Na, k, Ca which can damage reactor and heat exchangers.

Other weakness is safety, permissions and environment

Other challenges are high CAPEX and OEX due to high pressur operation.

Only threat is disposal of waste

B.21.1: Project Title: A Comprehensive Technological Innovation: Quantum Confinement Induced Reconfigurable Synergistic Activation of Steel Industry-derived CO_x into CNG

B.21.2: Project objectives: Create cavity-confined catalytic sites to study/enhance CO_x reduction under encapsulation; 2) Reassess synthesis/protocols for Z-scheme photocatalysis for bulk green-fuel production; 3) Optimize composition for maximum quantum yield; 4) Design & fabricate an industrial unit targeting ~500–600 L h⁻¹ pure solar-CNG.

B.21.3: Duration of the Project: 24 months

B.21.4: Project starting date: 19 May 2025

B.21.5: Project Completion date: 18 May 2027

B.21.5: Status of the Project: On-time

B.21.6: Project cost:

i. Total Project Cost: 59,09,040

ii. Scheme's funding: MOS + Industry Funding

iii. Organization's own contribution:

iv. Any other source: 17,72,712

B.21.7: Principal Investigator: Dr. N. Siva Mohan Reddy

B.21.8: Name of the Institute: Indian institute Technology Roorkee

B.21.9: Achievements:

S.no	Outcome Indicator	Envisaged Outcome
1	Publications/working papers	Probably two publications and 1 or 2 National/international conferences works

2	IPR/Patents	1 (might be possible)
3	New Process developed	1 (Hydrothermal oxidation of waste streams)
4	New Product developed	Fuel gas (H ₂ + CH ₄) mixture along with (CO ₂ ≤ 10 vol%)
5	Workshop for the dissemination of the knowhow developed	1 (for UG/PG students)
6	Skill development	JRF will be trained
7	Commercialization	Industry might take it further after the demonstration of the treatment of waste water effluent

B.21.11: Observations:

The project is activating steel industry derived CO/Co₂/top-gas into CNG (Methane)-
Conversion of carbon oxides methane is done primarily by hydrogenation.

Preferred industrial route are:

- Catalytic methanation
- RWGS + methanation
- Biological methanation
- Electrochemical

Carbon feed in steel plants come from BF/BOF top gas, coke oven gas or DRI gas.

Cox gases are captured, conditioned, cleaned and treated in methanation reactor.

Water and if needed Co is also removed and remaining gases are compressed filled into CNG vessel.

Major cost factors are H₂ cost, CAPEX. OPEX and CNG market price.

B.22.1: Project Title: PROCESSING OF TIN SLAG AND TECHNOLOGICAL EXTRACTION OF CRITICAL ELEMENTS FOR HIGH STRENGTH LOW ALLOY STEELS (PATEL

B.22.2: Project objectives:

1. Pre-Processing of tin slag for enrichment of Nb and Ta (50-55% concentrate)
2. Extraction and separation of Nb and Ta from tin slag (>90% extraction of Nb and Ta)
3. Conversion of Nb and Ta salts to pure salts and ferroniobium (63-70% Fe Nb)
4. Demonstration of a process flowsheet for extraction of Nb and Ta and synthesis of pure metal salts and ferroniobium from tin slag at 10kg feed scale at NML, and 100kg at Industry site

B.22.3: Duration of the Project: 36 months

B.22.4: Project starting date: 01/05/2022

B.22.5: Project Completion date: 01/04/2022

B.22.5: Status of the Project: Delayed

B.22.6: Project cost: i. Total Project Cost: 85.4665 Lakhs

ii. Any other source: 85.4665 Lakhs

B.22.7: Principal Investigator: DR. ABHILASH

B.22.8: Name of the Institute: CSIR-NML

B.22.9: Achievements: Beneficiation of Tin Slag and Selective Extraction of Nb

B.22.11: Observations:

Tin slag is a waste product from the smelting of tin ore, containing valuable metals like titanium, Niobium, iron and Aluminium along with silica and other elements. While once considered waste, efforts are underway to recycle tin slag to extract these valuable metals or to use it as a component in cement and asphalt, reducing waste and the need for virgin materials.

There is a huge scope for improvement in design and operation of the slag extraction otherwise it will be a weakness in wasting valued materials

B.23.1: Project Title: A laboratory/pilot scale set up to optimize the process parameters for producing DRI with varying H₂ and CO ratio along with 3D Multiphysics modelling of DRI shaft reactor

B.23.2: Project objectives: Development of Multiphysics model of shaft reactors for DRI production Setting up of pilot scale DRI reactor (1 tpd) at RDCIS, SAIL Ranchi.

- Development and fabrication of a single cell SOEC for conversion of simulated blast furnace top gas to syngas with added steam as a feed material for a time period around of 1000 hrs and optimizing cell conditions and material morphology to use least amount of steam for syngas generation of desired composition.

B.23.3: Duration of the Project: 24 months

B.23.4: Project starting date: 12-02-2024

B.23.5: Project Completion date: 12-02-2027

B.23.5: Status of the Project: Delayed

B.23.6: Project cost:

The project has two cost components; Ministry of Steel is funding both IIT Kharagpur and RDCIS Ranchi.

i. Total Project Cost: 9.81 Crore (Consolidated sanctioned funding: RDCIS SAIL: 7 Crores, IIT Kharagpur: 2.81 Crores)

ii. Scheme's funding: 5.47 Crores

iii. Organization's own contribution: none iv. Any other source: Funding from RDCIS SAIL amounts to 4.34 Crores

B.23.7: Principal Investigator: Professor Shiv Brat Singh

B.23.8: Name of the Institute: Indian Institute of Technology, Kharagpur

B.23.9: Achievements: We have successfully completed the development of a 3D Multiphysics model that incorporates all the relevant transport equations along with the

complex reaction engineering associated with the shaft reactor process. This model can become the design basis for scaling up and development of indigenous reactors in India

B.23.11: Observations: Solid Oxide Electrolyzer Cell (SOEC) can reduce the carbon footprint of iron making.

SOEC use high temperature heat + electricity to split H₂O and CO₂ into H₂ and CO, producing low-carbon hydrogen/Syngas more efficiently than low temperature electrolysis when useful waste heat is available.

Major strength is conversion BF top gas CO/CO₂/H₂O into CO/H₂ that can be recycled to the BF and reduce net carbon emission.

Produce high temperature H₂ for PCI coal injection and recover Oxygen.

Net effect of all this is lower coke consumption.

Major weakness is generation of contaminants viz. Sulphur, Tar and particulates which need proper treatment like filters, condensers etc.

B.24.1: Project Title: Development of Type Designs of Aanganwaadi and Houses using Structural Steel as part of Pradhan Mantri Awas Yojana towards Enhancing Use of Steel in Housing Sector

B.24.2: Project objectives: To meet the national aspiration of Housing for All by 2020, this project seeks to promote the use of structural steel as construction material in primary load-carrying system. The basic approach of the project is development and validation of appropriate type designs to build individual houses under the Pradhan Mantri Awas Yojana (PMAY) scheme. The considered type designs have variants depending on local geo-climatic conditions and social (rural and urban) requirements.

B.24.3: Duration of the Project: 24 months

B.24.4: Project starting date: 04/04/2022

B.24.5: Project Completion date: 30/09/2025

B.24.5: Status of the Project: Ongoing

B.24.6: Project cost:

i. Total Project Cost: 443.940000 Lakh

ii. Scheme's funding: Rs. 177.58 Lakhs (Ministry of Steel, Govt. of India).

iii. Organization's own contribution: None iv. Any other source: Rs. 266.26 Lakhs (Five Industry Partners:

(i) Steel Authority of India Limited (SAIL),

(ii) Tata Steel Limited (TSL),

(iii) Jindal Steel and Power Limited (JSPL),

(iv) Jindal Steel Works Limited (JSWL), and

(v) ArcelorMittal Nippon Steel (AMNS) Limited

B.24.7: Principal Investigator: Prof. S D Bharti

B.24.8: Name of the Institute: Malaviya National Institute of Technology Jaipur

B.24.9: Achievements: (i) Full-scale testing of five identified building types to understand their structural behaviour under cyclic loading.

(ii) Testing results provide clarity on the mismatch between the assumed and actual values of (a) material properties, (b) behaviour of the structural components, and (c) loading and load effects.

(iii) Testing and FE analysis results validate the code specified methods that are in practice in India.

(iv) Preparation of construction manuals and fabrication drawings for engineers and professionals at site.

(v) The findings and outcomes of this project related to structural designs will be documented properly to enable its use by potential beneficiary of the PMAY

B.24.11: Observations:

Pradhan Mantri Avas Yojna (PMAY) is mainly focused on low-cost, mass housing using mainly, brick, cement and concrete. Steel is used in lesser quantity (mostly rebars and roofing sheets).

To increase the use of steel in PMAY housing strategies need to focus on lower cost and durability.

To increase the steel usage following steps will help:

- Light gauge steel frames
- Structural steel section Pré-fab modular units
- Increase public-private partnership

In 2025-26 Central government aim to construct about 4 crore houses with a budget of Rs. 6,317 cr.

This is going to give boost to increase housing and steel usage.

B.25.1: Project Title: A comparative study on the controlling mechanisms during reduction of iron oxides with CO and hydrogen – Impact on decarbonization of iron and steel manufacturing.

B.25.2: Project objectives:

- 1) Understand the mechanism(s) causing faster / slower reduction rates
- (2) Identify optimal agglomerate characteristics to maximise reduction rate under H₂-rich gas atmosphere
- (3) Aim to develop technology that can retrofit existing CO-based reactors such as Blast Furnaces for use of H₂-rich reducing gas, in order to bring down the carbon-intensity

B.25.3: Duration of the Project: 24 months

B.25.4: Project starting date: 06/03/2025

B.25.5: Project Completion date: 05/03/2027.

B.25.5: Status of the Project: On- time

B.25.6: Project cost:

- i. Total Project Cost: 76,38,920/-
- ii. Scheme's funding: 48,38,920/-
- iii. Organization's own contribution: .7,00,000/-
- iv. Any other source: 21,00,000/- (Industry contribution)

B.25.7: Principal Investigator: Somnath Basu

B.25.8: Name of the Institute: Indian Institute of Technology Bombay

B.25.9: Achievements: All the activities scheduled to be carried out during the first quarter have been initiated. None of the tasks have yet reached completion. Procurement of the custom-designed equipment was scheduled to be completed within 9 months from start. However, the first prototype device was found lacking during initial trials. As a result, it is being re-designed, which will be followed by manufacturing and

subsequent testing. The necessary software and sensors / accessories will be integrated with the equipment after successful test-run

B.25.11: Observations: Co and H₂ are the two gaseous reductants used to turn Fe oxides into metallic iron.

High H₂ fraction leads to faster reduction, less carbon deposition.

High CO fraction good at high temperature but may cause more CO₂ and can lead to carbon deposition.

H₂ and CO are flammable, hence adequate safety precaution has to be taken.

Steel sector is responsible for 7-9% of global carbon emission, because BF-BOF depends heavily on coke/coal as fuel and reductant.

Decarbonization of steel industry is the basic requirement now a days that's why Top Recovery Turbine (TRT) and dry quenching of coke are a must now a days.

Green steel is the need of hour that why stress is being to reduce carbon emission by 15% and increase Carbon Capture, Utilisation & Storage (CCUS).

There is a great strength in using natural gas and Hydrogen gas as reducing agent.

Only challenge is large renewable H₂ supply.

Only threat in this process is under ground storage of captured carbon and disposal in a useful manner.

B.26.1: Project Title: Beneficiation of coking coal by hybrid mode: dry and wet processing to reduce the ash forming impurities.

B.26.2: Project objectives: Dry de-shaling to improve the quality of the feed material for wet processing and to study the feasibility of dry beneficiation of coking coal for reducing ash content of the ROM Coal and water consumption and to beneficiate the high ash coking coal in combination with dry and wet methods (hybrid mode) to generate the metallurgical coal grade of 14 to 17% ash with maximum yield towards the development of the process flowsheet.

B.26.3: Duration of the Project: 24 months

B.26.4: Project starting date: 12-04-2024

B.26.5: Project Completion date: 12-02-2027

B.26.5: Status of the Project: Delayed (Ongoing)

B.26.6: Project cost: 9.28 Core

B.26.7: Principal Investigator:

B.26.8: Name of the Institute: NML Jamshedpur

B.26.9: Achievements: We have successfully completed the development of a 3D Multiphysics model that incorporates all the relevant transport equations along with the complex reaction engineering associated with the shaft reactor process. This model can become the design basis for scaling up and development of indigenous reactors in India.

B.26.11: Observations: Coking coal processing is a technique to reduce:

- Shale
- Stones
- High ash material

Now a days both dry and wet processes are used to reduce the ash content in coking coal.

Dry processing has advantages of no water requirement, no slurry disposal and lower operational cost but it has lesser efficiency to come to low ash level.

Wet processing is faster but has many environmental issues.

There is no coking coal mine in India except BCCL-Mahuda & TISCO Jamadoba and West Bokaro

Lower the ash content better is metallurgical property.

Ash content is reduced in coal washeries which is available with TISCO only. only.

B.27.1: Project Title: Hydrothermal oxidation of industrial compressed to generate H compressed fuel gas mixture. effluents to generate H₂ rich

B.27.2: Project objectives:

Hydrothermal partial oxidation of coal plant effluent to remove ring compounds and other organic matter to generate natural gas (H₂+ CH₄ + CO₂)

Optimization of process parameters (Temperature and residence time) for the generation rich fuel gas mixture. Removal of the phenols/phenolics and other components completely and generating

- Removal of the phenols/phenolics and other components completely and generating kinetic data to implement it continuous mode.
- Treatment of the effluent in continuous mode with an objective to meet the CPCB standard limits for liquid disposal.

Understanding the impact of the process parameters for complete removal of organic matter to attain maximum yields of the valuable products.

B.27.3: Duration of the Project: 24 months

B.27.4: Project starting date: 17/01/2025

B.27.5: Project Completion date: 16/01/2027

B.27.5: Status of the Project: On-going

B.27.6: Project cost:

i. Total Project Cost: 59,09,040

ii. Scheme's funding: MOS + Industry Funding

iii. Organization's own contribution: iv. Any other source: 17,72,712 (Specify the source also) – JSP Pvt Ltd

B.27.7: Principal Investigator: Dr. N. Siva Mohan Reddy

B.27.8: Name of the Institute: Indian institute Technology Roorkee

B.27.9: Achievements:

S.no	Outcome Indicator	Envisaged Outcome
1	Publications/working papers	Probably two publications and 1 or 2 National/international conferences works
2	IPR/Patents	1 (might be possible)
3	New Process developed	1 (Hydrothermal oxidation of waste streams)
4	New Product developed	Fuel gas (H ₂ + CH ₄) mixture along with (CO ₂ ≤ 10 vol%)
5	Workshop for the dissemination of the knowhow developed	1 (for UG/PG students)
6	Skill development	JRF will be trained
7	Commercialization	Industry might take it further after the demonstration of the treatment of wastewater effluent.

B.27.11: Observations: For converting hydrothermal oxidation of industrial effluent to H₂ enriched fuel gas there are two routes:

- Supercritical water gasification
- Supercritical water oxidation

This converts most organics 9Sewage sludge, oily sludge, black liquor, distillery waste water to gases

This can achieve high carbon conversion and produce H₂-rich gases.

Major operational weakness is presence of salts, Na, k, Ca which can damage reactor and heat exchangers.

Other weakness is safety, permissions and environment

Other challenges are high CAPEX and OEX due to high pressur operation.

Only threat is disposal of waste.

B.28.1. Name of the Project: Development of an Advanced Artificial Intelligence based Instrument to Control the Iron Ore Disc Pelletizer

B.28.2: Project objectives:

1. Online monitoring and size analysis of iron ore pellets being produced.
2. Vision based monitoring of pellets at the discharge end of the disc using state of the art online monitoring and size analysis of iron ore pellets being produced.
3. Vision based monitoring of pellets at the discharge end of the disc using state of the art machine learning and deep learning algorithms.
4. Vision based monitoring of pellets at the discharge end of the disc using state of the art machine learning and deep learning algorithms.

(b) Decision making and generation of control signals

(a) Based on real time analysis of disc parameters like speed of rotation, material feed rate,

(c) moisture percentage, bentonite content etc. using machine learning based models.

(d) By making the required change of the pelletizer disc parameters in order to machines.

(e) optimized and efficient production of iron ore pellets in desired size range.

B.28.3: Duration of the Project: 36 months

B.28.4: Project starting date: 09-03-2022

B.28.5: Project Completion date: 30-09-2025

B.28.5: Status of the Project: Delayed

B.28.6: Project cost: 64.9 Lakhs

B.28.7: Principal Investigator: Dr. Santosh Kumar

B.28.8: Name of the Institute: CSIR - Institute of Minerals and Materials Technical Institute of Minerals and Materials Technology

B.28.9: Achievements:

wheat. Bio-sorption of Cr on biochar applied together with steel slag reduced the total concentration

B.28.9: Observations: In iron ore disc palletizer disc most important is to control pellet size and strength.

AI based instrument must deliver following:

- Maintain target pellet size, moisture and strength
- Optimize energy use
- Detect faults
- Provide proper dash board to operator for strict quality control

Level 3 automation is must for better control AI based instrument must give- off size pellets, mean pellet diameter. Energy consumption, binder consumption and unscheduled down-time.

Major weakness is non-adherence of SOPs

With depleting Fe content there is huge strength in growing pellet industry.

Pellet use in BF is increasing, some are having their own pellet plant and some are purchasing from open market.

B.29.1. Name of the Project: "Understand the melting behavior of HDRI/gas based DRI with variation of properties such as porosity, carbon content, ore type etc.

B.29.2: Project objectives: To develop procedure for joining next generation high temperature material to be used for supercritical/ultra supercritical power plant by Friction Stir Welding

B.29.3: Duration of the Project: 7 Years

B.29.4: Project starting date: 29/09/2015

B.29.5: Project Completion date: 19/09/2022

B.29.5: Status of the Project: Completed

B.29.6: Project cost: 481 Lakhs

B.29.7: Principal Investigator: Dipankar. Sanyal

B.29.8: Name of the Institute: Jadavpur.University

B.29.9: Achievements:

B.29.9: Observations:

1. The melting behaviour of HDRI and DRI mainly depends upon Fe content.
2. The high Fe content Iron ore melt faster and Gangue(higher Silica and aluminum (SiO_2 and Al_2O_3) content slower the melting behaviour of HDRI
3. Higher porosity melts faster and lower porosity melts slower.
4. Phosphorus and Sulphur in iron ore have less impact on melting behaviour but it has got impact on the refining of the steel chemistry.
5. There are two types of iron ore hematite (melt faster) and magnetite(melt slower)
6. To improve the melting behaviour, it is necessary that iron ore Fe content is more and alumina silica content is less
7. Higher carbon content Iron Ore melt slower , lesser the carbon content melts faster.
8. The calorific value of the melting gas, higher the calorific value of the melting gas and higher the melting rate, lower the value and lower the melting rate.
9. Higher residue FeO MDRI delayed melting process.

B.30.1. Name of the Project: Technology development for utilization of spent EAF graphite electrode to prepare high commercial value graphene products

B.30.2: Project objectives: (i) Production of SiC from rice husk.
(ii) Bench scale production and cost estimation in order to establish the cost of SiC per kilogram

B.30.3: Duration of the Project: 6 years

B.30.4: Project starting date: 11/10/2018

B.30.5: Project Completion date: 31/03/2024

B.30.5: Status of the Project: Completed (Extended)

B.30.6: Project cost: 195 lakhs

B.30.7: Principal Investigator: S. K. Singh

B.30.8: Name of the Institute: CSIR-Central Building Research Institute, Roorkee

B.30.9: Achievements: Developed a process for utilisation of LD slag for making cementitious binders / blended cement via: Mechano-chemical activation study: Mechanical activation of LD slag through grinding for different time intervals followed by particle size optimization. Further, chemical activation using four different activator solutions i.e., sodium silicate, sodium sulphate, sodium hydroxide and sodium carbonate. Preparation of blended paste cubes incorporating 70% OPC and 30% milled LD slag with different activator solutions. Thereafter, mechanical strength testing, mineralogical and morphological studies of 28 days aged specimens of paste was conducted. Here mechano-chemical activation process and 30% processed LD slag were optimised for the development of sustainable binder. Durability studies on the developed binders in concrete with different test methods were also established. Conduct of modelling of the developed LD slag-cement for measuring the degree of reaction and also experimental validations. In this context, novel test methods have been developed for evaluating reactivity of OPC-LD slag composite binder. Test included acid dissolution combined with XRD and BSE image analysis. Thereafter, lab

scale and industrial scale trials were conducted and also demonstrations completed. The project objectives were met as envisaged.

B.30 .9: Observations:

1. Graphite electrodes have contaminates metal inclusion, metal winders, oil , rust and lose particles
2. Used graphite electrodes are converted into graphene by using following steps:
 - Mechanical cleaning
 - Cleaning with the solvents
 - Washing with the Hydrochloric acid,
 - drying and sizing

Then it is converted by the process of electro chemical exfoliation

3. After using the electrolytes, high voltage currents is passed to purify the used electrodes.
4. Graphene results in better quality and yield because it gives more oxygen then process yield is 75%-80%.
5. If graphene electrodes are more porous and can be used as direct electrodes
6. This use of graphene is more safe and environment friendly.
7. this product is also used in waste water treatment
8. If this conversion process is in experiment stage, and very soon going to be used on commercial basis.

B.31.1. Name of the Project: Decarburization of High Carbon Ferro Manganese for Carbon Ferro Manganese

B.31.2: Project objectives:

1. To develop a process technology for the utilization of high-volume LD/ steel slag for making cementitious binders / blended cement/ concrete.
2. Performance and durability assessment of developed cementitious binders/ blended cement for mortars/ concrete under aggressive environment."

B.31.3: Duration of the Project:

B.31.4: Project starting date: 01/ 10/ 2018

B.31.5: Project Completion date: 31/03/2024

B.31.5: Status of the Project: Completed

B.31.6: Project cost: 195 lakhs

B.31.7: Principal Investigator: Prof. S. K. Singh

B.31.8: Name of the Institute: CSIR-Central Building Research Institute, Roorkee

B.31.9: Achievements: Developed a process for utilisation of LD slag for making cementitious binders / blended cement via: Mechano-chemical activation study: Mechanical activation of LD slag through grinding for different time intervals followed by particle size optimization. Further, chemical activation using four different activator solutions i.e., sodium silicate, sodium sulphate, sodium hydroxide and sodium carbonate. Preparation of blended paste cubes incorporating 70% OPC and 30% milled LD slag with different activator solutions. Thereafter, mechanical strength testing, mineralogical and morphological studies of 28 days aged specimens of paste was conducted. Here mechano-chemical activation process and 30% processed LD slag were optimised for the development of sustainable binder. Durability studies on the developed binders in concrete with different test methods were also established. Conduct of modelling of the developed LD slag-cement for measuring the degree of reaction and also experimental validations. In this context, novel test methods have

been developed for evaluating reactivity of OPC-LD slag composite binder. Test included acid dissolution combined with XRD and BSE image analysis. Thereafter, lab scale and industrial scale trials were conducted and also demonstrations completed. The project objectives were met as envisaged.

B.31 .9: Observations:

1. Conversion of high carbon ferro manganese to low carbon ferro manganese by the process of selective oxidation of carbon using appropriate gas and slag chemistry.
2. Oxidation of manganese to MnO is faster than Carbon to oxygen.
3. Now A days instead of using high carbon ferro manganese AOD (Argon, oxygen, decarbonization), it lowers activity of oxygen and help reduce the Mn. Oxidation and Foaming
4. Another process is also used VOD (vacuum oxygen decarbonization), apart from the above method top and bottom oxygen injection is also used.
5. It helps in environment control and carbon capture.
6. Now a days instead of using high carbon ferro manganese hydrogen and prereduction route are used.

Recommendations

1. **The scheme is needed to help increase the R&D in iron and steel sector.**

RND expenditure in the iron and steel sector in India is abysmally low. The sector is not important only for the economy, but also from the point of view of environment (presently marked by high energy intensity and high emission intensity) and society (employment and regional development). R&D is a recognised essential activity to introduce efficiencies in the processes and product development.

2. **The Mission / goal(s) of the scheme may be specifically spelt out.**

The scheme has enlisted a number of objectives, but it does not clearly spell out what it aims to achieve. Mere funding the R&D projects may lose the focus. The Ministry needs to take note of the fact that the present level of the R&D expenditure is very low. The annual reports, almost every year, and the National Steel Policy emphasis the need to increase funding in the R&D. But as discussed, the country is far below the global average. The need for specifying goal in terms of outcomes stems from the fact that 'what gets measured gets done'.

3. **The Ministry may include one more objective of 'creating and facilitating enabling environment for R&D'.**

The Ministry has established a procedure of consultation for identifying the thrust areas for R&D through stakeholder consultation. However, the study team is of the opinion that the scope of this consultation needs to be broadened. The consultation mechanism needs to have continuity. After identification of the thrust areas, the stakeholders help may be sought to identify the sub-components of each thrust area and mobilise researchers and research organizations, both in public and private sectors, to increase the base of researchers and research institutions, rather than confining to select few research institutions.

4. The guidelines stipulate that the scheme would prefer collaborative projects. However, the data collected about the ongoing projects reveals that most of the projects are from single institution only. It is acceptable if the project merits the consideration and meets all other criteria. However, **the Ministry may consider bringing at least one multidimensional team together of researchers from different institutions to prepare a futuristic proposal and fund it under the scheme.** Such a proposal could be a long term as well, as currently most of the projects are of two years or less aimed at

getting benefits to the industry at the earliest. Only a few of them are of three years duration. Futuristic projects, by design, are long term.

At China Baowu, after seven years of technical exploration and research, the world's first 400m³ industrial grade hydrogen-enriched carbonic oxide recycling oxygenate furnace (abbreviated HyCROF) was built in 2022, and a major technological breakthrough was made. Top gas recycling injection under pure oxygen blowing conditions has been realised. Production capacity has increased by 30% to 40%, and solid fuel ratio has reduced by more than 30%.

5. The Ministry may modify the condition of finding industrial partner for the submission of the project proposal.

The government has taken the essential step to strengthen R&D and make R&D responsive to the needs of the industry by making industrial participation mandatory, both in terms of collaboration and financial contribution for the R&D proposal to be considered for funding under this scheme. This seems to be a necessary condition, but not sufficient. This mechanism requires the scientist, who is planning to submit the proposal, to look for the industrial partner. There is large scientific manpower in the research labs engaged in this sector, but it may be difficult for many of them to be able to find a partner in this case. Scientists who have previously worked successfully with some industrial partner would be in the advantageous position in such a scenario. The study team is of the considered opinion that this may be institutionalized in a slightly different manner.

The study team members were told by the officials during interactions that the thrust areas for research are now identified with greater stakeholder consultations and that this consultation is quite frequent. The Ministry already puts out such problem / research areas seeking research proposals from the researchers. Here, the government may seek the commitment of the industrial partner for industrial collaboration and financial contribution at the scheme level itself. Now the researchers may focus on the quality of proposals and there could be a competitive environment where two or more researchers may submit their proposals. This may lead to some innovative ideas also being put forth, while the quality of the proposals would be improved in any case. The industrial partnership could be assigned to the better proposal. This system may also be beneficial for the industrial partner as he / she would be making an informed choice. The industrial partner may be made a member or at least invited to the proposal presentations. Post

the presentations and choices being made, the researcher may be asked to further strengthen the proposal in consultation with the assigned industrial partner.

6. The Ministry needs to take care of the procedural problems being faced by the scientists, conducting the research under this scheme.

There are two specific problems which were highlighted by the scientists engaged in the scheme projects. First, procurement. A lot of time is wasted in the procurement process while it is a critical issue and Government of India has issued detailed guidelines regarding procurement. However, a committee may be constituted by the Ministry incorporating at least one member from the Procurement Division of the Ministry of Finance to look into the issues.

The second problem pertains to the retention of 10% of the total grant. The provisions stipulate that 10% of the total grant would be released only after the acceptance of the final report of the project. The grouse of some scientists with whom the study team interacted was that if money was released later, how can they spend it? If it is not spent, then it has to be refunded to the Ministry. The problem is compounded because in most cases the budget is reduced during the approval stage itself. The study team is of the opinion that while it is standard practice to hold back the last installment till the final report is accepted by the sponsors, the ministry may think of retaining 10% of revenue grant only.

7. The detailed and complete process of monitoring and funds release needs to be documented and provided to the scientists after a project is awarded to him or her.

Many a times the scientists or the researchers are not aware about the processes or the procedures obtaining in the government. That hampers their activities. A detailed document regarding procurement, funds release, etc. may be prepared and given to each awardee along with the award letter of the project.

8. Incentivizing R&D for the scientists may improve the quality of researches.

Scientists in the Western world are given intellectual property ownership over their research outcomes. They also get a share in profits depending on the agreements that are fostered with the end users. Incentivization theoretically also motivates people. Many academic institutions in India offer rewards for publications. IIT and IIM faculty members charge decent consultancy fees for their work with the industry. Interaction with

scientists engaged with this scheme revealed that there are no such provisions in place right now. CSIR too had performance linked incentives for its scientists. The Ministry may draft guidelines for the institutes carrying out the researchers under the scheme for enabling the scientists to share the proceeds from the contractual research, development consultancy and royalties from technology transfer.

9. Some measures need to be put in place for non-performance as well.

The Ministry may frame modalities in case of delayed and foreclosed projects and include them in the guidelines itself. If Rewards need to be there for the good performance, there needs to be some measures against non-performance as well. Some officials voiced their concerns about delays in starting the project. The data collected about the research projects shows that indeed some projects were delayed. In fact, 2 projects were closed before completion. There could be situations beyond control. The PRC is in a better position to judge as to whether delays are due to genuine reasons or due to negligence of the scientists. In the case of negligence, provision may be made about the recovery of money from the institution along with some penalty on the faculty member. Some part of the penalty should be borne by the scientists concerned as well. It can be monetary or non-monetary. The respective institution may draft their guidelines in this regard. In this regard, the Ministry may include modalities for the same in the guidelines.

10. The Ministry needs to include MSMEs in the process.

The National Steel Policy has articulated the need for adoption of energy efficient technologies in the MSME sector. However, the challenge is that the MSME enterprises are not 'included' in the R&D mechanism / R&D process, so it becomes supply driven response even if they are provided the technologies.

11. A pool of money can be created at the scheme level, with contributions coming from industry, including the MSMEs.

As the guidelines stipulate that Industrial partner is mandatory for any research to be considered for funding, the Ministry may suggest the industry stakeholders to contribute their share at the scheme level. This can be pegged at 30% as the guidelines indicate that the maximum the government can fund any research project is up to 70%. The private contributors can indicate their preference for a particular project at the approval

stage. This measure will increase the corpus of the scheme and induce greater accountability in the research community.

12. In view of the significance of the MSMEs for the economy, the Ministry may consider incorporating one or two representatives from their associations in the Project Approval Committee.

Presently, the issues concerning them, as previously discussed, are reflected in the R&D projects, but the benefits do not reach them. Their incorporation in the PC would lead to articulation of their interests in determining the research agenda of this scheme. If required and feasible, they may be contributors also to the scheme level pool as recommended above.

13. An inventory at the national level of equipment purchased under the scheme needs to be maintained and the facility thus created be made available to all the researchers who want to work on those equipment.

A lot of equipments and softwares have been purchased under the various projects. An equipment register would help the Ministry in ensuring the availability of equipment to other researchers outside the institution as and when required. This will also help in maintenance of these assets.

14. Strong linkages should be developed between the scheme with the Steel Research and Technology Mission of India.

SRTMI has been in existence since 2015. It has broader perspective and can be useful for the scheme in identifying the priority areas and pool together resources for the scheme. Ministry should try to have good convergence among the two.

15. The scheme needs to be aligned with R&D initiatives and related activities of other ministries as well.

To make optimal utilization of resources, both human and capital, it is necessary that the Ministry develops close coordination with other ministries involved in researches which might be beneficial for the steel sector. For example:

- a. Coal ministry has research projects on coal beneficiation, coal washeries, etc.
- b. Ministry of Heavy Industries for product development.
- c. Ministry of Petroleum and Natural Gas.
- d. Ministry of Railways for rail and other applications.
- e. Ministry of Defence, etc.

16. The Ministry may also explore establishing linkages with Global Capability Centres relevant to steel industry.

GCCs, among their other activities, also focus on R&D. Major steel MNCs are increasingly consolidating their GCC operations in India to drive transformation in the sector. For example, Arcelor Mittal GCC operates capability centres focused on steel technology and R&D with significant presence in India. In fact, India is fast emerging as a global GCC hub, including that for steel.

17. The ministry may establish linkages with the startup ecosystem and invite individuals to take up their innovative ideas in the steel sector under this scheme.

The startup ecosystem is getting stronger in the country. The ministry may take advantage of this. The scheme may be modified to include individuals who want to pursue research in the sector. They may be given access to the facilities and equipment purchased from the grant of the ministry by different research institutions like NML, IIMT etc. ISRO's model can be assessed to tailor the Ministry's response.

18. There has been greater focus on the process development through R&D in the scheme. The Ministry may think of funding product development projects more.

Most of the major steel producing countries are today focusing on product development. Presently, the focus of the scheme is highly skewed in favour of processes. MSME sector can be a good partner in this record.

Third Party Evaluation of the “Promotion of Research & Development in Iron & Steel Sector” Scheme

QUESTIONNAIRE

Sponsored by



सत्यमेव जयते

**Ministry of Steel
Government of India**

Conducted by



**Indian Institute of Public Administration
New Delhi**



Indian Institute of Public Administration New Delhi

Third Party Evaluation of the “Promotion of Research & Development in Iron & Steel Sector” Scheme

(sponsored by Ministry of Steel, Government of India)

Questionnaire for the Principal Investigators

1. Name of the Organisation/Company.....

2. StateCity.....

3. Name of the Respondent.....4. Designation.....

4. Contact Details. (a.) Phone(b) email.....

5. Name of the Project.....

.....

6. Objectives of the Project.....

.....

.....

.....

7. Project Duration (Year/Month):

8. Project Start Date.....9. Project Completion Date.....

10. Project Status

Completed Not Completed

On-time Delayed

If delayed, reasons/constraints for delay in the project

.....

.....

.....

11. Project Cost & Sources of Funds (Rs.)

- i. Total Project Cost:
- ii. Scheme's funding:
- iii. Organization's own contribution:
- iv. Any other source: (Specify the source also)

12. Date of release of funds.....

13. Is the budget sufficient for the study? (i) Yes (ii) No (iii) Can be increased

14. If not, please state the reason for insufficiency of funds.

.....
.....

15. Sources of funding from other sources (If any, please mention source & amount)

.....
.....

16. List out the equipments purchased under the project with Ministry of Steel's Fund along with value of the equipment

- i.
- ii.

17. Is it a collaborative project? (i) Yes (ii) No

ii. If yes, who is the collaborator?

- a. Government Research Institute
- b. Private /Organization
- c. University / autonomous academic institution

18. How is the current project different from existing technology / process?

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.....

19. Status of progress of the project as per envisaged objectives/timelines

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.....
.....

20. Achievements/ Outcomes vis-à-vis the project objectives

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.....

21. Mention the publications out of Project (if any).....

.....
.....

22. Paper presented in seminars / conferences out of the Project (if any)

.....
.....

23. Patents out of the Project (if any).....

.....
.....

24. Did you have to modify your project after any Project Review Committee (PRC) suggestions?

Yes No

25. Is any other institution also engaged in a similar research?

Yes No

26. If yes, is there any cooperation between the two?

Yes No

27. How useful is your research for the industry?

.....
.....

28. How useful is your research for the academics?

.....
.....

29. Has the current project reached the commercialization stage, specifically regarding the transition of the process/technology from the laboratory to industry?

i. Yes No

ii. If yes, are you in touch with some industry? Yes No

30. Do you get royalty in IPR?

Yes No

31. How many PRC meetings were held for your project?

32. What was the frequency of the PRC meetings?

Once a year Twice an year Four times an year Irregular

33. Have you undertaken more than one project under the same scheme over the years?

Yes No

34. Title of earlier researches (if any)

.....
.....

35. Does your project serve any Sustainable Development Goal?

i. Yes No

ii. If yes, which one

.....
.....

36. Do you think that the scheme is useful in promoting R&D for the steel sector?

Yes No

37. Give your suggestions to improve the scheme

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