Decarbonization of Iron Ore Pellet Manufacturing Industry

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Foreword

The iron and steel sector in India is poised for significant expansion, driven by rapid economic growth, large-scale infrastructure development, and increasing urbanization. However, this growth must be underpinned by a sustainable approach to resource utilization, particularly in the beneficiation and processing of low and medium-grade iron ore. Ensuring the long-term viability of the sector while aligning with global decarbonization commitments requires urgent action and the adoption of advanced technologies to minimize emissions from upstream processes such as iron ore beneficiation and pellet manufacturing. A well-defined policy and regulatory framework will also be critical in facilitating this transition towards a low-carbon future.

Recognizing this imperative, The Energy and Resources Institute (TERI), in collaboration with the Pellet Manufacturers' Association of India (PMAI), has undertaken an in-depth study to explore technological pathways and strategic interventions for reducing the carbon footprint of the pellet manufacturing industry. This study adopts a holistic approach, incorporating a comprehensive review of existing literature, primary surveys for data validation, technical consultations with industry experts, energy and emissions analysis, and an evaluation of global best practices.

The findings of this report emphasize key decarbonization strategies, including the adoption of energy-efficient technologies, integration of renewable energy sources, electrification of thermal processes, utilization of low-carbon fuels, circular economy practices and carbon sequestration. While technological and economic challenges persist—such as complex ore mineralogy, high capital investment, water consumption, and tailings management—the long-term environmental and economic benefits of decarbonization are undeniable. Strengthening policy measures, promoting the use of pellets in ironmaking, incentivizing beneficiation, expanding public infrastructure, and fostering international collaborations will be essential in driving this transition.

Through this publication, TERI aims to contribute to the ongoing discourse on industrial decarbonization and provide actionable insights for policymakers, industry stakeholders, and researchers. The journey towards a sustainable and low-carbon iron and steel sector is challenging but necessary. We believe that with a concerted effort, India can position itself as a global leader in green steel manufacturing, ensuring long-term resource security and environmental sustainability.

Dr Vibha Dhawan
Director General
The Energy and Resources Institute (TERI)

President's Message

The Pellet Manufacturers' Association of India (PMAI) is conscious of the landmark and pioneering steps being undertaken by the Ministry of Steel towards promoting green technologies. Iron ore pellets are a 'green input' to the blast furnaces and DRI units as their use leads to lower emissions and carbon dioxide. Use of pellets takes care of the sustainable development of iron ore mines as it helps by agglomeration of iron ore fines which cannot be otherwise used in iron & steel making. In line with the vision of the Steel Ministry, our association has attempted to document the sources of carbon emissions in the entire pelletization process and identify measures for its abatement.

To carry out a scientific assessment of carbon emissions from the pelletization process, we requested the think tank – The Energy and Resources Institute (TERI) to take up an integrated, customized approach in the form of an extensive survey of pellet plants in India through a detailed questionnaire which was sent to pellet plants. This was followed up by field survey and visit to selected pellet plants and interviewing shop floor pellet plant personnel.

This study has a wide coverage, right from an overview of India's iron ore to beneficiation, pellets industry along with the techno-economic benefits of the use of iron ore pellets, challenges like management of tailings, and international scenario. The report includes an action plan with decarbonization strategies for Indian beneficiation and pellet industry.

We are confident that the findings will be helpful not only for the pellet industry in India but also suggest policy formulation by the Ministry of Steel. We hope that this study will act as a major milestone in our journey towards the decarbonization of pellet industry in India.

I would like to take this opportunity to thank the team at TERI who have done an outstanding job of preparing this report.

I would also like to thank all our PMAI members who contributed to this study.

Manish Kharbanda

President

Pellet Manufacturers' Association of India

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Abbreviations

BAT	Best Available Technologies
BAU	Business As Usual
BEE	Bureau of Energy Efficiency
BESS	Battery Energy Storage Systems
CAGR	Compounded Annual Growth Rate
CBM	Coal Bed Methane
CEA	Central Electricity Authority
CPT	Circular Pelletizing Technology
DG	Diesel Generator
DISCOM	Distribution Company
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EE	Energy Efficiency
EMS	Energy Management Systems
ESP	Electrostatic Precipitator
Gcal	Giga Calorie
GEOA	Green Energy Open Access
GHG	Greenhouse Gases
HGMS	High Grade Magnetic Separator
IPCC	Intergovernmental Panel on Climate Change
KPI	Key Performance Indicator
LOI	Loss On Ignition
MSW	Municipal Solid Waste
Mt	Million Tonnes
Mtoe	Million Tonnes of Oil Equivalent
NG	Natural Gas
OEM	Original Equipment Manufacturers
OMC	Odisha Mining Corporation
PMAI	Pellet Manufacturers' Association of India
RE	Renewable Energy
RLNG	Reliquefied Natural Gas
RTC	Round The Clock

SEC	Specific Energy Consumption
SERC	State Electricity Regulatory Commission
STG	Straight Travelling Grate
t	Tonne
TRL	Technology Readiness Level
UNFCCC	United Nations Framework Convention on Climate Change
VFD	Variable Frequency Drives
WSA	World Steel Association

Executive Summary

The iron and steel sector in India is poised for continual growth in India driven by economic development, infrastructure growth, and urbanization. The growth and sustainability of the steel depends on effective utilization of domestic iron ore resources. This would require a comprehensive study on technologies to support decarbonization of upstream sectors such as iron ore beneficiation and pellet manufacturing industries. It would further require enabling policies and strengthening government support to transition of the sector to achieve net-zero.

The pellet manufacturing industry in India relies heavily on fossil fuels resulting in emission of greenhouse gases (GHG). The Pellet Manufacturers' Association of India (PMAI) has collaborated with The Energy and Resources Institute (TERI) with an objective to develop comprehensive strategies for decarbonizing iron ore beneficiation and pellet production and establish the environmental advantages of pellets as a sustainable and eco-friendly raw material for iron-making processes.

The study adopted an integrated and customized approach drawing upon domain expertise of TERI. It comprised data and information collation from representative beneficiation and pellet industries and secondary literature collation followed by data validation and detailed analysis of key performance indicators. The study involved extensive consultations with key stakeholders such as technology suppliers, sectoral experts, industry associations, and their inputs have been thoughtfully integrated into the report.

Beneficiation industry

Beneficiation is the process of enhancing the iron content of the ore by removing the impurities and gangue materials. There are 27 beneficiation plants in India with a total installed capacity of 136 Mtpa and production of 94 Mtpa in 2024. Odisha and Jharkhand states together account for more than half of the total installed capacity.

Beneficiation process involves iron ore crushing and grinding, washing, screening, slurry concentration, and dewatering. It is electricity intensive process with electricity drawn mainly from grid. The average specific energy consumption (SEC) of beneficiation is 17 kWh per tonne of beneficiated ore with grinding accounting for about 2/3rd of total energy requirement. The total energy consumption of beneficiation industry is estimated to be 400 million kWh per annum (34,350 tonne of oil equivalent) in 2023–24. The corresponding GHG emissions were estimated as 280,000 tonne CO_2. The average emission intensity is 12.5 kg CO_2 per tonne of beneficiated ore.

Tailings are a by-product of beneficiation process that remain after iron ore concentrate has been extracted by beneficiation process. Tailings contain unrecovered iron up to 40–45%, along with other minerals and materials. In India, tailings are generally stored in ponds located within the premises of beneficiation plants. Effective tailings management is essential to enhance resource utilization, minimize environmental impacts and ensure regulatory compliance. Tailings owing to its useful chemical and physical properties can be used in clinker production in cement making, replace natural aggregates in concrete, and as pavement material.

Pellet manufacturing industry

The total installed capacity of pellet industry in India was 145 Mt with a production of about 94 Mt during 2023–24. Pellet plants are predominantly situated close to iron ore mining regions to optimize logistics. There are 53 pellet manufacturing plants across the country. Five states, namely Odisha, Karnataka, West Bengal, Jharkhand, and Chhattisgarh account for 82% of total capacity share with Odisha alone accounting for 34% of the total capacity.

The key steps in pelletization include batch preparation, formation of green pellets, separation and screening, preheating, and induration. Technologies predominantly used in pellet plants include (i) balling technology to form green pellets and (ii) induration furnace to enhance strength and durability of pellets for efficient iron making. While various technology options are available for induration furnaces, Indian industries use either Grate kiln or Straight travelling grate furnace. A new technology, Circular Pelletizing Technology (CPT) at commercial scale has presently started operations in Odisha.

Induration is the energy intensive process in pelletization with thermal energy accounting for about 80–90% of total energy consumption. The overall energy consumption of the pellet manufacturing industry is estimated as 2.86 Mtoe during 2023–24. The SEC of different induration technologies in pellet production ranges from 0.29 to 0.36 GCal per tonne and the average SEC is 0.30 GCal per tonne. The corresponding emissions are estimated to be 12.6 Mt CO_2. The average emission intensity is 134 kg CO_2 per tonne of iron ore.

Utilization of pellets is beneficial for both blast furnace and direct reduced iron (DRI) routes of iron making owing to their superior physical and chemical characteristics. The key benefits of pellets include their uniform size, consistent composition, low impurities, high porosity, and excellent reducibility. Pellets exhibit flexibility of using raw materials including the utilization of fines generated during mining process thereby effectively utilizing low and medium grade domestic ores while maintaining consistent quality.

A detailed scenario analysis of CO_2 emissions for different burden mix in blast furnace route shows that increasing the pellet share from the present level of 15% to about 50% (by substituting sinter) can lead to a reduction of about 4.22 Mt CO_2.

Decarbonization levers

Decarbonizing India's iron ore beneficiation and pellet manufacturing industry poses various challenges, including technological barriers, cost implications, financing, and market dynamics. However, the long-term benefits far outweigh the challenges. The key decarbonization levers identified for beneficiation and pellet manufacturing industries include the following.

Beneficiation

The decarbonization levers for beneficiation industry include (1) Energy efficient technologies and practices and (2) Use of RE electricity.

Pelletization

The decarbonization levers identified for pellet industry include (1) Energy efficiency in process and utilities, (2) Switch to low carbon fuels, (3) Electrification of thermal processes, (4) Promoting circularity practices such as recycling of mill scale, (5) RE electricity, and (6) Carbon sequestration. Further, domestic and international technology collaborations, research and development (R&D) for new technologies, enabling policies and regulations and government incentives and support, and infrastructure strengthening are essential to facilitate decarbonization efforts of the iron and steel sector.

SHORT-TERM MEASURES

Beneficiation
- EE technologies - Stirred media mills, wet grinding, and EE auxiliaries
- Slurry pipelines for beneficiated ore transport
- Process automation
- Enhance RE power share (RE captive power plants/Open access)

Pellet making
- Process automation
- Energy efficient auxiliaries
- Low carbon fuels e.g., NG, CBM
- Enhance RE power share (RE captive power plants/Open access)

MEDIUM-TERM MEASURES

Beneficiation
- Round-the-clock (RTC) RE electricity

Pellet making
- EE technologies - Straight traveling grate and Grate kilns
- Low carbon fuels e.g., Green H_2, biomass/biochar
- Circular economy practices
- Carbon sequestration

LONG-TERM MEASURES

Beneficiation
- New beneficiation circuits

Pellet making
- Induration furnace electrification

Decarbonization levers for beneficiation and pellet industries

Introduction

Iron and steel industry is the backbone of Indian economy. Iron ore is the basic raw material in iron and steel manufacturing process. With high-grade iron ore reserves rapidly depleting in India, it is important for Indian steel sector to focus on sustainable production using the available low and medium grade iron ores.

The utilization of low and medium grade iron ores would necessitate beneficiation process to enhance the quality and use them efficiently in iron making process. Beneficiation involves physical process to increase the economic value of low-grade iron ore by eliminating impurities, or gangue minerals. It enhances iron content, making it suitable for steel production.

In addition, pelletization technology is used to convert iron ore fines or low-grade ore into 'high-strength pellets'. Pellets, an agglomerated form of iron ore fines, offer better durability compared to the original ore and can effectively replace iron ore lumps or sinter in iron-making processes like blast furnaces or direct reduced iron (DRI) kilns. Pellets offer both economic and environmental benefits, as they contain lower impurities, making them a more efficient and sustainable alternative in iron making process. The iron and steel sector, thus, envisages iron ore beneficiation and pelletization are crucial for sustainable growth of the Indian steel industry.

Decarbonization of fossil-fuel dependent pellet manufacturing industry assumes importance for achieving sustainable development and overall decarbonization of iron & steel sector in India. The Pellet Manufacturers' Association of India (PMAI) and TERI collaborated to develop decarbonization strategies for iron ore beneficiation and pellet manufacturing industries. The study would help in supporting the overall transition of iron and steel sector towards India's net-zero target of 2070.

Purpose and scope

The purpose of the study is to evaluate eco-friendliness of iron ore pellets as raw material for iron and steel sector, evaluate decarbonization strategies and review the global best practices for adoption by Indian industry.

Decarbonization strategies for beneficiation industry

- Conduct a secondary literature search on current scenario, utilization of low and medium-grade iron ores, tailings management, and technology readiness level' (TRL) of decarbonization options along with barriers and challenges
- Review of global practices and benchmarks
- Conduct site visits for data collection and interactions
- Development of strategies for decarbonization of beneficiation industry

Decarbonization strategies for pellet manufacturing industry

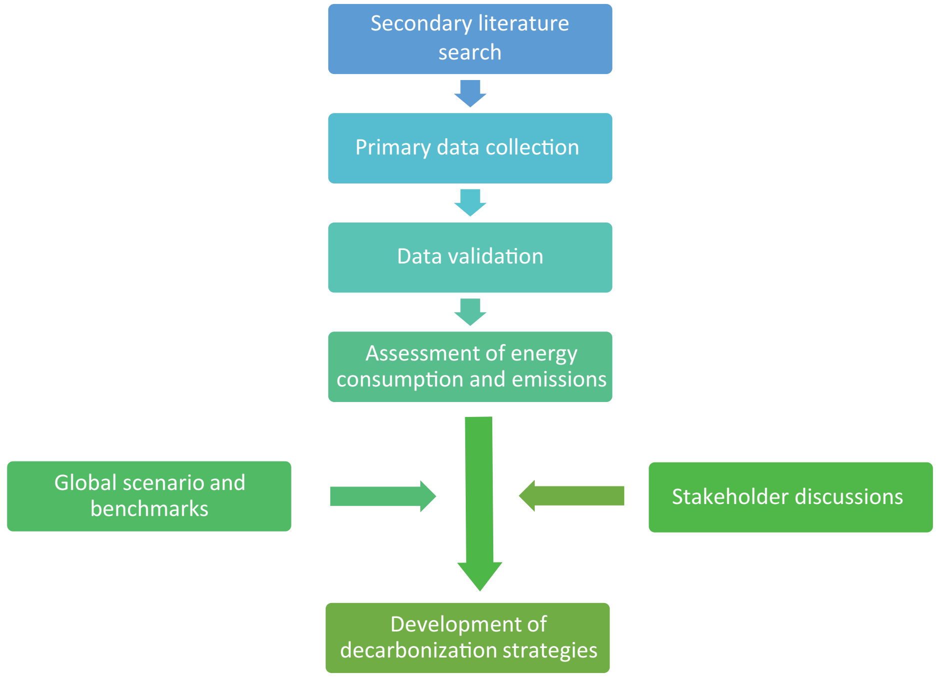
- Conduct a comprehensive review on the decarbonization of iron ore pellets industry by reviewing the secondary literature and documenting current domestic scenario
- Examine international scenario, best practices, and benchmarks
- Identify technologies and measures for decarbonization of pellets manufacturing industry, GHG reduction potential, technology readiness level (TRL), and challenges and barriers for decarbonization
- Undertake field visits for detailed interaction and data collection
- Discussions with original equipment manufacturers (OEM) for techno-commercial information
- Develop strategies for decarbonizing the iron ore pellet manufacturing industry along with cost-benefit analysis

Evaluation of pellets as eco-friendly raw material

- Assess techno-economic feasibility of using low and medium-grade iron ore in pellet production as a sustainable raw material for blast furnaces and DRI units
- Evaluate energy and environmental benefits of pellet utilization in blast furnaces and DRI units

Approach and methodology

TERI adopted a tailored, integrated approach to carry out this study, leveraging its extensive experience in the domain areas. Over the past four decades, TERI has been at the forefront of advancing energy efficiency in energy-intensive sectors, particularly in sectors like iron and steel. TERI has developed net-zero roadmaps for the hard-to-abate industry sectors such as iron and steel, and cement. TERI was knowledge partner for seven of the 14 task forces constituted by the Ministry of Steel for developing a roadmap for greening the steel sector and contributed significantly to the report "Greening the Steel Sector in India: Action Plan and Roadmap" released by the Ministry in 2024.



Secondary literature search

An extensive desk-based literature review was carried out to collate detailed information and gain comprehensive understanding of the current status of iron ore beneficiation and pellet industry. The collated information and data included details of beneficiation and pellet making facilities across India, installed capacity, production, manufacturing process, technology use, operational practices, raw material and fuel consumption, barriers and challenges, and global best practices. Focused discussions were held with the PMAI and industry stakeholders for deeper insights into the technical and operational aspects of the industry.

Validation of data through site visits

Based on consultations between the PMAI and TERI, site visits were undertaken to representative beneficiation and pellet plants in Keonjhar and Barbil (Odisha) and Durgapur (West Bengal) clusters. Detailed information was collected pertaining to technologies adopted, raw materials, fuels, energy consumption, operational practices and other relevant information from the plants. The site visits also helped validating the data and information.

Assessment of key performance indicators

Primary data collected through structured questionnaires was analyzed to evaluate gate-to-gate energy performance across participating plants. Key performance indicators such as specific energy consumption and emission intensity were calculated and benchmarked against different technologies within India as well as international standards. This analytical approach helped identifying performance gaps and recommending measures to reduce overall energy consumption and associated emissions.

In addition, CO_2 emissions from the beneficiation and pellet-making processes were estimated using standard emission factors. The sources include the Bureau of Energy Efficiency (BEE), Central Electricity Authority (CEA), the Intergovernmental Panel on Climate Change (IPCC), and the World Steel Association (WSA). The study estimated CO_2 emissions for different plants, encompassing Scope 1 (and Scope 1.1 wherever applicable) and Scope 2 emissions, following the GHG Protocol.

Scope 1 emissions: This category includes direct emissions from owned or controlled sources. The approach for Scope 1 emissions[i] is based on a mass balance approach. Emissions are calculated by accounting for the input materials and their carbon content, thus accurately reflecting the emissions generated within the production process.

Scope 2 emissions: These are indirect emissions from purchased electricity, heat, or steam. The template employs a straightforward conversion method based on emission factors to quantify these emissions, ensuring that the carbon intensity associated with energy sources is considered.

This approach to CO_2 emission calculation enabled a comprehensive assessment of overall emissions and emission intensity.

Stakeholder consultations

TERI engaged with key stakeholders across the industry, including pellet-making units, beneficiation plants, DRI facilities, BF-BOF units, original equipment manufacturers (OEMs), technology providers, sectoral experts, financial institutions, raw material suppliers, government bodies, and industry associations. The inputs from stakeholders have been duly incorporated in the document.

Review of international benchmarks and best practices

The international benchmarks on 'best available technologies' (BATs) and energy performance were reviewed and compared to evaluate potential for improvements in Indian industries.

i Scope 1.1 includes off gases such as blast furnace gas, coke oven gas or LD gas from other sections of the plant.

1

Chapter

An Overview of Iron Ore Sector in India

India is one of the leading producers of iron ore globally, with abundant reserves. This section discusses distribution, types and quality of iron ore across the country.

1.1

Types of iron ore

Hematite and magnetite are the two principal iron ores used for iron making in India. Hematite is one of the most important ores occurring in oxide form as Fe_2O_3. The total hematite resources[1] in India are estimated as 24,058 million tonnes (Mt) in 2020. Of these, about 26% is under the 'reserve' category and the balance 74% is under the 'remaining resources' category. Four states namely Odisha, Jharkhand, Chhattisgarh, and Karnataka account for about 90% of hematite resources; the balance resources are distributed in Andhra Pradesh, Assam, Bihar, Goa, Madhya Pradesh, Maharashtra, Meghalaya, Rajasthan, Telangana, and Uttar Pradesh (Figure 1).

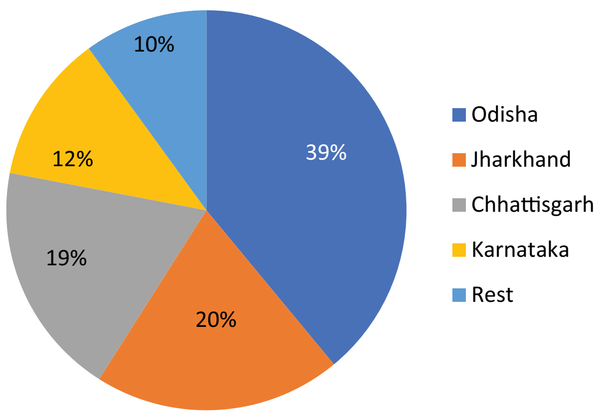


Figure 1: Hematite iron ore resource distribution in India

Source: National Mineral Inventory 2020, IBM

Magnetite resources, which occur as Fe_3O_4 form, are not exploited for domestic consumption. The total magnetite resources of India are estimated at 11,228 Mt in 2020; of these only 2% fall under the 'reserve' category and the balance 98% are under 'remaining resources' category. Most of the magnetite ore deposits are either in eco-fragile regions like the Western Ghats of Karnataka or water-scarce areas of Rajasthan. The document focuses on 'hematite' which is widely being used by the existing steel plants in India.

1.2

Classification of hematite

The major constituents of hematite include iron (Fe), silica (SiO_2), alumina (Al_2O_3), and phosphorus (P). Hematite has been classified into different grades as per the Fe content (Table 1).

Table 1: Classification of hematite

Grade	Fe content (%)
High grade	≥62
Medium grade	58–62
Low grade	45–58

The low and medium grades of hematite plays an important role in iron making. With lower iron content of low and medium grades of the ore, cumulatively accounting for nearly 70% of the total resources (Figure 2), it becomes essential to improve their quality through beneficiation for their use in iron making.

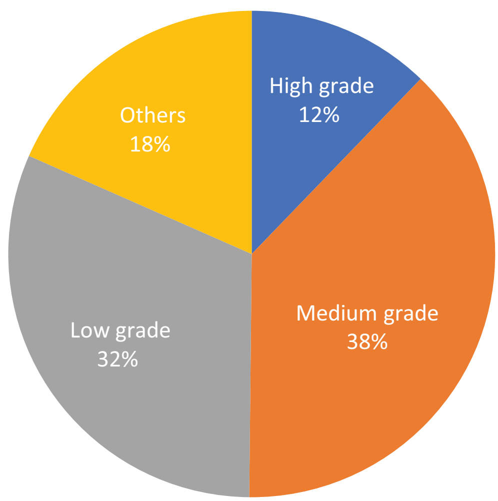


Figure 2: Share of different grades of hematite resources in India

Source: National Mineral Inventory 2020, IBM

1.3

Fines in iron ore

The total ore production in India is about 254 Mt in 2021–22. Hematite is characterized by significant presence of fines. The fines content in total ore production in India has increased to 71% in 2021–22 from 68% in 2017–18 (Figure 3); and the share of lumps reduced to 29% from 32% during this period. The domestic utilization of fines in India is limited as it would require agglomeration requiring additional costs. The bulk of the iron ore fines is exported.

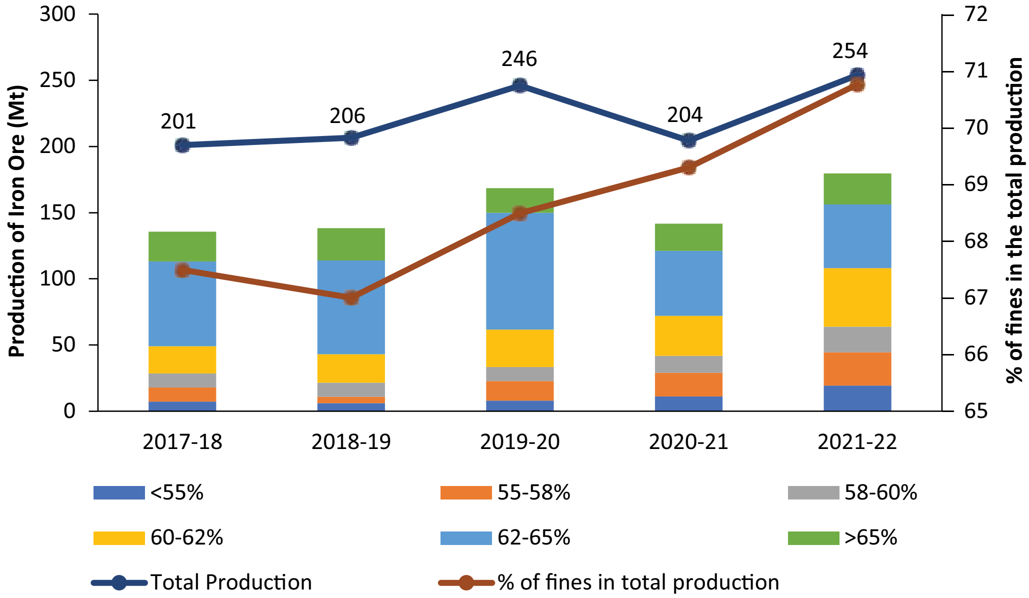


Figure 3: Share of fines in total iron ore production

Source: Indian Bureau of Mines, Indian Minerals Yearbook: 2017 to 2022 India exports[2]

1.4

Quality of iron ore

Based on mineralization, gangue content and chemical constituents, hematite is classified as massive ore, laminated ore, lateritic ore, and blue dust[3] (Table 2). The massive ore is hard, compact, rich in iron, and contains low level of impurities; the laminated ore is further categorized into hard and soft varieties, wherein soft laminated ore has comparatively higher alumina and silica. The blue dust is powdery in nature; it has higher Fe content suitable for high-quality pellets.

Table 2: Composition of iron ores in India

Iron Ore Type	Specific Gravity	Fe (%)	SiO_2 (%)	Al_2O_3 (%)	Iron minerals	Gangue minerals	Nature
Massive	>5.0	64.2–69.0	0.34–4.19	0.55–3.66	Hematite, Geothite, Martite	Quartz, clay	Hard & compact
Hard laminated	4.2–4.7	56.8–66.6	0.81–5.73	1.00–7.14	Hematite, Geothite, Limonite	Clay (kaolinite), gibbsite, quartz & chert	Laminated structure hard & compact
Soft laminated	4.2–4.5	57.0–65.5	1.20–8.60	1.10–11.0	Hematite, Geothite, Limonite	Clay (kaolinite), gibbsite, quartz & chert	Laminated structure soft & friable
Lateritic	3.8–4.2	58.8–61.5	1.00–6.88	3.72–8.85	Geothite, Limonite, Hematite, ochre	Clayey lateritic materials, gibbsite & silica	Dull lustre, cavernous & friable
Blue dust	>5.0	65.0–69.0	0.64–2.12	0.35–2.49	Hematite, Geothite	Quartz, clay	Powdery

Source: Iron & Steel Vision 2020, Indian Bureau of Mines, Ministry of Mines, Govt of India

1.5

Exports and imports of iron ore

The export of iron ore stood at 14.74 Mt in 2022–23. Iron ore was exported to China, Turkey, Slovakia, Indonesia, the Netherlands, the United Kingdom, Malaysia, Poland, Finland, Germany, France, and Italy. Of the total exports, fines having less than 58% Fe content constituted a major share of 80%. Imports of iron ore was about 6.2 Mt in 2024–25. The export trend for iron ore is illustrated in Figure 4.

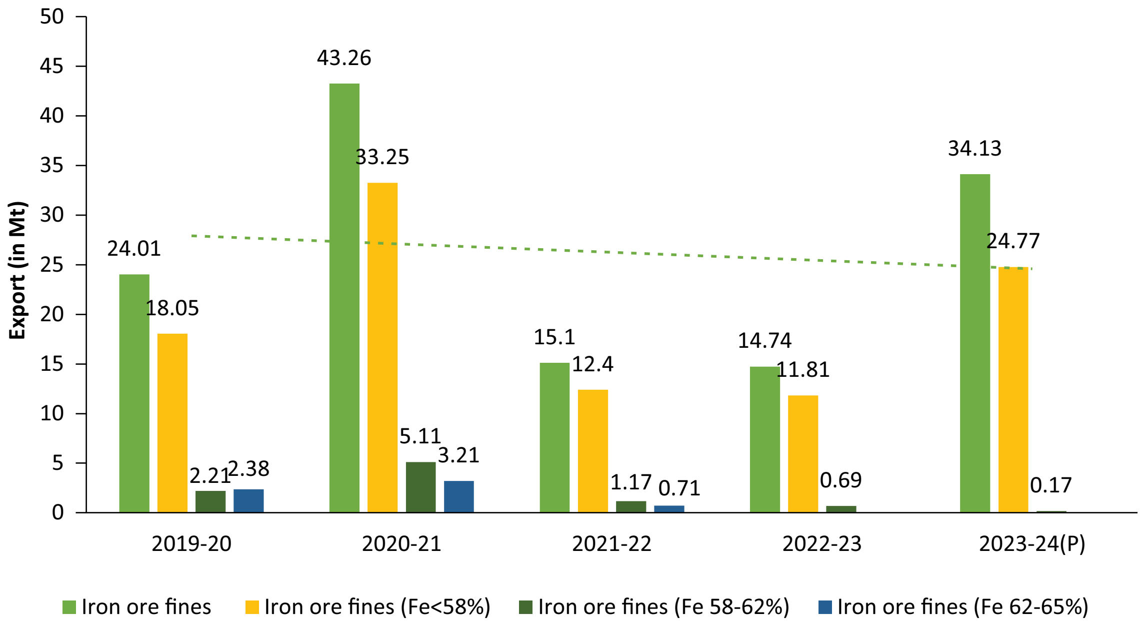


Figure 4: Trend of export of iron ore fines

Source: Annual Statistics, JPC 2024

2

Chapter

Beneficiation Industry

With low and medium grade iron accounting for about 70% of total iron ore production, it is important for Indian steel industries to utilize them optimally. Indian iron ore contains impurities such as clay and gibbsite minerals often found in association with goethite-limonite mineral phases. It is crucial to limit or minimize these impurities, particularly alumina, for enhancing the yield of iron metal. Beneficiation is the process of enhancing the iron content of the ore by removing the impurities and gangue materials. Indian hematite has a high share of Al_2O_3 (1–7%) and low silica content, resulting in a high alumina-to-silica ratio of 1.5–3.0 for lumpy ore and 3–4 for fines. This imbalance leads to increased flux and higher energy requirements for iron production.

2.1 Installed capacity and production

The total installed capacity of the beneficiation industry in India was 135 million tonnes per annum (Mtpa) in 2024 with Odisha and Jharkhand together account for more than half of the total installed capacity (Figure 5). There is a wide variation in the capacity of beneficiation plants, ranging from 0.3 Mtpa to 19.5 Mtpa. The major players of beneficiation industry are JSW Steel, SAIL, NMDC Steel, Tata Steel, Odisha Mining Corporation (OMC), and Vedanta Steel. A comprehensive list of beneficiation plants in India, locations, and installed capacity during 2024, is provided in Annexure 1.

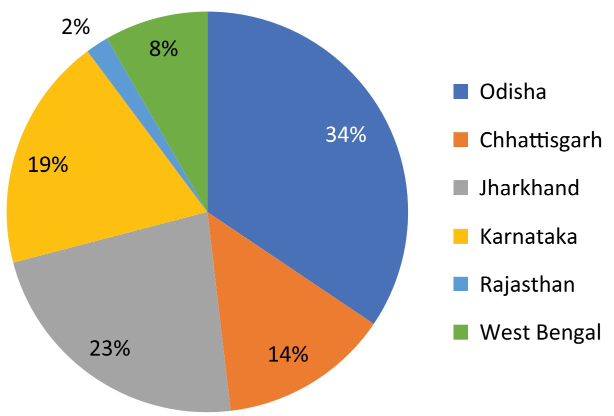


Figure 5: Installed capacity of beneficiation plants

Source: BigMint and PMAI

Responding to the increasing demand for iron ore, major steel companies have committed to establishing new beneficiation plants with an additional capacity of 192 Mtpa by 2030 (Source: PMAI and industry stakeholders). The major players include JSW Steel, Adani Group, Rungta & Sons, Tata Steel, Jindal Steel & Power, and Essar Minmet (Annexure 2).

2.2

Classification of beneficiation plants

Currently, there are 27 beneficiation plants in India with a total installed capacity of 135 Mtpa (Table 3).

Table 3: Installed capacities of beneficiation plants

Category	Number of plants	Capacity range (Mtpa)	Total capacity (Mtpa)
Small	14	Up to 3	21
Medium	9	3–10	52
Large	4	More than 10	62
Total	27		135

Out of this, large plants (JSW Steel, Tata Steel, and ArcelorMittal Nippon Steel (AM/NS India) account for nearly 46% of total installed capacity (Figure 6).

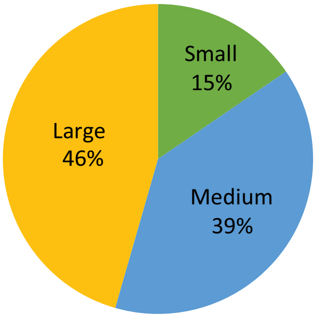


Figure 6: Classification of beneficiation plants

2.3

Manufacturing process

The beneficiation process depends on the quality of input ore material and the targeted level of enrichment. It typically involves crushing and grinding, washing, screening, slurry concentration, and dewatering (Figure 7). Additionally, some plants employ advanced techniques such as gravity concentration, flotation, and magnetic separation tailored to specific ore characteristics and processing requirements.

2.3.1

Crushing and grinding

The iron ore goes through crushing and grinding along with wet or dry classification of extracted ore using dry or wet feed. Wet grinding is widely used in India. Fine grinding reduces the ore particles to the consistency of fine powder (325 mesh, 0.045 mm). The type of grinding circuit used is based on the density and hardness of ore. Grinding mills generally employ ball mills using steel balls as grinding media. These are tumbling mills with a smaller length-to-diameter ratio which ranges up to 1.5. The grinding efficiency is greatly influenced by the classification efficiency and the mill operating parameters such as mill speed, media charge, slurry density, and viscosity (Figure 7).

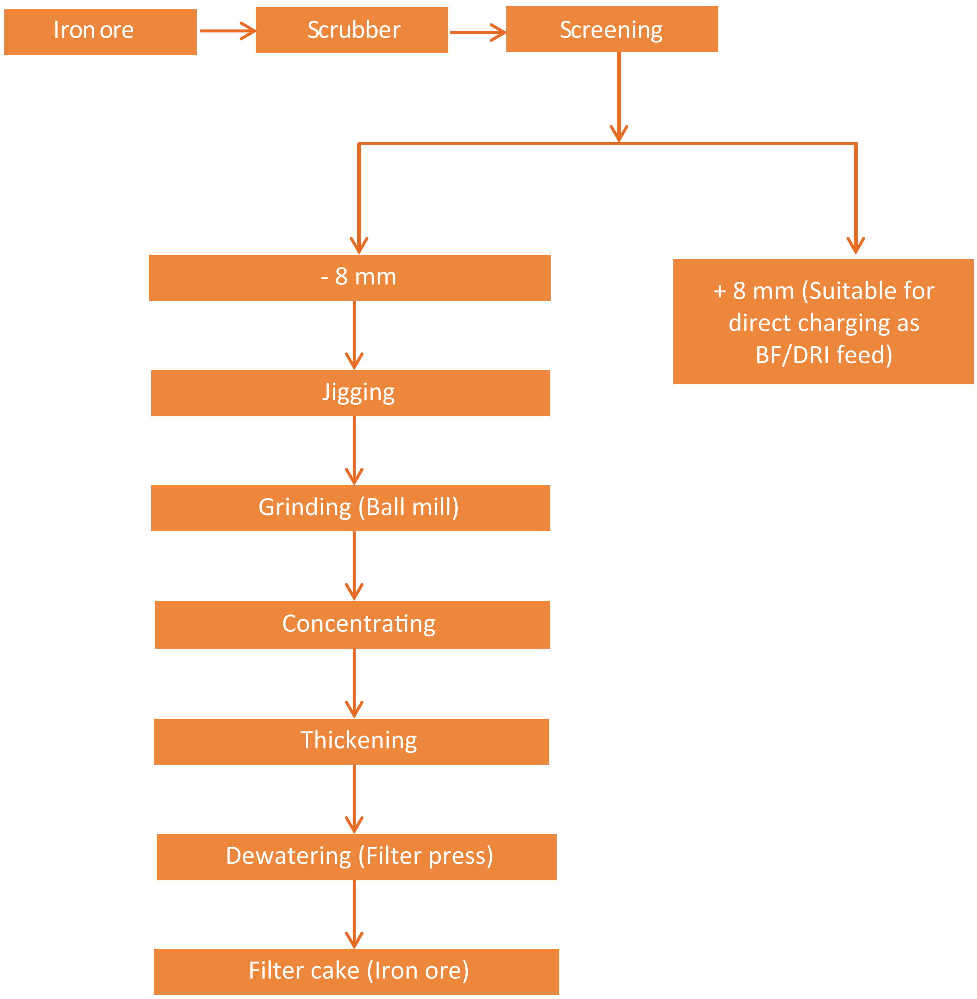


Figure 7: Process flow diagram for iron ore beneficiation

2.3.2 Flotation

Flotation is effective for the concentration of fine iron ore (minus 100 mesh or less than 0.15 mm). Suitable reagents added to water suspension of finely grounded iron ore selectively cause either iron oxide minerals or gangue particles to exhibit an affinity to air. The suspended particles are removed as a froth product. Important factors for flotation include uniformity of particle size, use of reagents compatible with the ore, and water condition that do not interfere with the attachment of the reagents to the ore or air bubbles. Wastes from the flotation cell are collected from the tailings overflow weir. Depending on the grade of the froth, it is recycled for further recovery of iron or discharged as tailings. Tailings contain remaining gangue, unrecovered iron minerals, chemical reagents, and process wastewater.

2.3.3
Thickening

Thickeners are used to remove most of the liquid from slurry concentrates and waste slurries (tailings). Thickening is employed in two phases—(i) concentrates are thickened to reduce moisture content and reclaim water, and (ii) slurried tailings are thickened to reclaim water. In addition, there are other processes such as gravity concentration and magnetic separation that are also selectively adopted depending on the quality of iron ore and the finished product.

2.3.4
Dewatering

Dewatering iron ore concentrate involves removal of excess water to improve handling and transportation of the concentrate. Filter press is used for dewatering.

2.3.5
Gravity concentration

Gravity concentration is widely used in the beneficiation of hematite. It is used to suspend and transport lighter gangue away from the heavier valuable minerals. The separation process is based on differences in the specific gravities of the materials and the size of the particles. Three gravity separation methods are being used by the industry—washing, jigging, and heavy-media separators.

2.3.6
Magnetic separation

Magnetic separation is generally used to separate natural magnetic iron ore (magnetite) from a variety of less magnetic or non-magnetic materials. However, a substantial percentage of iron being beneficiated is lost to tailings due to hematite being weakly magnetic. Magnetic separation is either conducted in dry or wet environment with wet systems being more commonly used. Magnetic separation of iron ores can be categorized as either low or high intensity. Low-intensity separators use magnetic fields between 1,000 and 3,000 gauss. It is normally used for magnetite ore and is generally an inexpensive and effective separation method. High-intensity separator employs fields as strong as 20,000 gauss. It is used to separate weakly magnetic iron minerals (hematite) from non-magnetic or less magnetic gangue materials.

2.3.7
High grade magnetic separator

Currently, the iron ore beneficiation process includes sizing, washing, and classification to meet the size requirement with nominal rejection of silica and alumina impurities. A magnetic separation technique known as High Grade Magnetic Separator (HGMS) is employed by a few units to concentrate iron ore by separating gangue. By employing HGMS, iron ore containing 56–58% iron can be enriched by about 4–5% (Figure 7).

2.4

Key performance indicators

The key performance indicators (KPIs) of iron ore beneficiation industry include specific energy consumption and emission intensity. Specific energy consumption assesses energy efficiency of production process with lower values signifying better efficiency. Monitoring GHG emissions is essential for environmental compliance and sustainability. The reduced emissions reflect improved process conditions and energy use.

2.4.1

Specific energy consumption

Electricity is the only source of energy used in iron ore beneficiation with no thermal energy requirement. Key energy consuming operations within beneficiation include grinding, separating, filtering, and dewatering. The total energy consumption of iron ore beneficiation industry is estimated as 34,350 toe (tonne of oil equivalent) during 2023–24.

The specific energy consumption (SEC) of beneficiation is the ratio of total energy used to the quantity of iron ore beneficiated. The variations in SEC levels in beneficiation may be attributed to factors such as plant capacity, technology employed, ore characteristics & size distribution, extent of beneficiation, and the specific sub-processes involved. The average SEC of beneficiation industry is about 17 kWh per tonne of beneficiated ore. In a beneficiation plant, grinding alone accounts for over half of the total energy consumption; the balance is accounted by utility equipment like slurry pumps, fans, blowers, conveyors, and other auxiliary systems (Table 4).

Table 4: Specific energy consumption of iron ore beneficiation industry

Section	SEC range (kWh/t)
Grinding	8–14
Utilities	4–8
Total	12–22

Source: TERI industry data analysis, 2024

Note: Data pertains to hematite ore, non-HGMS units

Electricity requirements in the beneficiation industry are primarily met through grid supply, with diesel generator (DG) sets serving as backup sources. Several beneficiation plants have begun integrating renewable energy (RE) solutions—particularly solar power—to reduce reliance on grid electricity and lower carbon emissions.

Box 1: Addition of RE capacity

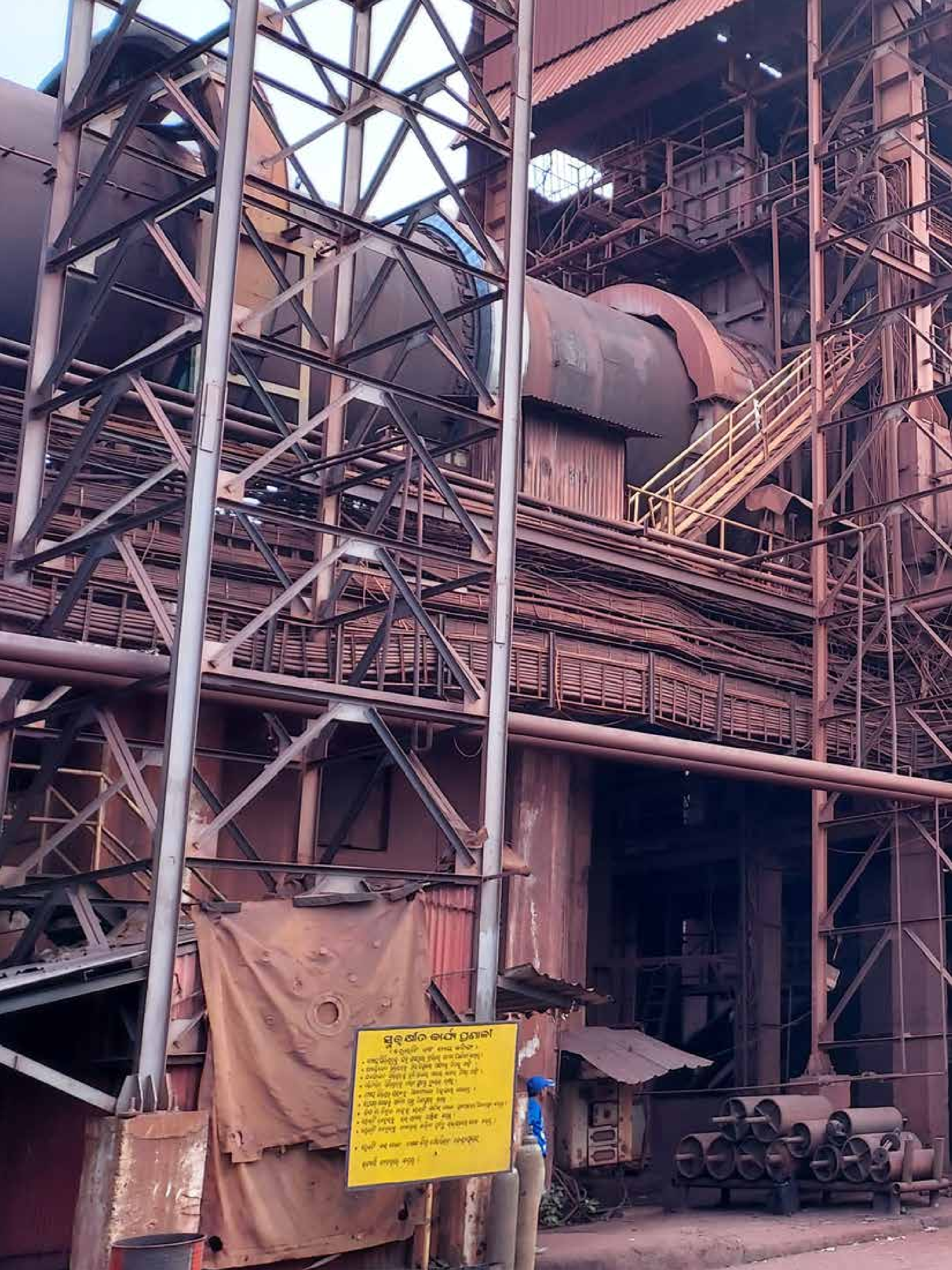
A beneficiation plant in West Bengal has installed a floating solar plant of 1.1 MW capacity. It has plans for an additional 3.4 MW solar rooftop capacity. A number of beneficiation plants are keen to expand their solar capacities with different options like rooftop system or open-access mechanisms.

2.4.2

GHG emissions

Greenhouse gas (GHG) emissions from the beneficiation process are primarily attributed to electricity consumption by various equipment and systems. The total GHG emissions of beneficiation industry in India are estimated to be 280,000 tonnes of CO_2 in 2023–24. With grid electricity serving as the primary source of electricity,[ii] the average emission intensity[4] of beneficiation is 12.5 (range: 9–16) kg CO_2 per tonne of beneficiated iron ore.

ii Except for few plants which source from captive plants or waste heat recovery systems.



3 Chapter

Pellet Industry

The pellet industry plays an important role in Indian steel sector, providing raw material for iron production. Pellets are value-added products of iron ore that undergo a process of agglomeration, which improves yield in steel making. Pellet manufacturing process enhances physical and metallurgical properties thereby optimizing the utilization of iron ore. Unlike iron ore lumps of varied size and shapes, uniform size of pellets helps in improving furnace efficiency thereby enhancing energy performance and reducing emissions. As India is expanding its steel production capacities and transitioning towards greener steel production, the pellet industry is gaining more importance in steel value chain.

3.1

Installed capacity and production

The total installed capacity of pellet industry in India was 145 Mt in 2023–24 with actual production reaching 94 Mt, (65% capacity utilization). Pellet plants are predominantly situated close to iron ore mining regions to optimize logistics. Currently, there are 53 pellet manufacturing plants across the country. Five states, namely Odisha, Karnataka, West Bengal, Jharkhand, and Chhattisgarh account for 82% of total capacity share with Odisha alone accounting for 34% of the total capacity (Figure 8). Other pellet plants are located in states such as Andhra Pradesh, Goa, Gujarat, Maharashtra, Rajasthan, Telangana, and Uttar Pradesh. A detailed list of pellet plants and production capacities along with their locations marked on the country map is provided in Annexure 3.

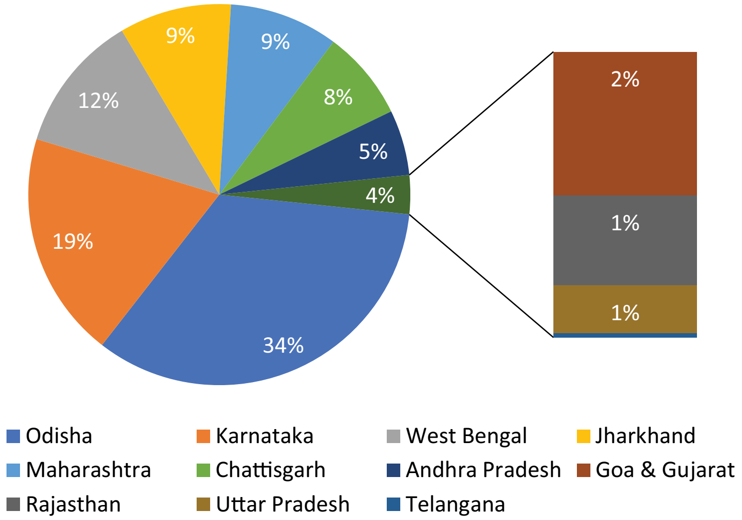


Figure 8: State-wise pellet production capacity in India

Source: BigMint, PMAI

3.2

Classification of pellet manufacturing plants

Pellet production in India can be broadly categorized into two types based on their end-use: (1) Captive industries and (2) Merchant industries. Captive and merchant units produce pellets for internal consumption, whereas merchant units also cater to external buyers, both domestic and global. Most merchant pellet units are concentrated in key states such as Odisha, Karnataka, West Bengal, Chhattisgarh, Gujarat, and Goa. A breakup of pellet production capacity for intended use (captive or merchant) in different states is given in Figure 9.

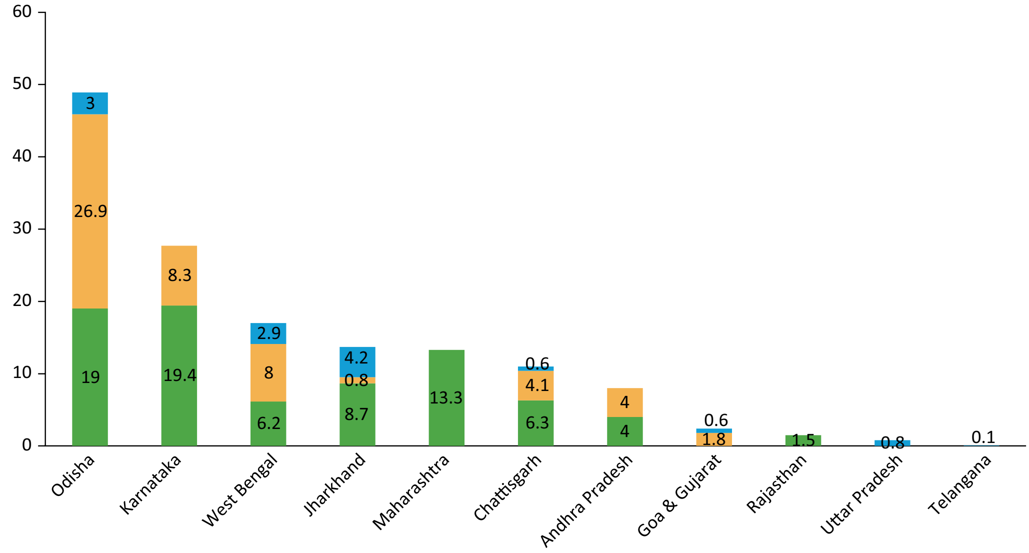


Figure 9: Pellet production capacity for intended use

Source: BigMint/PMAI

The capacity of pellet plants in India varies widely, ranging from 0.6 Mtpa to 17.2 Mtpa. The pellet plants in India may be categorized based on their capacities (Table 5).

Table 5: Installed capacities of pellet manufacturing industries

Category	Capacity range (Mtpa)	Number of plants	Total installed capacity (Mtpa)
Small	Up to 3	41	52
Medium	3–10	9	50
Large	More than 10	3	43
Total		53	145

Source: BigMint, PMAI, and TERI

The majority of pellet plants in India are small-scale units primarily catering to local demand, collectively accounting for only 36% of the total installed capacity. The medium and large pellet plants constitute approximately 64% of the overall capacity (Figure 10).

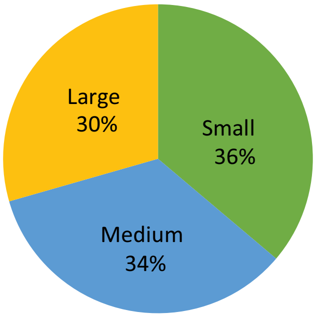


Figure 10: Share of pellet production capacities

Figure 11 illustrates the trends in production capacity, actual pellet production, exports, and capacity utilization of pellet manufacturing industry. In 2023–24, out of 94 Mt of pellets produced in India, approximately 82 Mt was consumed domestically across various processes such as DRI, blast furnaces, and the Corex process. The remaining 12 Mt of pellets were exported.[5]

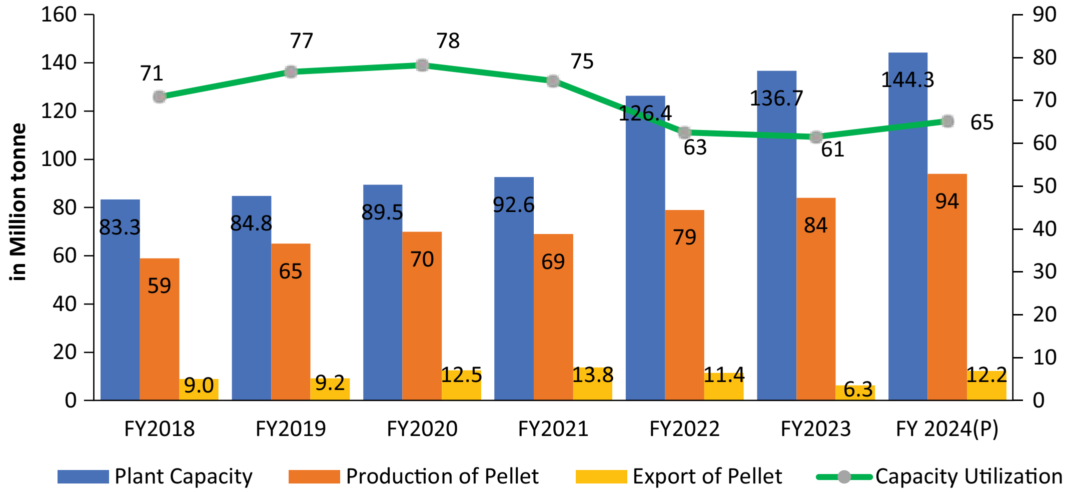


Figure 11: Trend of capacity, production, and export of the Indian pellet industry

Source: BigMint, PMAI, Annual Statistics JPC 2024

The pellet production has grown at a compound annual growth rate (CAGR) of 6% during the last five years. It is expected to reach about 142 Mtpa by 2030–31 at the current CAGR. However, considering the growth potential of steel production, the pellet production growth rate could be higher than 6%. The production is estimated to reach 161 Mtpa and 183 Mtpa at a CAGR of 8% and 10% respectively by 2030–31 (Figure 12).

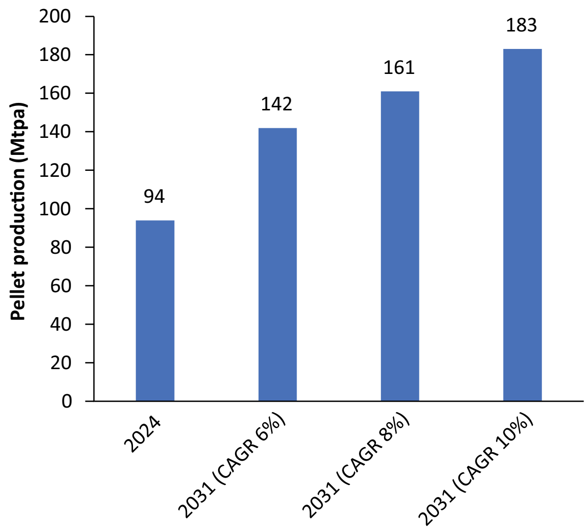


Figure 12: Projected pellet production in 2030–31

3.3

Manufacturing process

The production of iron ore pellets involves preparation of a batch mix comprising of iron ore, coal, coke, dolomite, and a binding agent such as bentonite. The mixture is processed to form green pellets, which are subjected to thermal treatment in induration furnace. The key stages of the pelletization process include (i) batch preparation, (ii) formation of green pellets, (iii) screening and separation, and (iv) preheating and induration (Figure 13).

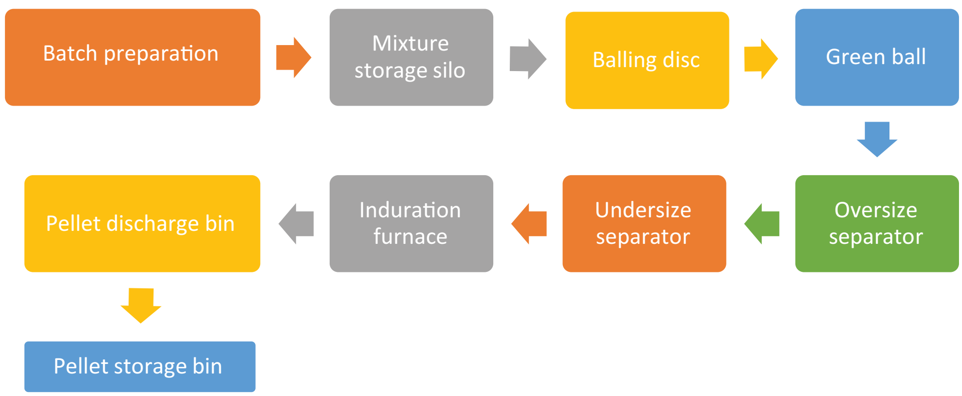


Figure 13: Pellet manufacturing process

3.3.1

Formation of green pellets

The raw materials comprising iron ore, pulverized coal, coke, and fluxing material (limestone, dolomite) are mixed with binding chemical (bentonite or organic binders) at the required proportion and transferred to storage silos. The addition of lime imparts strength to the pellets (Box 1). The batch mixture from storage bins is conveyed to rotating balling disc, where the mixture is turned into various sizes of green pellets. These pellets are passed through a double-deck roller-feeder to remove both oversized and undersized pellets and recycled. The pellets of desired sizes, generally 6 to 18 mm, roll off the roller feeder and deposited in a uniform layer onto a supporting hearth layer of a travelling grate for further processing.

3.3.2

Induration of pellets

The induration of green pellets is a thermal treatment process to enhance the mechanical strength for withstanding tumbling and falling during transport and loading inside the reactors. Green pellets are gradually heated to about 1275–1300^{0}C by the counterflow of hot combustion gases while moving from the inlet point of the

Box 1: Role of lime in pellet manufacturing

Hydrated lime use in pelletization leads to better drop resistance and compressive strength. Fluxing also leads to shrinkage in pellets during firing which further leads to higher strength. Thus, hydrated lime could be a better alternative to ordinary lime.

Source: Rout Kalpataru. A comparative characterization of Iron Ore Pellet agglomerates prepared from low grade goethite raw ultrafine and beneficiated goethite ultrafine. IJCRT. Volume 6, Issue 1 March 2018. ISSN: 2320-2882.

endurance furnace to the heating zone to improve physical and mechanical properties such as tumbling index, abrasion index, porosity, etc., resulting in lower energy consumption and higher productivity in iron-making processes.

The main sections of the furnace consist of an updraft zone, downdraft zone, pre-heating zone, firing zone, after-firing zone, primary cooling zone, and secondary cooling zone. The length of each zone is designed based on the ores chemistry to be processed. The working temperature range in each section of the furnace is maintained as per the requirement of batch material. The moisture in green pellets is removed using hot gases from the updraft fan followed by drying in the downdraft zone and pre-heating with hot gases from the recuperator fan. Air enters from primary and secondary cooling zones, where hot air from the primary cooling zone travels to the firing zone for combustion completion, which is transferred to the downdraft zone by the connected recuperator/downdraft fan in line. Hot air from the secondary cooling zone is transferred to the updraft zone by the connected updraft fan in place. Finally, exhaust gas streams from the wind boxes and hood pass through an electrostatic precipitator (ESP) or bag filter being sent to the stack (Figure 14).

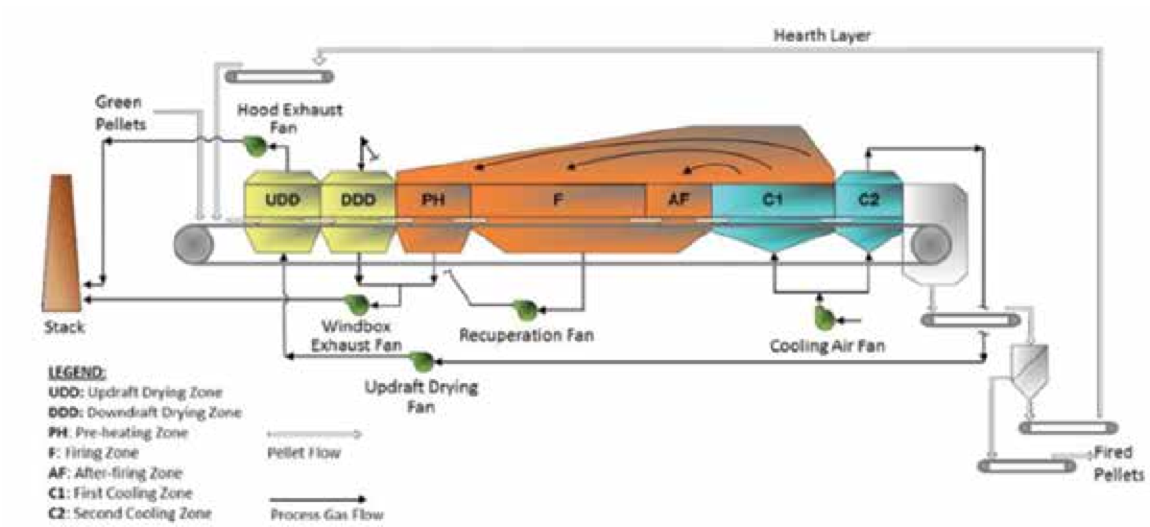


Figure 14: Induration furnace

Source: https://pmai.co.in/pellet-technology/

3.4

Technologies for pelletization

Pellet manufacturing in India primarily involves two key technologies: (i) balling technology, used to form green pellets from the raw material mix, and (ii) induration furnaces, which impart the necessary strength and durability to the pellets, enabling their efficient use in iron-making processes.

3.4.1

Balling technology

The balling technology could be either a balling disc or balling drum. The balling disc is an equipment, which rotates on its axis at a pre-set angle to the horizontal. The main body has a pan with a circular vertical shell at the edge to ensure a closed boundary, creating open space for batch mixture holding. It is fitted with a scrapper and arrangement for raw material flow onto the pan surface.

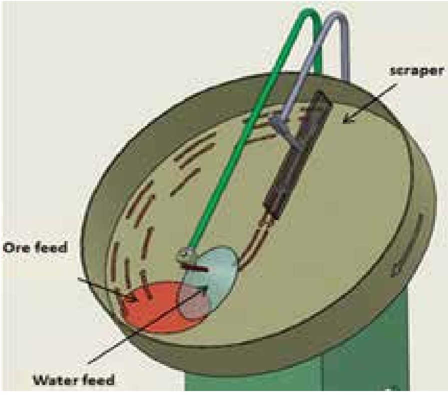


Figure 15: Pictorial view of balling disc

A supplementary water sprayer is provided to feed raw material with less moisture than the requirement. Initial pellet formation starts at the nucleation zone of the pan bottom surface area by rolling action and gradually builds up the size to move in a semi-circular trajectory. Finally, the balls fall on the conveyor surface and are transferred to a double-decker roller to the screen while rolling over. The pellets smaller than 8 mm or larger than 16 mm are desegregated, and the material is recirculated to the balling process. The screened pellets are transferred to the endurance furnace for heat treatment. A pictorial view of a generic balling disc[6] is shown in Figure 15.

Apart from balling discs, balling drums[7] are also used in ball-making process, which is an inclined rotating cylindrical shell with water sprays in its inlet end, where the feed material is introduced to make balls. The 'formed pellets' are discharged, regardless of particle size, which is different compared to the balling disc where only balls larger than a certain size are discharged. While the balling drum gives more throughput, the recirculation rate is higher due to non-uniformity in size.

Balling drum is the most commonly used technology in India (Figure 16). Balling drums are favoured due to their ability to produce uniform-sized pellets and their efficiency in processing large quantities of material. While balling discs are also used, particularly for smaller operations, balling drums are generally preferred for larger-scale production which can handle a wide range of feed materials; they typically offer better pellet quality and productivity. The choice between balling drums and discs depends on specific operational requirements, moisture content of the feed, and the scale of production.

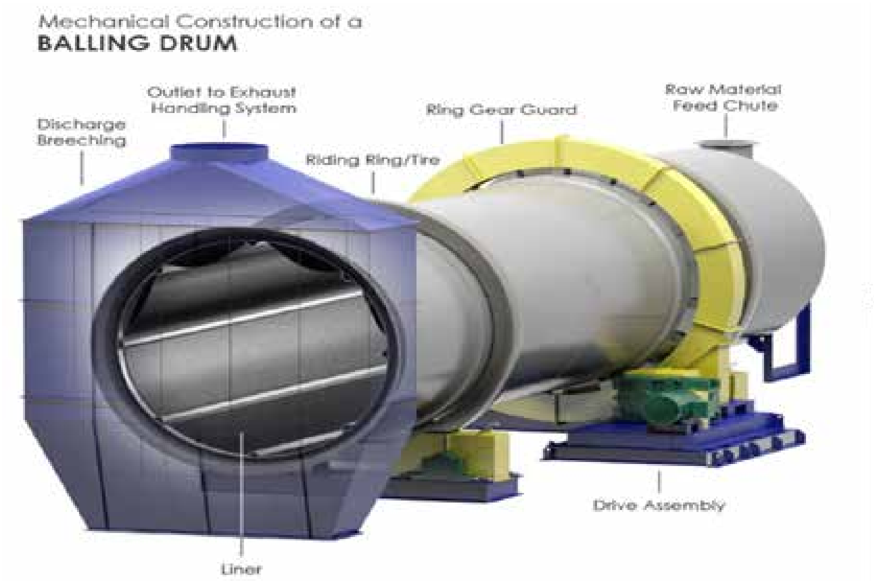


Figure 16: Balling drum for green pellet production

Source: Feeco

3.4.2

Induration furnace

An induration furnace is a heat treatment furnace for heating green pellets to improve both its mechanical and metallurgical properties. There are several induration technologies available,[8] and these are:

i. Grate kiln
ii. Straight Travelling Grate (STG)
iii. Circular Pelletizing technology (CPT)
iv. Process shaft furnace
v. Cement bonded process (Grangcold Process, MIS Grangcold Process, Char Process)
vi. Hydrothermal Processes (COBO Process, MTU Process, INDESCO Process)

The most commonly used induration furnaces in India are (i) Grate kiln and (ii) Straight Travelling Grate. The 'Circular Pelletizing Technology' (CPT) is a state-of-the-art technology, with the world's first CPT plant established in Odisha. An overview of various induration technologies, highlighting their unique features, advantages, and applications in the industry are presented below.

(a) Grate kiln

The Grate kiln process was developed by *Allis Chalmer*. Grate kiln systems are available up to 6 Mtpa capacity (Bahrain Steel).[9] In this, a travelling Grate is used to dry and preheat green pellets. The material moves on a straight travelling Grate while attaining a temperature of 800–1000°C. The preheated material is transferred to a refractory lined rotary kiln for induration wherein the temperature is raised to about 1250–1300°C for further hardening and strengthening of the pellets. The heat hardens the green balls which is helpful to withstand the tumbling impact in the rotary kiln.

The Grate kiln process has three units for meeting radically different thermal conditions. While drying, pre-heating, and oxidation are carried out in a travelling Grate, pellets are fired in a rotary kiln by radiation. The Grate kiln units in India can use multiple fuel types in the kilns including solid, liquid, and gaseous fuel. Hot pellets are cooled in a rotary cooler. Hot air from the rotary kiln is used in the Grate kiln for drying and preheating. The hot air from the rotary cooler is recirculated in the rotary kiln. Heat supply from various types of fuels can be used as setup that can be regulated easily because of three separate units. A schematic of the Grate-kiln is given in Figure 17.

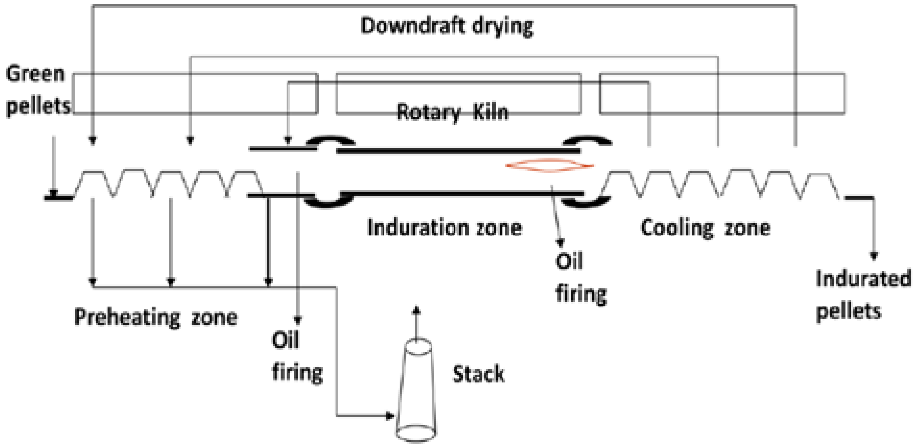


Figure 17: Schematic of a Grate-kiln process for iron ore pelletization

Source: https://pmai.co.in/pellet-technology/

(b) Straight Travelling Grate

The traight travelling Grate (STG) process (Figure 18) was developed by the former *Lurgi Metallurgie* and has the world's major installed capacity. STG plants.[9] have capacities of up to 8.5 Mtpa In this process, a double-deck roller screen ensures the right size of green pellets (8–16 mm) is evenly distributed across the width of the travelling Grate. The Grate carries green pellets on a bed 300 mm to 550 mm thick through a furnace with updrafting, downdraft drying, preheating, firing, after firing, and heating zones.[10]

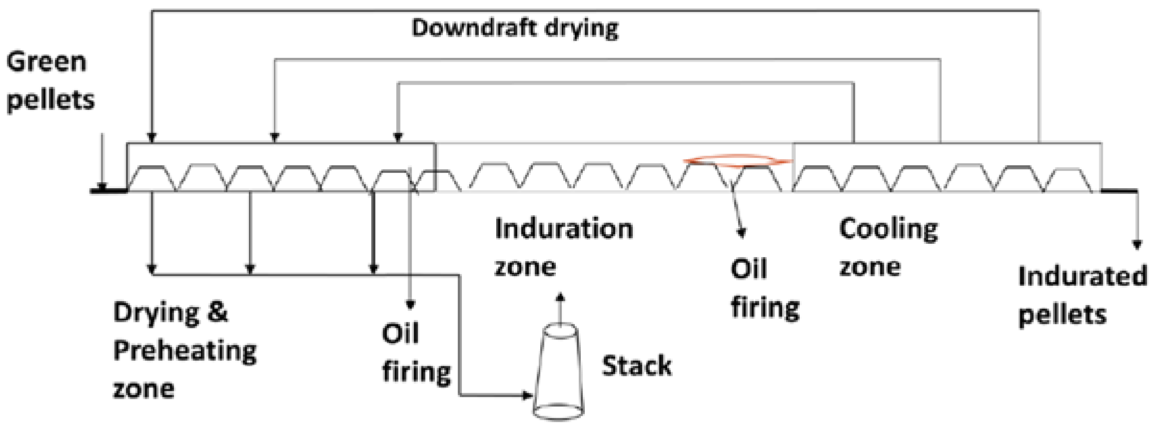


Figure 18: Straight Travelling Grate process

Source: https://pmai.co.in/pellet-technology/

A comparison of Grate kiln and Straight Travelling Grate technologies is shown in Table 6. As can be observed, Straight Travelling Grate technology performs better in terms of quality and energy consumption, as compared to Grate kiln, but Grate kiln technology is more flexible in terms of fuel usage.

Table 6: Comparison of Grate kiln and Straight Travelling Grate technologies

Parameter	Grate kiln	Straight Travelling Grate
Plant availability	Lower	Higher
Compatibility with different grade of ores	Less flexibility in using different types of ores	More flexibility with hematite, magnetite, and mixture of both
Usage of solid fuel	More flexibility with main burner can use solid fuel	Limited as an additive to pellet feed
Energy consumption – Electrical	Lower	Higher
Energy consumption – Thermal	Higher	Lower
Refractory consumption	Higher due to direct contact with pellets	Lower
Burner system	Simple	Sophisticated
Product quality	Uniform quality	Better porosity and metallurgical properties
CO_2 emissions	Higher due to high thermal energy consumption	Lower

Source: Kordzadeh E et al. 2017. Contributions to the technology comparison between Straight Travelling Grate and Grate-kiln. Refer to endnote 10 for the full url.

Note: Data for CPT technology is not available as the technology is new.

(c) Circular pelletizing technology

The circular pelletizing technology (CPT) was developed by Siemens Metals Technologies and features a circular design of the induration furnace (Figure 19). It has a compact layout and a light-weight construction design. While straight induration furnace alignment typically employs only 40% of the pellet car number at any given time, the circular furnace layout in circular technology allows 75% of the pellet cars to be in permanent active use. Pellet production capacity of CPT ranges from 800,000 tpa up to 3 Mtpa. The quality of the pellets can be flexibly adjusted according to production requirements. A schematic of a CPT is shown in Figure 20.

Figure 19: 3D view of Circular Pelletization Technology

Source: Primetals (https://www.primetals.com/portfolio/agglomeration/pelletizing-technology)

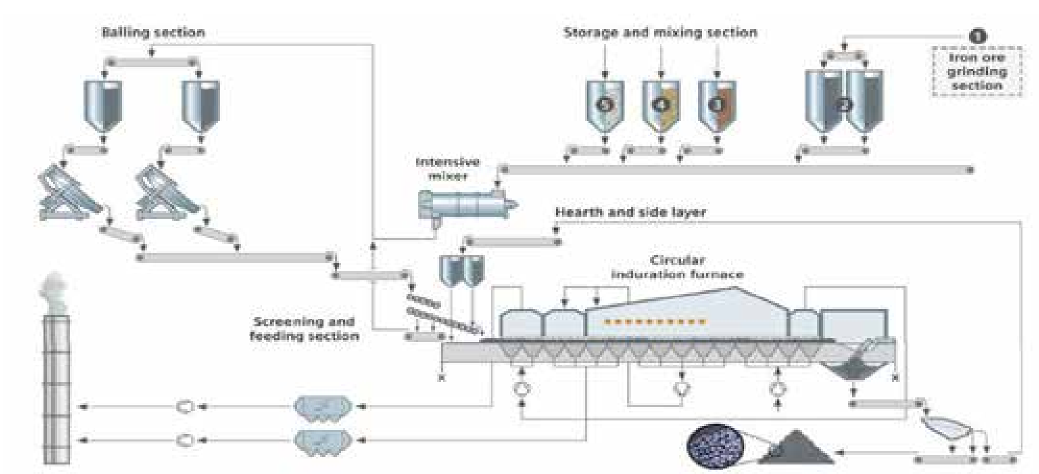


Figure 20: Schematic of Circular Pelletizing Technology (CPT)

Source: https://pmai.co.in/pellet-technology/

3.5

Key performance indicators

The performance of the pellet manufacturing industry are linked to a set of measurable parameters- key performance indicators (KPIs). These indicators provide useful insights into the operational efficiency, energy consumption, and carbon footprint of pellet plants. Monitoring of KPIs such as capacity utilization, specific energy consumption (SEC), and greenhouse gas (GHG) emissions is essential for evaluating industry trends and identifying performance gaps.

3.5.1

Capacity utilization

The overall performance of the pellet industry is influenced by the utilization of existing capacity. Higher capacity utilization shows the optimal use of production facilities and resources, leading to improved operational efficiency. There has been a downward trend in capacity utilization of pellet industry, dropping from 71% in 2018 to about 61% in 2023 (Figure 11). The capacity utilization of the pellet plants visited during field studies ranged from 57% to 94%. The plant employing Circular Pelletization Technology is currently in the stabilization phase, operating at a low-capacity utilization of 57%, but is expected to ramp up production within the next 2–3 years. The plants employing Straight Travelling Grate or Grate kiln technology have reported capacity utilization levels exceeding 85%.

Capacity utilization in pellet manufacturing plants across India varies due to various factors—including market demand and raw material availability. Despite these variations, the industry operates with a capacity utilization of 60% to 70%. Several challenges, such as logistical constraints and regulatory hurdles, also affect production levels. Additionally, shifts in international iron ore prices and demand dynamics play a significant role in influencing capacity utilization.

However, ongoing investments in technology upgrades and infrastructure improvements are aimed at enhancing efficiency and further increasing utilization rates. The generation of fines increased during iron ore mining, coupled with the industry's willingness to increase the share of pellets as an iron-bearing raw material in iron production, is expected to contribute positively to the capacity utilization of the pellet industry in the near future.

3.5.2

Specific energy consumption

The pellet-making process is thermal energy-intensive, with thermal energy accounting for approximately 90% of the total energy consumed, primarily in the induration process with the balance 10% being electrical. Pellet plants in India rely on a diverse mix of fuels—including coal, furnace oil, coal bed methane (CBM), and producer gas—selected based on factors such as cost, availability, and regional policy frameworks. Electrical energy is primarily used for grinding operations and auxiliary systems.

The SEC in the pellet industry varies significantly, influenced by several factors including the technology employed, type of fuel used, plant design, equipment efficiency, capacity utilization, and characteristics of the raw materials. The SEC levels of pellet plants in India[iii] is shown in Table 7.

iii Primary data from 8 units was used for the analysis.

Table 7: Specific energy consumption of Indian pellet plants

Induration technology	SEC-thermal (GCal/t)	SEC-electrical (kWh/t)	Overall SEC (GCal/t)
Grate Kiln	0.32	43	0.36
Straight Travelling Grate	0.27	33	0.29
Circular Pelletization Technology	0.28	67	0.34

Source: TERI analysis, 2024

The overall SEC[iv] of pellet production was 0.29 to 0.36 GCal per tonne for different induration technologies. The total energy consumption of the pellet manufacturing industry is estimated at 2.86 Mtoe for the year 2023–24. The Grate kiln process, while characterized by a relatively high SEC of 0.36 GCal per tonne, remains a preferred option for smaller-capacity plants due to its lower capital investment requirements. CPT plant has a lower SEC of 0.34 GCal per tonne—more efficient than the Grate kiln route but slightly higher than the Straight Travelling Grate technology. The world's first CPT plant has been established in Odisha which is under stabilization. Hence, its operational data has not been included in the current estimates of industry-wide energy consumption and emissions.

3.5.3
GHG emissions

The overall emission intensity of pellet production in India is 134 kg CO_2 per tonne of pellet. Scope 1 emissions represent the majority of total emissions, accounting for 82% while Scope 2 emissions contribute 18%.[v]

Among the different technologies employed, the straight Grate technology exhibited the lowest emission intensity at 127 kg CO_2 per tonne of pellet. In contrast, the CPT and Grate-kiln technologies recorded higher emission intensity, at 152 kg CO_2 per tonne of pellets and 178 kg CO_2 per tonne of pellets, respectively. The overall CO_2 emissions from pellet manufacturing industry is estimated as 12.60 Mt in 2023–24. The emissions and energy consumption calculation methodology are provided in Annexure 4. Table 8 presents the average emission intensity of pellet plants in India.

Table 8: Emission intensity of pellet plants

Type of scope	Average emission intensity (kg CO_2/t pellet)
Scope 1	110 (82%)
Scope 2	24 (18%)
Total	134 (100%)

iv SEC includes grinding, green pellet making, and induration.

v Energy used for grinding ore is included under pellet production.

4

Chapter

International Scenario

The international iron ore beneficiation and pellet industry has experienced notable shift due to evolving market dynamics, technological advancements, and environmental regulations. The industry is witnessing a trend towards greater vertical integration, with mining companies investing in beneficiation and pelletizing facilities to ensure supply chain stability and quality control. The shift towards green steel production, utilizing hydrogen-based reduction methods, is poised to further transform the industry, underscoring a broader move towards sustainability.

4.1

Iron ore status

Globally, the estimated iron ore reserves exceed 800 billion tonnes of raw ore, containing over 230 billion tonnes of metallic iron.[11] The total iron ore production of the world was 2,477 Mt in 2021.[12] The largest iron ore producers are Brazil, Australia, China, India, USA, and Russia with Australia and Brazil leading global iron ore exports. Australia is the leading producer of iron ore, which contributed to 37% of the world's production followed by Brazil (16%), China (11%), and India (10%). The iron ore-producing companies are either expanding their existing facilities or planning to start new mines to meet the increasing demand. Globally, it is estimated that around 595 Mt of iron ore mining capacity is under replacement, expansion, restart, ramp up and green field development.[13] Figure 21 shows major iron ore exports and imports globally, in 2021.

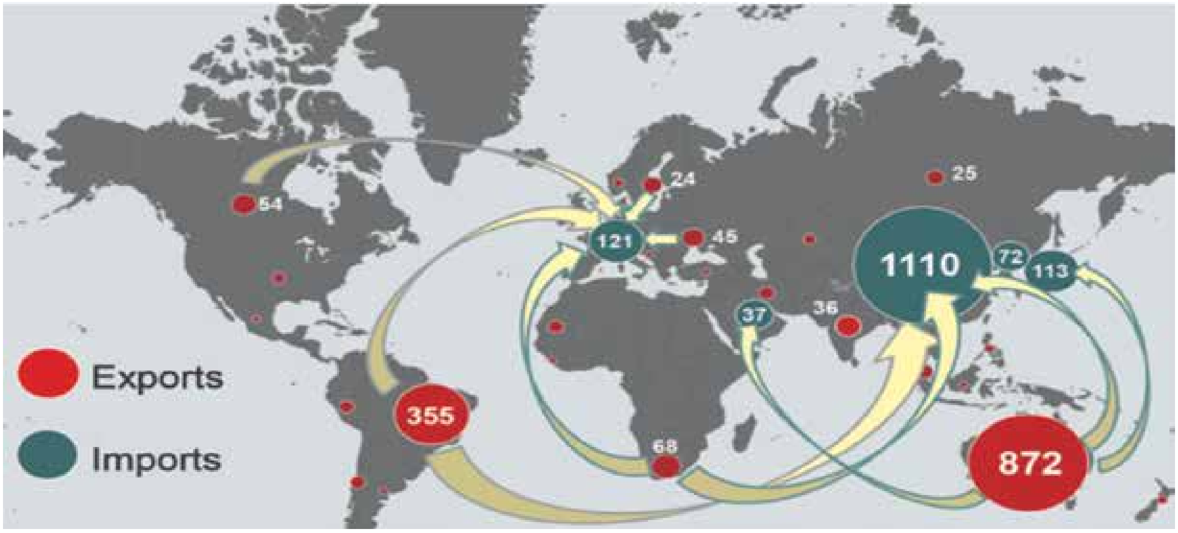


Figure 21: World iron ore export and imports in 2021

Source: Engineering and Mining Journal (E&MJ)[14]

Australia: Australia produced 922 Mt and exported 877 Mt of iron ore in 2021. Five major producers in Australia (BHP Billiton, Rio Tinto, Anglo American, Fortescue, and Vale) produced around 44% of the global iron ore in 2021 and exported about 85% of the iron ore globally (mainly to China and Europe). The ore produced by these companies contains about 62% Fe content.

Brazil: Brazil produced 399 Mt and exported 359 Mt iron ore in 2021. Vale is the largest iron ore-producing company in Brazil. The Fe content of the reserves is in the range of 46.2–66.1%.

China: China produced around 266 Mt of iron in 2021 with adjusted Fe content and 1126 Mt of ore was imported. In 2021, China consumed around 1,368 Mt of iron ore.[15]

4.2 Beneficiation

The quality of iron ore in terms of Fe content has been declining globally for years, which is attributed to the selective depletion of higher-grade reserves, specifically the grade with 67% or higher Fe content, coupled with the expansion of supply to meet the rapidly increasing steel demand. Historically, the average iron content in the ore was above 62% with impurities around 5%. However, by 2016, the average iron content had decreased to 61%, with impurities at 6.5%.[12] Further, smelting of this low-grade iron ore leads to higher costs and environmental emissions. This highlights the challenges and opportunities in the evolving landscape of global iron ore quality. Environmental regulations and technological advancements will shape the industry's future trajectory. Keeping this in mind, the major iron ore mining companies are increasingly adopting beneficiation facilities to enhance ore quality and meet the growing demand for high-grade iron ore. Thus, the beneficiation of ore fines and lean-grade ore presents a promising avenue for optimizing resource utilization and overcoming the challenges posed by dwindling high-grade lump reserves.

4.2.1 International developments in beneficiation technologies

Iron ore beneficiation technologies vary globally, with regions adopting specific methods based on ore characteristics, environmental regulations, energy availability, and economic considerations. Several countries are recognized for their expertise in iron ore beneficiation, driven by technological advancements, infrastructure development, and the availability of high-quality ore deposits. Australia, Brazil, China, and South Africa are notable leaders in this field, each leveraging unique techniques tailored to their ore deposits. Some of the efforts led by them are summarized as follows:

China – Plants utilize wet and dry processing along with magnetic separation to upgrade low-grade ores, maximizing resource use.

Brazil – Units employ advanced methods such as flotation, magnetic separation, and gravity concentration to produce high-quality iron ore.

South Africa – Dense media separation, jigging, and spirals are widely used to enhance ore quality.

These countries showcase the diversity of beneficiation approaches, driven by both technological advancements and the need to meet stringent environmental standards.[15] Further, global companies have developed processes such as Metso Outotec TankCell® and FloatForce® technology for enhanced recovery of ore from mineral concentrate.[vi]

Primetals have also developed a new 'hybrid flotation technology' for processing ultra-fines for enhanced recovery. The Vale Company in Brazil has adopted dry iron ore beneficiation process in which water consumption has reduced by 70% where iron ore containing more than 40% Fe is beneficiated. In addition, the industry is adopting innovative grinding processes to improve the efficiency of beneficiation. Automation and artificial intelligence are also being increasingly integrated into operations to optimize performance and reduce energy consumption.

vi https://www.metso.com/mining/flotation/?creative=686253189116&keyword=flotation%20machine&matchtype=b&network=g&device=c&gad_source=1&gclid=CjwKCAjwl4yyBhAgEiwADSEjeGLqWIXiqLWUvvW4D0nhOqe-iOU52AVL7PQaAYeKRy8vWBBH-vewbhoCDHcQAvD_BwE

Further, there is a growing emphasis on sustainable practices, with many companies investing in technologies that reduce energy consumption and emissions associated with beneficiation processes. This includes more efficient water management systems and use of renewable energy sources. Aligning with net-zero goal, the beneficiation industry is witnessing a shift towards green steel production, where hydrogen is used as a reducing agent instead of carbon intensive methods. This shift is driving changes in beneficiation practices, as the quality of iron ore plays a crucial role in the efficacy of hydrogen-based reduction processes.

4.3

Pellet industry

The global production[15] of pellets was 830 Mt during 2021. The global demand for iron ore pellets, driven by the steel industry's need for high grade raw materials, has surged, particularly in Asia. Sales are expected to increase at a CAGR of 4.3% between 2021 and 2031. There has been a significant increase in the global production and export of iron ore pellets over the past decade. The share of pellet production within the global iron ore market has increased from 19% in 2016 to 23% in 2021. This reflects a growing preference for iron ore pellets compared to other forms of iron ore products[16] (Figure 22). China had the highest pellet production capacity in the world with 220 Mtpa, while Australia, being the largest iron ore producer had the lowest (15 Mtpa) pellet production capacity in 2021.

Also, the pellets' share in charge mix for iron making is the highest in Europe (33%) and the lowest in Asia (11%) (Figure 23). The world's average pellet utilization stands at 22%. Since pelletizing is more energy efficient than any other form of agglomeration, a recent study by EU recommends increasing the ratio of pellets in the ferrous burden to at least 50%, on an average in blast furnaces. This highlights the substantial potential for increasing the use of pellets in the charge mix, globally.

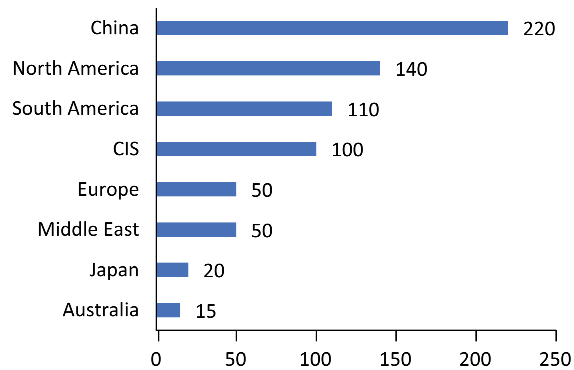


Figure 22: Global pellet production capacity in 2021 (Mtpa)

Source: GSI, MoS, 2024

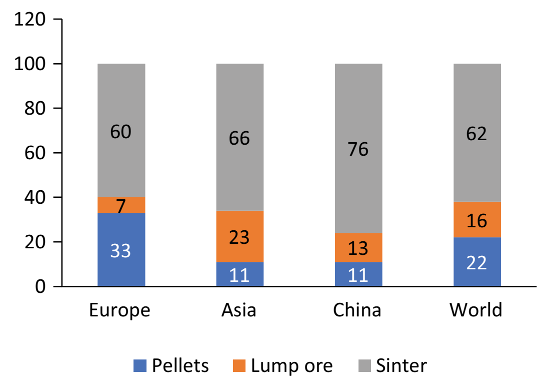


Figure 23: Charge mix in iron making (2021)

Source: GSI, MoS, 2024

Similarly, exports of pellets witnessed an increase, reaching 135 Mt in 2021, about 3.3% increase over the previous year. China was the largest pellet producer in the world with 230 Mt[17] iron ore pellet production in 2022 registering 5% growth year-on-year. These figures indicate a robust performance of the global pellet market in terms of demand and production capacity. The major exporters of iron ore pellets are Brazil, Sweden, Ukraine, Canada, Russia, USA, and India. Brazil is the largest exporter, given its significant iron ore reserves and production capacity.

4.3.1 International developments in pelletization technologies

The pellet industry globally is adopting advanced technologies to meet stringent environmental regulations and demand for high grade ores. Innovations in pelletization techniques such as alternative binders and energy efficient processes are gaining importance to enhance sustainability and competitiveness of the sector. Hydrogen-fired pelletizing furnaces are also being developed by Metso (Brazil) to reduce CO_2 and NO_x emissions. Advanced Grate-kiln and Straight travelling-Grate systems incorporate AI-driven automation and industrial IoT systems for real-time optimization of fuel consumption, temperature profile, and uniformity of products.

5

Chapter

Benefits of Pellets

The utilization of low to medium-grade iron ores in pellet manufacturing offers significant benefits. The ore containing lower iron content is economically unviable for iron making processes. However, beneficiation and pelletization processes help in enhancing the Fe content (and reducing impurities) in low grade ores. These pellets can be used in DRI kilns and blast furnaces (Figure 24).

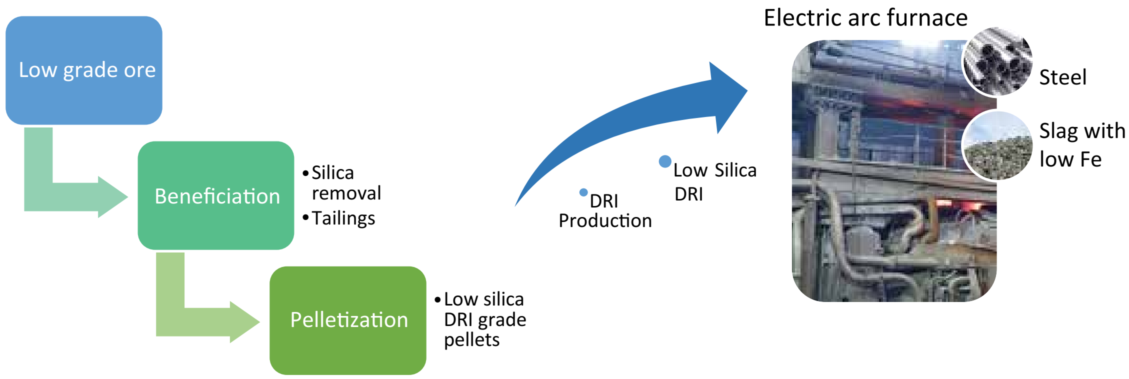


Figure 24: Beneficiation and pelletization in steel value chain

5.1

Pellets use in DRI production

Pellets are preferred raw material for DRI production since they offer better economic and environmental benefits. While lumps and pellets can be used in coal-based DRI kilns, gas-based DRI process would necessitate use of 100% pellets. The benefits[18] of using pellets in DRI production include:

- Uniform size and consistent quality of pellets enhances overall efficiency of DRI production process
- Lower impurities such as sulphur and phosphorus in pellets result in high-quality DRI, which is crucial for producing high-grade steel
- Better structure and porosity of pellets help in improved gas flow during the reduction process, enhances reactivity, resulting in faster reduction rates
- Spherical shape of pellets allows improved heat transfer and minimizes thermal degradation, leading to higher production efficiency
- Pellets allow effective utilization of waste heat in DRI production
- Pellets are more compact and can be transported more efficiently than fines or lump ore, leading to reduced transportation costs
- Use of pellets minimizes the loss of materials in the form of fines during handling and transportation
- Pellets enhance circularity and reduce environmental footprint by utilizing low grade fines
- Pellets, due to their high consistent quality, are well-positioned to meet the growing demand for high-quality steel produced by electric arc furnaces.

5.2

Pellets use in blast furnaces

Pellets offer a range of metallurgical, operational, and environmental benefits over other raw materials such as lumps or sinter in iron making through blast furnace route:

- Use of pellets improves blast furnace productivity and reduces coke consumption. Every 1% increase in Fe content in ore improves[15] blast furnace productivity by about 2% and reduces coke consumption by about 1%.
- By using pellets, steel makers have a wider choice of raw materials without compromising the quality of the final product.
- Utilization of low to medium-grade ores in pellet-making enhances the resource base for iron ore supply, reducing dependence on high-grade ore reserves and ore lumps. This diversification of feedstock sources enhances supply security and mitigates the risks associated with fluctuations in ore quality and availability.
- Pellets have a superior tumbling index and low abrasion index compared to lumps, making them viable substitutes in blast furnaces[19].
- Pellets have spherical shape, uniform size ranging from 8 mm to 16 mm, and high porosity (25–30%) compared to lump and sinter to ensure optimal bed permeability, enhance blast furnace efficiency, and reduce coke consumption.
- Pellet production is less energy and emission intensive compared to sinter production. Typically, sintering process emits 216 kg CO_2 per tonne of sinter[20] which is about 38% higher than pellets (134 kg CO_2/t of pellet).
- Pelletization reduces gangue elements such as silica and alumina in iron ore which results in reduced energy requirement for heating and processing in iron making. The reduction in energy consumption lowers production costs and GHG emissions, making pellet production more environment-friendly compared to conventional iron ore processing methods like sinter making.

5.3

Comparison of ore agglomeration techniques

Iron ore can be used in various agglomerated forms to produce iron. Some of the prominent agglomeration techniques are pelletization, sintering, roller press briquetting, vibro press briquetting and direct processing of fines in melt. A comparative analysis[21] of the existing techniques for agglomeration of iron ore is shown in Table 9.

Table 9: Comparative analysis of iron ore agglomeration technologies

Agglomeration Technology	Advantages	Disadvantages
Pelletizing	• High strength of final pellets • Ease of transportation • High surface area to volume ratio leading to better reducibility	• Low strength of green pellets • Possibility of swelling in subsequent processes
Sintering	• Large production capacity • Absence of swelling during subsequent reduction	• Not suitable for small production capacity • High energy consumption and carbon footprint
Roller press briquetting	• Technical simplicity • Low cost of equipment • Possibility of transportation	• Binders' requirement is more than pellets • Possibility of swelling during subsequent reduction
Briquetting (vibro pressing)	• Less amount of binders requirement as compared to roller press briquetting • Minor swelling during subsequent reduction	• Green briquettes can't be transported directly
Direct processing of fines in melt	• High process versatility and flexibility (in comparison with blast furnace) • Use of non-coking coal	• Low productivity of the plants • Increased wear of lining • High carbon footprint

Source: Kapelyushin Yu. E., 2023, Comparative review on the technologies of briquetting, sintering, pelletizing and direct use of fines in processing of ore and technogenic materials

Thus, pelletization offers several advantages over other iron ore agglomeration technologies in iron making process. Pellets provide more favourable properties that enhance the efficiency and effectiveness of iron production process. One of the key benefits of pellets is their lower energy consumption, contributing to a more sustainable production process. Additionally, pellets can be produced in smaller quantities compared to other agglomeration processes like sintering, which typically require larger volumes and are less flexible in production scale.

5.4 Emissions abatement potential with enhanced pellet share

5.4.1 Pellet utilization in blast furnaces

Currently, sinter represents a major portion of the burden mix, up to 60–70% in blast furnaces in India, with lumps accounting for 20–30% and the balance (about 10–20%) is pellets. The lower share of pellets may be attributed to factors such as cost and availability.

The sinter making process is energy intensive and utilizes fossil fuels—coal/coke and results in significant CO_2 emissions. The average emission intensity[22] of sinter making in India is 216 kg CO_2 per tonne of sinter. Pellets have the potential to replace sinter in the charge mix for blast furnaces as pellets emit 38% less CO_2 compared to sinter.

5.4.2

Scenario analysis of pellet share in burden-mix

A detailed scenario analysis of CO_2 emissions for different burden mix in blast furnace route shows that increasing the pellets share can lead to significant reduction in CO_2 emissions (Table 10). The sensitivity analysis of replacing sinter with increased share of pellets in the burden mix shows significant CO_2 reduction in 2030. The base case for 2024 shows CO_2 emissions of 20 Mt with a burden mix of 25% lump, 60% sinter, and 15% pellets. By 2030, under the BAU scenario with the same burden mix, it is estimated that the CO_2 emissions will rise to about 35 Mt.

Table 10: Sensitivity analysis for increasing pellets in burden mix in blast furnace route

	Lump (% share)	Sinter (% share)	Pellets (% share)	Sinter requirement (Mt)	Pellets requirement (Mt)	Total CO_2 emissions in agglomeration processes (Mt)	Emission reduction (Mt CO_2)
2024*	25	60	15	79	20	19.78	-
BAU- 2030	25	60	15	141	35	35.27	-
Scenario: 1 (2030)	20	50	30	118	71	34.92	0.35
Scenario: 2 (2030)	20	40	40	94	94	32.99	2.29
Scenario: 3 (2030)	20	30	50	71	118	31.05	4.22

**Based on interaction with stakeholders*

However, three alternative scenarios for 2030 shows the potential for CO_2 reduction by increasing the share of pellets. In scenario-1, with a burden mix of 30% pellet, 20% lump, and 50% sinter, the CO_2 emissions would decrease marginally, resulting in an emission reduction of about 0.35 Mt vis-à-vis BAU scenario. In Scenario-2, with a mix of 40% pellets, 20% lump, and 40% sinter, CO_2 emissions reduce to about 33 Mt, leading to an emission reduction of about 2.29 Mt.

Significant reduction in emissions may be observed in Scenario-3, with a burden mix of 50% pellets, 20% lump, and 30% sinter. This scenario results in CO_2 emissions of approximately 31 Mt and achieves emission reduction of around 4.22 Mt compared to the BAU scenario.

As an illustration, shifting to a higher pellet share (50%) against business-as-usual scenario (BAU) can help reducing emissions up to 4.22 Mt CO_2 in 2030. Thus, by optimizing burden mix, the iron and steel industry can reduce the environmental impacts and enhance economic benefits. These findings highlight the importance of increasing the share of pellets in iron production to achieve substantial CO_2 reductions by 2030 (Figure 25).

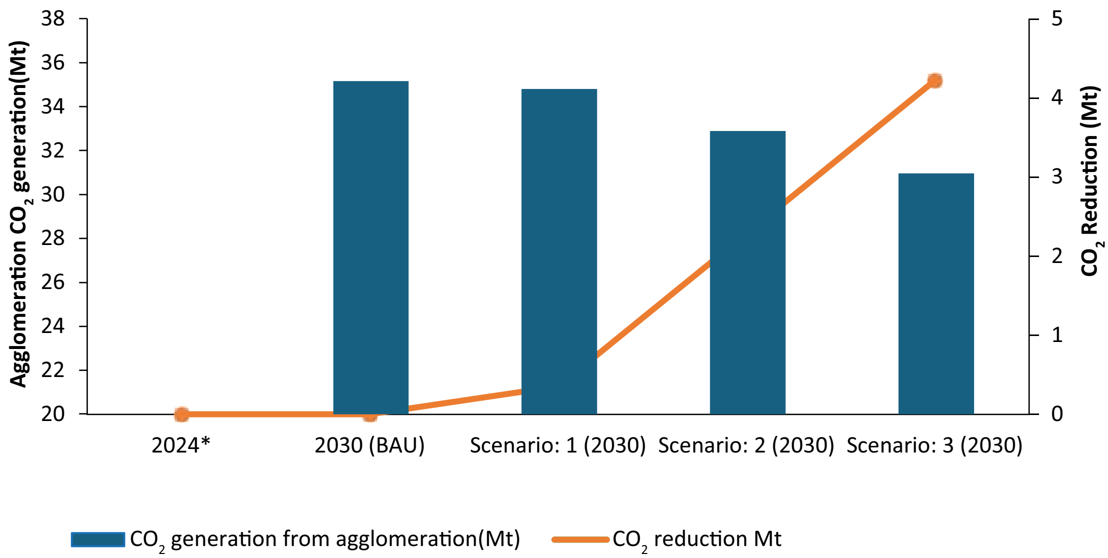


Figure 25: Emission reductions with varying pellet share

5.4.3

DRI route

It is reported in several studies that pellet utilization results in significant productivity improvement. Detailed studies may be carried out to establish energy and CO_2 reduction potential using pellets in coal based DRI production.

6

Chapter

Tailings Management

Iron ore tailings are the left-over materials from the processing of mined iron ore. These tailings consist of ground rock, unrecoverable and uneconomic metals, chemicals, organic matter, and effluents from the process used to extract the desired products from the ore. Most of the tailings are stored in ponds within the beneficiation plants in India, and only a fraction is used in construction sector. Tailings are generally -100 mesh (<0.15 mm) waste particles, which is approximately 20–25% of the feed material. For beneficiating each tonne iron ore of 40–45% Fe to 58% Fe (3% enrichment), about 0.25 tonne tailing is generated having about Fe content of 45%. Figure 26 shows excavator organizing an iron ore tailings pond in one of the beneficiation units in eastern India.

Figure 26: Iron ore tailings pond in a beneficiation plant

The potential applications of tailings generated in beneficiation process are provided below.

6.1 Cement production

Tailings can be used for clinker production in cement industry. The cement produced using iron ore tailings has better properties such as better acid resistance[23] than ordinary cements. The Portland clinker produced using tailings has better grindability, and the hydration heat of Portland cement is lower.[24] The availability and low cost of iron ore tailings make it attractive to replace clay as alumina-silicate raw material for producing Portland cement clinker. A beneficiation unit in Odisha is marketing tailings with 48% iron content to cement plants.[vii]

6.2 Concrete production

Tailings can be considered a partial or complete replacement for natural aggregates in concrete production. After segregation of tailings, both fine and coarse aggregates can be utilized for concrete making. The compressive strength of concrete with iron ore tailings is 12% higher than that of concrete with conventional aggregates. Further, concrete with tailings aggregates has lower corrosion and acid attack due to the high pH value of the resulting solution.[25]

vii Facts shared during the visits to various units as part of study.

6.3

Pavement material

Soil–cement mixtures with iron ore tailings can be an excellent alternative for pavement material. The structures with the addition of 10% and 20% iron ore tailings had about the same results as soil–cement structures with no addition of iron ore tailings. Moreover, the use of iron ore tailings in pavement layers can also contribute to new disposal methods, reduce environmental impacts, and lower the costs related to pavement construction.[26]

6.4

Iron recovery

Iron ore tailings can be processed to concentrate iron. The process involves primary grinding followed by low-intensity magnetic separation and subsequent high-intensity magnetic separation. Apart from the above applications, tailings can also be used to produce iron powder using a novel technology called 'reduction roasting' (Box 3).

Box 3: Reduction roasting

To increase iron content, tailings are subjected to primary grinding followed by low-intensity magnetic separation and subsequent high-intensity magnetic separation. An iron grade of 36.58 weight% and a total iron recovery of 83.86 weight% can be obtained when 50 weight% of the particles was smaller than 0.038 mm, and the magnetic separation was conducted using a low magnetic field intensity of 0.11 Tesla (T) and a high magnetic induction of 0.8 T.

The bitumite ratio, roasting temperature, roasting time, lime ratio, sodium carbonate ratio, and particle size of the roasted product are the six major factors that influence iron recovery.

The optimal reduction conditions include roasting temperature of 1250°C, roasting time of 50 min, and a mixing ratio of 17.5:7.5:12.5:100 for bitumite/ sodium carbonate/ lime/PC, respectively. Under these conditions, iron content of the reduced iron powder will be 92.30% (by weight) and the iron recovery rate will be 93.96% (by weight).

Source: Tang, C.; Li, K.; Ni, W.; Fan, D. Recovering Iron from Iron Ore Tailings and Preparing Concrete composite Admixtures. Minerals 2019, 9, 232. https://doi.org/10.3390/min9040232 (https://www.mdpi.com/2075-163X/9/4/232)

7

Chapter

Challenges and Constraints

India's beneficiation and pellet industry has experienced significant growth in recent years. However, despite this progress, the sector continues to face several challenges that must be addressed to ensure its sustainable development, as outlined below:

7.1
Beneficiation

7.1.1
Complex mineralogy of Indian ore

Indian iron ore deposits have significant variation in their mineralogy, with a mix of iron-bearing minerals such as hematite, magnetite, goethite, and siderite. In addition to iron content, ores differ in terms of hardness, alumina, silica, sulphur, phosphorus, and other impurities. This mineralogical diversity poses a major challenge, as each mineral type often requires specific beneficiation techniques tailored to its unique physical and chemical characteristics. The complexity of processing such diverse ore types increases the difficulty of achieving uniform beneficiation outcomes across different mines, which makes it a significant challenge for the Indian iron ore industry.

7.1.2
Particle size

The particle size distribution of iron ore affects the efficiency of beneficiation processes. Fine-grained ores are often more challenging to process as they would require finer grinding which would lead to an increase in energy consumption and processing costs.

7.1.3
Capital cost and economics

Beneficiation is a capital-intensive process that requires substantial investments in infrastructure, equipment, and technology. The high capital requirement is a barrier for smaller players in the industry, to adopt advanced beneficiation technologies and scale operations efficiently. The capital expenditure (capex), which influences the cost of beneficiation, is a critical factor in determining the overall economics.

7.1.4
Water consumption

The beneficiation industry in India is dependent on wet process. Beneficiation process such as flotation and wet magnetic separation would require significant quantities of water. Despite zero-liquid discharge and complete recycling of water, ensuring an adequate water supply for beneficiation operations can be challenging, especially in arid regions or areas facing water scarcity.

7.1.5

Tailings management

Effective tailings management is essential to minimize environmental impacts and ensure regulatory compliance. The beneficiation industry does not have enough land space to dispose of the tailings generated during the process. Wet tailing storage in the tailings dam has a risk of dam failure. The dry tailing disposal method, through a pressure filter, requires substantial capital and operating costs.

7.1.6

Location and logistics

The beneficiation plants are often located away from mining areas leading to increased transportation costs. Transportation of beneficiated ore poses issues such as high moisture content and environmental issues.

7.1.7

Policy support

At present, there are no suitable policies to promote beneficiation of low and medium grades of iron ores for steel making.

7.1.8

R&D efforts

Research and development (R&D) efforts in iron ore beneficiation processes and technologies are limited in India. The absence of government incentives and international collaborative efforts for R&D has hindered progress in the development of cost-effective and sustainable beneficiation technologies.

7.2

Pelletization

7.2.1

Particle size distribution

Optimal particle size distribution of crushed ore fines is important for pelletization. More fines lead to difficulties in pelletization and lower pellet quality whereas coarse particles lead to formation of uneven pellets.

7.2.2

Blending and homogenization

Iron ore from different sources can vary in chemical composition and physical properties. Ensuring consistent quality and properties of pellets requires effective blending and homogenization of raw materials.

7.2.3

Binders and additives

Binders and additives are used to improve the pelletization process by enhancing pellet strength, reducing dust generation, and improving pellet quality although selecting the appropriate binder and additive combination can be challenging due to their impact on pellet properties and process efficiency.

7.2.4

Market demand and quality

Meeting market demand for pellets requires consistent production of high-quality pellets. Variations in pellet quality can affect market acceptance and pricing, posing challenges for pellet producers.

7.2.5

Policy support

Pellets offer lower carbon footprint compared to sinter. However, the lack of supportive policies to encourage pellet utilization in blast furnaces remains a significant barrier to their wider adoption.

8

Chapter

Decarbonization Levers

The beneficiation and pellet production are low emission processes; however, it is important to decarbonize these processes to reach the national goal of net-zero by 2070. The decarbonization pathways for these industries are discussed below.

8.1 Beneficiation industry

Iron ore beneficiation primarily relies on electricity as its main energy source, with no thermal energy consumption. Improving energy efficiency and optimizing operational processes are critical to reducing both energy use and associated greenhouse gas (GHG) emissions. Incorporating RE electricity into beneficiation operations can further advance decarbonization goals. Key decarbonization levers for the beneficiation segment include: (1) enhancing energy efficiency and (2) transitioning to RE electricity sources.

8.1.1 Energy efficiency

Energy efficiency (EE) is a key decarbonization strategy for the beneficiation industry, with considerable potential for improvements across various operations—including grinding, conveying, screening, and utility systems. Potential EE measures include:

(i) Stirred media mills

In India, tumbling ball mills are commonly used for grinding, accounting for 2/3rd of energy consumption in beneficiation process. Stirred media mills is an energy efficient technology, which consumes 20–45% less energy[27,28] compared to the conventional tumbling mill[27] (Figure 27). Other advantages[29] of stirred media mills include low material loss, less accumulation, better heat transfer, and easier handling of toxic gases. Further, stirred mills do not require air cleaning system. The technology readiness level (TRL) of the stirred media mills is high (9–10) and are commercially available.

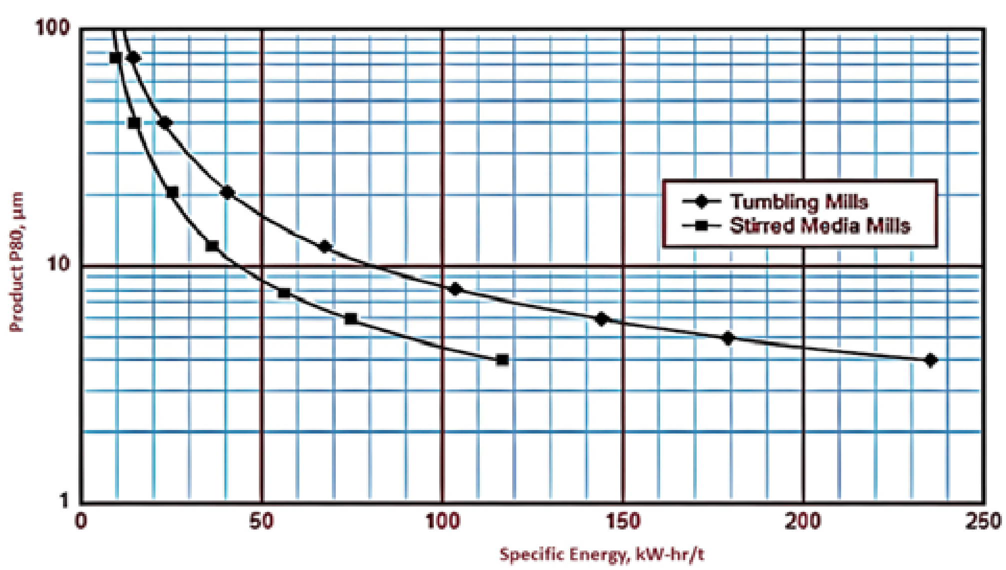


Figure 27: Comparison of energy consumption of Stirred Media Mills and Tumbling Mills

Source: Kumar A., 2023, Energy-Efficient Advanced Ultrafine Grinding of Particles Using Stirred Mills—A review

(ii) Switch to wet grinding

Wet grinding of iron ore has advantages over dry grinding such as lower energy consumption[30] (30–50%) to generate the same distribution of particle sizes and higher production rate. In wet griding, a consistent mill feed can be transferred faster. Dry grinding, on the other hand, takes longer time for grinding and has less medium wear.

(iii) Energy efficient auxiliary systems

Integration of energy-efficient technologies such as energy-efficient motors, variable frequency drives (VFDs), energy-efficient pumps, compressors, automation of operations, and Energy Management Systems (EMS) in beneficiation process can lead to significant improvements in energy efficiency. For instance, replacing standard motors with energy efficient motors (IE4/5) can result in energy savings of 5–10%, depending on the type of application and rating of the motor. Energy efficient pumps and compressors can achieve energy savings up to 30% compared to conventional equipment. Automation and EMS enable real-time monitoring, optimization of energy-intensive processes, identify inefficiencies, implement corrective actions, and thus contribute to energy savings up to 15%.

(iv) Slurry pipelines for ore transportation

Slurry transportation of ore/beneficiated ore through pipelines is energy efficient and cost effective compared to conventional transportation methods like road or rail. The process involves crushing and grinding the ore into a fine slurry with water, typically achieving a solids concentration of 65–70%. The slurry will be pumped through pipelines for longer distances from the mine site or beneficiation plant to the pelletization plant or port. Water used for making the slurry can be recycled. Through slurry pipelines, ore can be transported round the clock in any weather, and it overcomes the limitations of terrain conditions often faced by road or rail.

Table 11 presents a comparative analysis of emissions associated with different modes of iron ore transportation. As can be observed, slurry pipeline has the lowest emission intensity. Net-zero emissions in iron ore transportation can be achieved using RE electricity in slurry pipeline systems.

Table 11: Emission intensity of different modes of iron ore transportation

Mode of transport	Emission intensity (kg CO_2e/t)
Slurry pipeline	0.010–0.017[$]
Road (trucks)	0.204
Rail	0.017

Source: TERI analysis

$ – per tonne – dry basis

The existing and under construction slurry pipelines in the states of Odisha and Andhra Pradesh are shown in Figure 28.

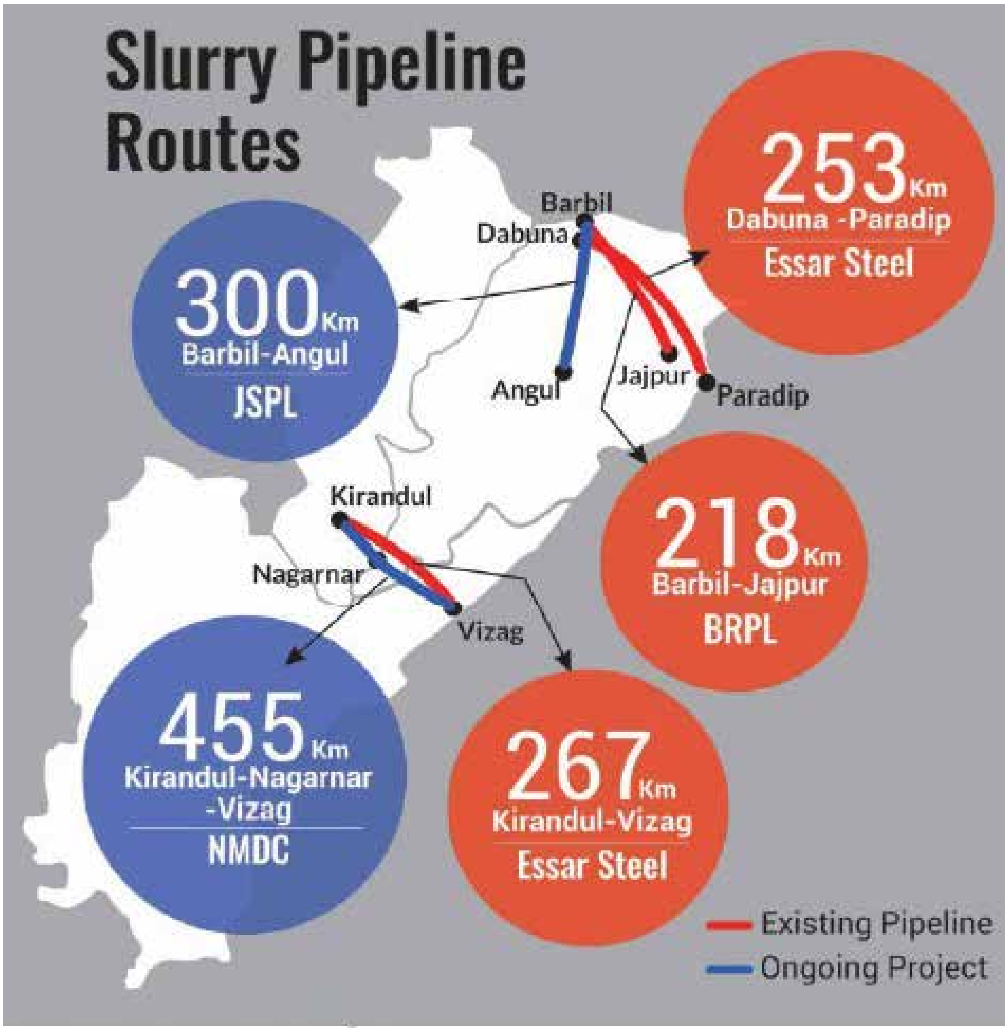


Figure 28: Existing and under construction slurry pipelines in Odisha and Andhra Pradesh

Image source: Study on transportation of iron ore over Indian Railways. Report no. TF-101, July 2021. https://rdso.indianrailways.gov.in/uploads/TFC-101-IronOre_Report.pdf

Exploring shared infrastructure or cooperative models for iron ore slurry transportation can facilitate the development of cost-effective and efficient logistics systems. Such collaborative approaches can optimize resource utilization, lower capital and operational costs, and promote wider adoption of sustainable transport solutions.

8.1.2

Switch to RE electricity

At present, stand-alone pelletization plants primarily rely on grid electricity; while integrated steel plants use a mix of grid and captive power for beneficiation operations. Captive power generated from coal and other fossil fuels can be progressively replaced with RE electricity, e.g., rooftop, ground-mounted, or floating solar systems, and wind energy systems. However, in cases where space constraints limit the feasibility of on-site installation of RE systems, green power can be procured through wheeling arrangements with RE aggregators providing round-the-clock supply. Solar and wind technologies are commercially mature, widely available, and cost-competitive, making them viable for decarbonizing beneficiation plants.

8.3.1
Status of decarbonization technologies for beneficiation

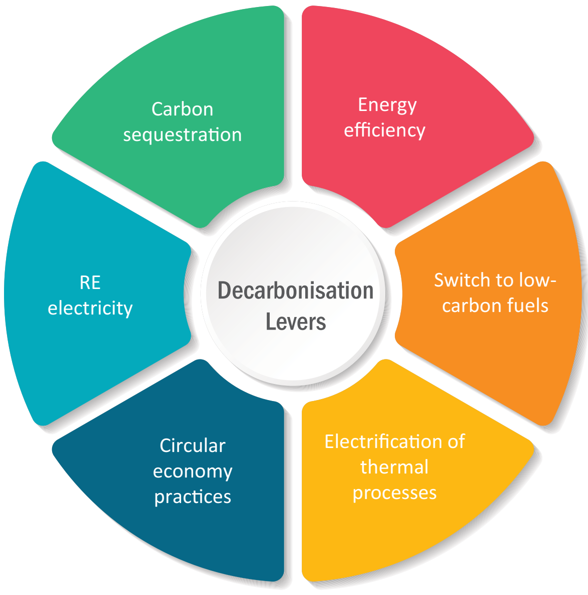
The status of decarbonization technologies for beneficiation industry is summarized in Table 12.

Table 12: Status of decarbonization technologies for beneficiation

Decarbonization technology	Commercially available	Commercially available but not at scale
Energy efficiency	Energy-efficient technologies in process and utilities Automation Wet Grinding	Stirred media mills Slurry pipelines
Switch to renewable electricity	Solar/wind-based captive power plants	Round-the-clock RE power

8.2
Pellet industry

The decarbonisation levers for pellet industry include (1) Energy efficiency, (2) Switch to low-carbon fuels, (3) Electrification of thermal processes, (4) Circular economy practices, (5) RE electricity, and (6) Carbon sequestration.



8.2.1
Energy efficiency

Pelletization is a thermal energy intensive process, accounting for 90% of the total energy consumption. The induration furnace is the most energy intensive process. There is a significant potential for improving energy efficiency in both thermal energy and electrical energy systems. While furnace automation and optimization can reduce thermal energy consumption[31] by about 10%, upgrading to energy-efficient motors, fans, air compressors, pumps, and conveyors, combined with automation, can lead to a reduction of 5–10% of electricity consumption.

8.2.2

Switch to low-carbon fuels

Transition fuels

A wide range of fossil fuels (coal, coke, furnace oil, etc.) are used in induration furnace for pelletization. Cleaner fuels like natural gas and coal bed methane (CBM) can be adopted as transition fuels until low carbon fuels such as green hydrogen, biomass/biochar are technically proven, economically viable, and the ecosystem is developed. The cost of low-carbon fuels per tonne of pellet and their emission intensities are shown in Figure 29. There is an emission reduction potential of about 30% with cleaner fuels like natural gas and CBM while green hydrogen can result in net-zero emissions. The energy cost of pellet production using green hydrogen, at a price of USD 4–5 per kg, is four times costlier than coal currently used in the industry.

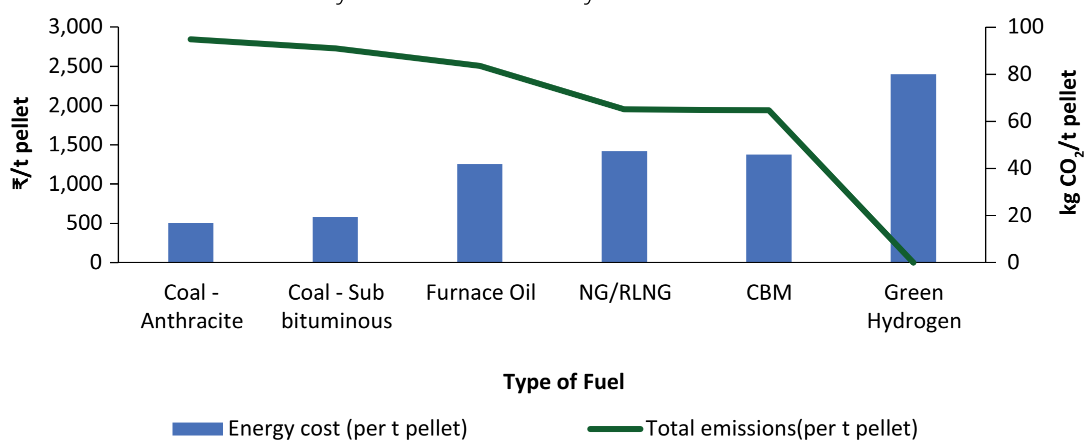


Figure 29: Emission intensity of induration furnace operation in pellet production

Source: Industry data analysis, TERI (2024)

The availability of natural gas or coal bed methane (CBM) near pellet producing locations of India is an advantage. Natural gas pipeline network is being constructed by GAIL near the pellet industry in various states but the supply of gas lines to the doorstep of the plants will be critical factor in adoption of these fuels by the industry. Aggregation of demand for natural gas can be crucial for assured supply of gas at competitive price.

Biomass/biochar

Ligno-cellulosic biomass is the most suitable type of biomass as a source of thermal energy. It mostly comprises energy crops, forestry waste, and agricultural waste, which are not used as animal feed. Bamboo is suitable to produce biochar[32] and is grown in around 14 million hectares. Bamboo's cost-effectiveness, rapid growth, impressive biomass yield, and properties like coal make it an ideal candidate for sustainable biochar production. Thus, biomass can be utilized in pelletization process as low carbon fuel by replacing the fossil fuels. The required fuel properties are summarized in Table 13.

Table 13: Properties of fuel required for pellet manufacturing process

	Size (mm)	Volatile Matter (%)	Ash content (%)	Sulphur (%)
Fuel	<25 mm	10–20 %	<14 %	<5 %

Source: Industry experts

Comparative characteristics of coal with other bio-products is provided in Annexure 5. Biomass cannot be utilized in its raw form for industrial purposes as it requires pre-treatment for optimal use. Biomass can be converted into useful materials such as charcoals, semi-charcoals, or torrefied substances through pyrolysis which are suitable for pellet industry due to their enhanced value. The benefits of processed biomass materials include: (i) reduced moisture absorption potential, (ii) reduced oxygen level and higher carbon content, (iii) higher calorific value, (iv) boosted apparent density, (v) better grindability (essential for mixing with ore), and (vi) better crushability (essential for embedding). Assuming coke breeze/coal replacement at 20–25% without degrading properties of pellets, a practicable maximum level of biochar demand in pellet manufacturing is estimated as 0.23 Mtpa.[15] To reduce GHG emissions from coal-based pellet plants, biomass-based pellets/torrefied pellets may be used along with coal through co-firing which is a technology recognized by the UNFCCC to mitigate carbon emission.

Municipal solid wastes

The use of municipal solid wastes (MSWs) and other industrial wastes like organic waste, textiles, paper, tyres, etc., could be explored in pellet-making plants. These could be sourced from nearby areas which would help in the avoidance of direct carbon emissions from fossil fuels.

8.2.3 Electrification of thermal processes

Induration furnaces in the pelletization process consume substantial amounts of fossil fuels to meet thermal energy demands. Electrifying these thermal processes by replacing fossil fuel–based systems with electric alternatives such as electric furnaces or induction heating presents a promising decarbonization pathway. When powered by renewable energy sources like wind or solar, this approach can significantly reduce carbon emissions compared to conventional fossil fuel–driven furnaces

Electrification offers long-term benefits such as reduced operating costs, enhanced energy efficiency, and a lower environmental footprint. However, the initial capital investment can be significant, as many electrification technologies are still in the development phase and have yet to achieve full commercial scalability. The electricity consumption[viii] for thermal energy requirement is estimated as 400 kWh per tonne of pellets. Considering a 10% electrification of pellet production capacity, the total electricity requirement is estimated as 5.7 billion kWh and 6.4 billion kWh in two growth scenarios of pellet production (6% and 8% CAGR), respectively. The electricity requirement for different electrification rates of 10%, 20%, and 50% of pellet production are shown in Table 14. This electricity requirement will be over and above the electrical energy requirement in existing conditions.

viii The estimate is based on 80% electrical to thermal efficiency and is limited to induration process.

Table 14: Electricity requirement for thermal energy replacement in 2030–31

Pellet production growth rate, CAGR (%)	6%	8%
Pellet production by 2030–31 (Mtpa)	142	161
Thermal energy replacement by electrical heating (pellet production % of total)	Electricity requirement (billion kWh)	
10%	5.7	6.4
20%	11.4	12.9
50%	28.4	32.2

Source: TERI analysis

Currently, the cost of electrical heating is approximately 5 times higher than coal. However, this cost is likely to decrease as the share of renewable energy in the energy-mix increases. As renewable sources of electricity become more prevalent and accessible, they will provide a more competitive and cost-effective alternative to traditional fossil fuels thereby, enhancing the overall economic feasibility of electrical heating solutions. The current TRL level[33] of electrical heating in pelletization process is 3–5 and needs to be studied in Indian conditions for further development of the technology. Additionally, advancements in electric heating technologies and the availability of cheaper renewable energy will make this option viable for sustainable iron ore pellet production.

8.2.4 Circular economy practices

Mill scale is generated during various metal-forming operations and contains oxides of iron mainly in the form of Fe_2O_3 and Fe_3O_4. Rolling mills are a major source of mill scale in steel plants. The usage of mill scale is a proven method to make pellets with the TRL levels being 8–9. Mill scale can be added in minor quantities in fluxed pellets (both acidic and basic). The pellets using mill scale up to 15% have improved properties. Moreover, the induration temperature of hematite-based pellets can be reduced up to 1250–1275 ^{0}C (reduction of about 75 ^{0}C). Further, mill scale has the potential to eliminate the need for fluxing in hematite ore-based pellets to be used for blast furnaces. It also helps in improving pellet strength in acidic pellets than basic pellets.[34] The consistent and sufficient availability of mill scale commercially is a constraint for using it in pellet manufacturing industry.

8.2.5 RE electricity

Pelletization plants have begun to install and integrate renewable energy projects (such as solar power) to partially replace grid electricity. This transition will not only help reduce dependency on conventional energy sources but also contribute to lowering operational costs and enhancing sustainability in the pellet production process. By utilizing renewable energy sources, pelletization process can significantly reduce its carbon footprint compared to traditional fossil fuel-based electricity generation.

Recent developments on round-the-clock (RTC) availability of renewable energy using battery energy storage systems (BESS), pumped hydro storage, etc., will significantly help to decarbonize electrical energy in pellet manufacturing. Although the government is taking initiatives to decarbonize the grid rapidly, pellet manufacturing units can switch their captive generation (partially or fully) to green electricity. The plants that are dependent on grid electricity can purchase green power from DISCOM or RE power companies. Wheeling renewable electricity from captive power plants at remote location/s could be another option. With proven technology and techno-economic feasibility, green electricity will help decarbonize the pellet manufacturing process.

Table 15 provides the break-up of landed cost of an intra-state RE project under the captive and third-party modes and compares it to the tariff of green power sourced from the discom for the steel rich states: Odisha, Jharkhand, Chhattisgarh, Karnataka, Maharashtra, Gujarat, West Bengal, and Andhra Pradesh. It can be noted that the RE cost (through open access) for captive plants is lowest in Chhattisgarh, while landed cost of power through DISCOMs is lowest in Odisha followed by Jharkhand.

Table 15: Landed cost for intrastate RE open access

Tariffs in ₹/kWh	Odisha	Jharkhand	Chhattisgarh	Karnataka	Maharashtra	Gujarat	West Bengal	Andhra Pradesh
Assumed ex-bus	2.75	2.59	2.63	2.59	2.50	2.51	2.77	2.71
Transmission C&L	1.53	0.31	0.08	0.08	0.93	0.97	1.01	1.33
Wheeling C&L	1.17	0.95	0.17	0.08	0.89	0.59	0.85	1.19
Captive RE OA	5.45	3.85	2.88	2.76	4.33	4.07	4.63	5.23
CS surcharge	0.42	1.41	0.45	1.95	1.70	1.50	1.13	1.76
Additional surcharge	-	-	-	-	1.32	0.31	-	-
Third-party RE OA	5.87	5.26	3.33	4.71	7.35	5.88	5.76	6.99
Charges for banking 30% of the energy	2.46	0.15	0.02	0.06	0.03	0.79	2.03	0.08
DISCOM(s) + green tariff	6.51	6.80	7.97	8.17	8.63	6.86	8.02	7.44

Source: GSI, MoS 2024

(ex-bus – net electrical power and energy output of a generating station; C&L – charges and losses; OA- open access; CS – cross subsidy)

8.2.6

Carbon sequestration

Carbon sequestration through plantation holds significant potential for the iron ore pellet industry in India to mitigate its carbon footprint. Implementing large-scale afforestation projects can utilize high carbon-sequestering species such as bamboo, which can absorb up to 400 tonnes of CO_2 per hectare over its lifecycle.[35] Fast-growing trees like Eucalyptus and Poplar can sequester around 10-20 tonnes of CO_2 per hectare annually. Integrating these plantations in mining and processing areas can effectively capture CO_2, enhance biodiversity, and improve ecosystem health.

Agroforestry practices, which combine tree planting with agriculture, offer additional benefits, including soil conservation and increased productivity. Collaborating with local communities and environmental organizations ensures the success and sustainability of these initiatives. By leveraging carbon sequestration capabilities of these species, the iron ore pellet industry in India can contribute to national and global climate goals, improve environmental sustainability, and strengthen community relations.

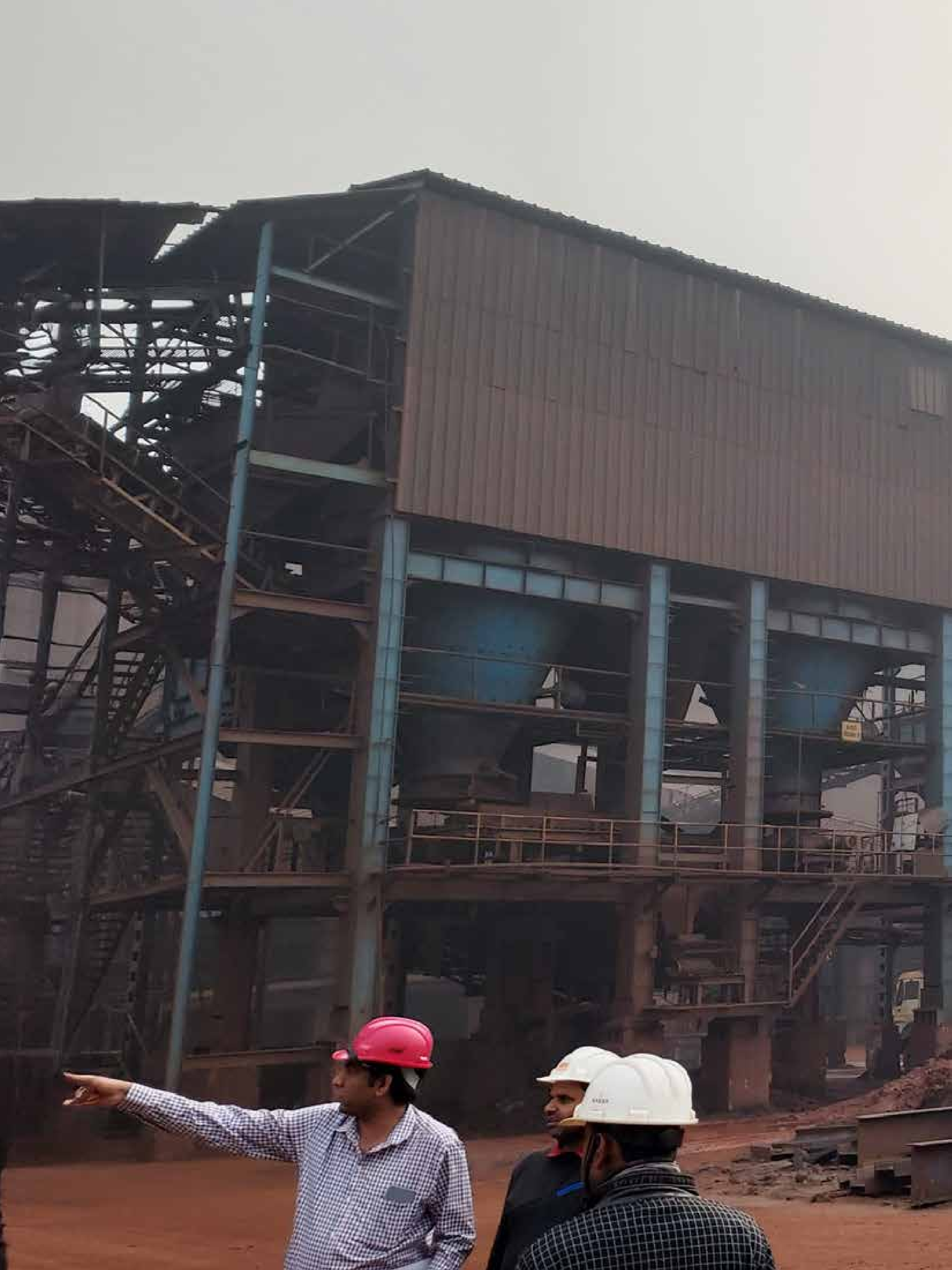
8.2.7 Status of decarbonization technologies for pellet industry

The decarbonization technologies are grouped mainly into three categories: (i) commercially available, (ii) commercially available but not at scale, and (iii) not commercially available. Commercially available technologies include those having high TRL levels and are financially viable. Commercially available technologies, but not at scale technologies are those technologies which are technically mature but the adoption level is low due to financial unviability, availability unreadiness or any other reason. Not yet commercially available technologies need more research to make them commercially viable. The status of decarbonization technologies for pellet industry is summarized in Table 16. A list of technology suppliers for various equipment is provided in Annexure 6.

Table 16: Status of decarbonization technologies in pellet industry

Intervention area	Commercially available technologies	Commercially available technologies but not at scale	Not yet commercially available
Energy efficiency	• Process automation • Optimization of furnace operation • Energy efficient technologies for electrical auxiliaries	–	-
Switch to low carbon Fuels	-	Natural gas/ CBM as transition fuels	• Pilots for green hydrogen in induration furnace • Pilots for MSWs and industrial wastes
Electrification of thermal processes	-	-	Pilots for electrification of induration furnace
Switch to RE electricity	RE-based captive plants	Round-the-clock (RTC) renewable power through energy storage systems	-

Intervention area	Commercially available technologies	Commercially available technologies but not at scale	Not yet commercially available
Use of mill scale	-	Consistent availability at scale	-
Use of biomass/ biochar	-	Pilots for biomass/ biochar in induration furnace	



9 Chapter

Action Plan

The iron ore beneficiation and pellet manufacturing industries play an important role in the steel supply chain. It is imperative that the sector contributes to overall decarbonization of iron and steel sector, mitigate climate change, and ensure steel sustainable production. The decarbonization levers for the beneficiation and pellet making industry are summarized in Figure 30.

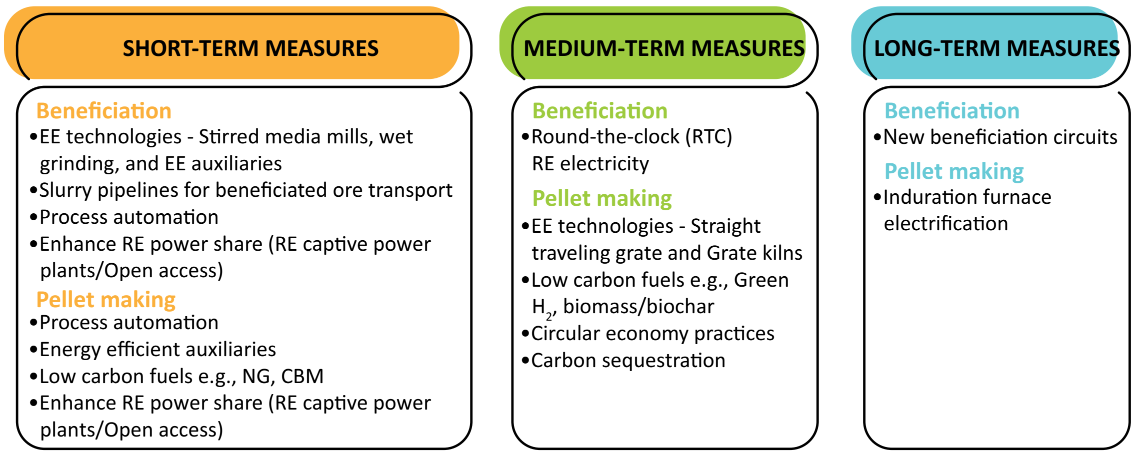


Figure 30: Decarbonization levers for beneficiation and pellet industry

The action plan outlines a comprehensive set of strategies and priority actions necessary for driving the decarbonization of the beneficiation and pellet industries. It identifies the specific roles and responsibilities of key stakeholders including industry players, government bodies, research and development institutions, and other relevant actors. These coordinated efforts aim to advance adoption of low-carbon technologies, improve process efficiencies, and support policy and investment frameworks essential for sustainable transformation of steel sector. The strategies and action plan for are elaborated in Table 17.

Table 17: Key strategies and actions for decarbonizing beneficiation and pellet industries

	Industry	Government	RD&D	Others
Beneficiation	• Conduct regular energy audits to identify energy efficiency projects and implement within a defined timeframe, aimed at reducing overall energy consumption and emissions. • Prioritize installation of solar rooftop or ground-mounted solar power projects, and/or other renewable energy (RE) projects, to reduce Scope 2 emissions. • Additionally, RE electricity procurement through open access should be explored to further increase the share of renewable energy share in their power mix. • Efforts should be made to enhance Fe enrichment in ore by adopting technologies such as High Gradient Magnetic Separation (HGMS) and other advanced methods.	• Given the diverse mineralogy of iron ore in India, government may consider support the development of optimized beneficiation circuits designed to efficiently process iron ores of varying Fe grades and mineral compositions. • States having beneficiation plants should be encouraged to align their regulations on open access with the Green Energy Open Access (GEOA) Rules, 2022. In this regard, if government may persuade State Electricity Regulatory Commissions (SERCs) towards full implementation of the GEOA Rules. • The government could consider supporting small beneficiation plants by offering subsidized technical services, including energy audits, feasibility studies, and implementation assistance, thereby accelerate energy efficiency improvements. • To encourage the establishment of beneficiation plants, the government could consider offering tax exemptions on capital investments, reduced royalty rates, and other fiscal incentives.	• RD&D efforts should prioritize effective tailings management, maximizing metal recovery through the development of advanced technologies and innovative extraction processes, such as bioleaching and hydrometallurgy, electrification of induration process, utilization of biochar, etc. • The government may develop policies that promote RD&D, facilitate technology development and transfer, and encourage international collaborations.	• Awareness-raising campaigns should be launched to educate small and medium enterprises about energy-saving opportunities, RE power, and other decarbonization measures.

	Industry	Government	RD&D	Others
	• Adopt slurry pipelines as a cost-effective, reliable, energy-efficient, and environment-friendly solution for the low-carbon transportation of iron ore concentrate to pelletization plants • Maximize metal recovery from tailings through advanced technology and implementation of innovative extraction processes like bioleaching and hydrometallurgy			
Pelletization	• Feasibility studies may be conducted to identify optimal locations for setting up pellet plants. • Conduct energy audits periodically to identify energy efficiency projects and implement the measures in a time bound manner to reduce energy consumption. • Units should prioritize setting up solar rooftop/ ground mounted power projects or other RE projects to reduce scope 2 emissions.	• The government should encourage the industry to maximize the use of pellets in both blast furnaces and DRI production by incentivizing pellet production and utilization. • This would require a well-structured policy from the government, aimed at promoting the use of beneficiated low-grade ore, and fostering investments in beneficiation and pelletization. Such policies would also contribute to resource optimization and environmental sustainability. • The government may consider setting mandatory regulations for the minimum use of pellets in blast furnaces and DRI plants. Setting such limits would drive the adoption of pellets and support the broader goals of resource conservation and raw material security.	• Prioritize R&D to develop innovative technologies for pelletization. • Pilots should be developed for utilization of green hydrogen, natural gas and CBM in induration furnace.	• Awareness raising campaigns should be conducted targeting small and medium units on energy saving opportunities, RE, and decarbonization measures. • Feasibility studies may be conducted to identify optimal locations for setting up pellet plants.

Industry	Government	RD&D	Others
	• Align State Regulations with Green Energy Open Access Rules, 2022. • Subsidized or free of cost technical services for small plants for energy audits, technical assistance for implementation, training, and capacity building. • Develop an ecosystem and shared infrastructure (e.g., hydrogen hubs) for low-carbon fuels, such as green hydrogen and biomass/biochar, should be prioritized for new pellet plants. • Promote international/national partnerships with academia, industry, and research institutions to explore emerging technologies, and collaboration with countries that are utilizing more advanced methods.	• R&D for electrification of induration furnaces should be undertaken by academia, industry, and research institutions such as IITs, IMMT.	• Access to low-cost financing for greenfield pellet plants.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Chapter

Conclusions

The Indian iron ore beneficiation and pellet industry is a vital part of the iron and steel sector. It plays a significant role in the development of the steel sector which is poised for sustained growth. The growth is attributed to the economic development, infrastructure expansion, technological advancements, rising demand from end-use sectors, and favourable government policies.

Using iron ore pellets for iron and steel making offers several benefits including raw material security, improved productivity, energy efficiency, reduced GHG emissions, and supply chain benefits. These advantages would position pellets as preferred raw material in iron and steel production and enhancing sustainability and competitiveness.

The performance assessment of the beneficiation and pellet industry shows that the specific energy consumption is in the range of 12–22 kWh pe tonne of beneficiated ore and 0.29–0.36 GCal per tonne of pellets. The total energy consumption of the beneficiation and pellet manufacturing industry are estimated as 300,000 toe and 2.86 Mtoe, respectively in 2023–24.

The corresponding GHG emission intensity is 9–16 kg CO_2 per tonne of beneficiated ore and 127–178 kg CO_2 per tonne of pellet. These figures are much lower than those for sintering—another common agglomeration process—which emits 185–246 kg of CO_2 per tonne of sinter. Thus, the total emissions from beneficiation industry are estimated as 0.28 Mt CO_2 and pellet industry are 12.60 Mt CO_2 in 2023–24.

In line with the Government of India's global environmental commitments and submission of updated NDCs, the iron ore pellet industry needs to decarbonize its processes to contribute to net-zero goal of the iron and steel sector by 2070. This transition not only aligns with global sustainability goals but also ensures long-term competitiveness and resilience of the steel industry.

Decarbonizing the pellet industry requires a multi-faceted approach, including enhancing energy efficiency and renewable energy, enhancing circular economy practices like mill scale, integrating and enhancing renewable energy, adoption of low carbon fuels, electrification of induration furnace to replace fossil fuels, and carbon sequestration efforts. It also necessitates collaboration of key stakeholders concerned to drive this transition to net-zero. Conducive government policies and financial incentives along with investment in RD&D will be crucial to achieve a sustainable and low-carbon future for the Indian iron ore pellet industry. The key levers for decarbonization of the sector are:

1. **Energy efficiency:** Adoption of energy-efficient equipment and optimization of furnace performance through advanced automation and digital technologies can significantly reduce energy consumption and associated emissions.
2. **RE electricity:** Transitioning to renewable sources of electricity such as solar and wind can substantially reduce carbon emissions associated with electricity consumption in pelletization.
3. **Electrification of thermal processes:** Replacing fossil fuel–based induration furnaces and drying systems with electricity powered by renewable electricity offers significant potential to reduce carbon emissions in pelletization.
4. **Low carbon fuels:** Substituting fossil fuels in pelletization process; such induration with low-carbon alternatives such as hydrogen, biochar, biomass, or municipal solid waste (MSW) will significantly reduce emissions and dependence on fossil fuels.
5. **Circular economy practices:** Adopting circular economy principles by recycling and reusing materials like mill scale will further contribute to decarbonization efforts.

6. **Carbon sequestration:** Implementing carbon sequestration options such as nature-based solutions (NbS) through afforestation within the plant premises will help reduce net emissions, and contribute to the industry's net-zero emissions.

7. **Efficient iron ore slurry transportation:** Adopting slurry pipelines for iron ore/beneficiated ore transportation can enhance logistical efficiency, reduce transportation-related emissions, and minimize environmental impact compared to conventional modes of transportation.

8. **Policy support and collaboration:** Supportive policies, incentives, and strengthening collaboration on research and development among industry stakeholders, governments, and research institutions will help accelerate the adoption of decarbonization technologies and practices.

Decarbonizing India's iron ore beneficiation and pelletization industry poses various challenges, including technological barriers, cost implications, financing, and market dynamics. Concerted efforts and strategic investments in decarbonization are crucial for transforming the iron ore beneficiation and pelletization into a sustainable, low-carbon industry that contributes positively to climate change mitigation and environmental stewardship.

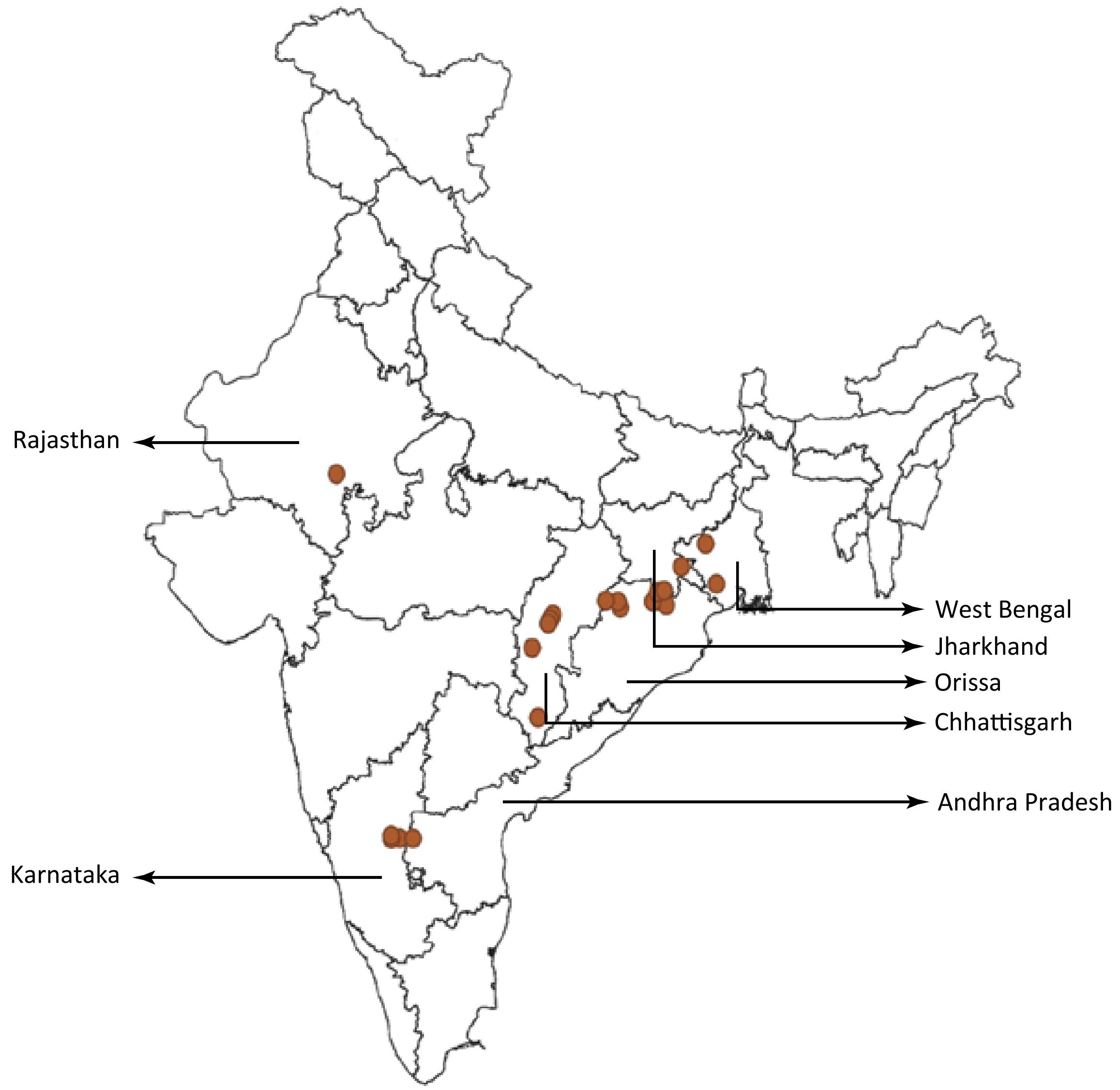
ANNEXURES

Annexure 1: Iron ore beneficiation plants in India (as of April 2024)

Industry	Location	Capacity (Mtpa)
Odisha		
ArcelorMittal Nippon Steel India Ltd	Dabuna, Keonjhar	12.0
Tata Steel Ltd	Joda East	12.0
Bhushan Power & Steel Ltd	Thelkoloi, Jharsuguda	6.5
BRPL	Barbil, Keonjhar	4.0
Shyam Metallic Energy	Sambalpur	2.0
Arya Iron & Steel	Barbil, Keonjhar	1.5
MSP Sponge Iron	Keonjhar	1.0
MSP Metallics	Jharsuguda	1.0
SAIL	Bolani	4.5
SAIL	Barsuan	2.0
Total – Odisha		46.5
Chhattisgarh		
ArcelorMittal Nippon Steel India Ltd	Kirandul	8.0
Shri Bajrang Power & Ispat	Tilda, Raipur	2.0
Sarda Energy & Minerals	Siltara, Raipur	1.2
MSP Steel & Power	Jamgaon, Raigarh	1.0
Mahendra Steel	Siltara, Raipur	0.3
SAIL	Dalli-Rajhara	6.0
Total – Chhattisgarh		18.5
Jharkhand		
Tata Steel Ltd	West Singhbhum	18.0
Usha Martin	Jamshedpur	2.5
SAIL	Kiruburu	5.0
SAIL	Meghahatuburu	5.25
Total – Jharkhand		30.75
Karnataka		
JSW	Toranagallu	19.5
BMM Ispat	Hospet	3.4
Janki Corp	Bellary	0.6
MSPL	Hospet	2.0
Total – Karnataka		25.5
Rajasthan		
Jindal SAW	Pur, Bhilwara	2.5
Total – Rajasthan		2.5
West Bengal		
Rashmi Group*	Kharagpur	10.0
Ankit Metal & Power	Bankura	1.26
Total – West Bengal		11.26
Total beneficiation capacity		135.02

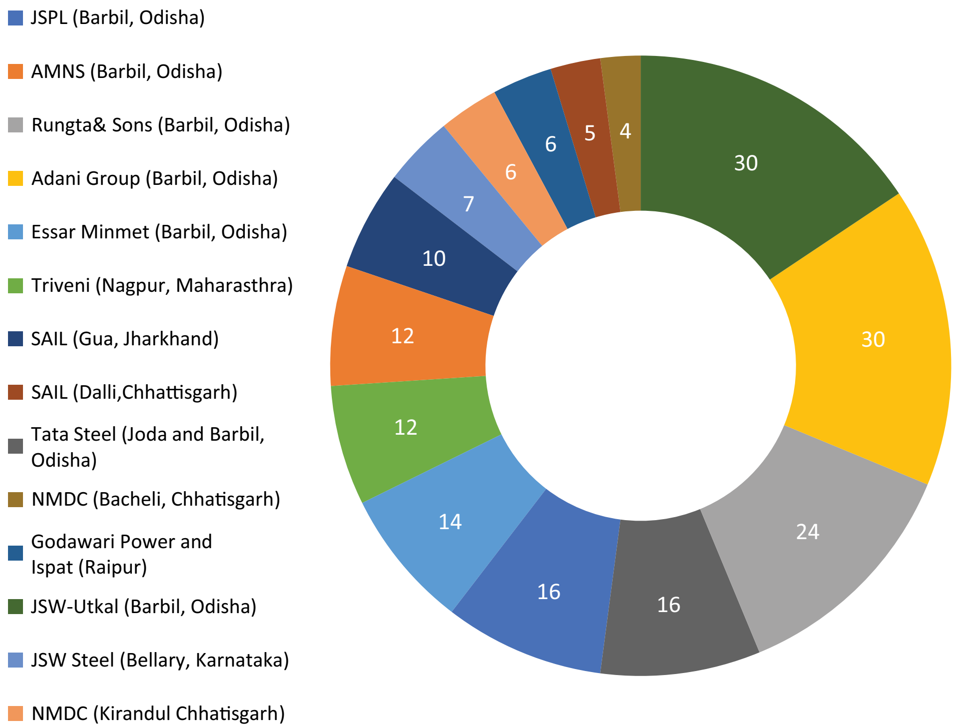
**Capacity of Rashmi group includes all units*

Source: BigMint/PMAI



Section of map of India showing beneficiation plants

Annexure 2: Proposed iron ore beneficiation plants in India by 2030



Source: PMAI & Industry information

Annexure 3: State-wise pellet plants in India

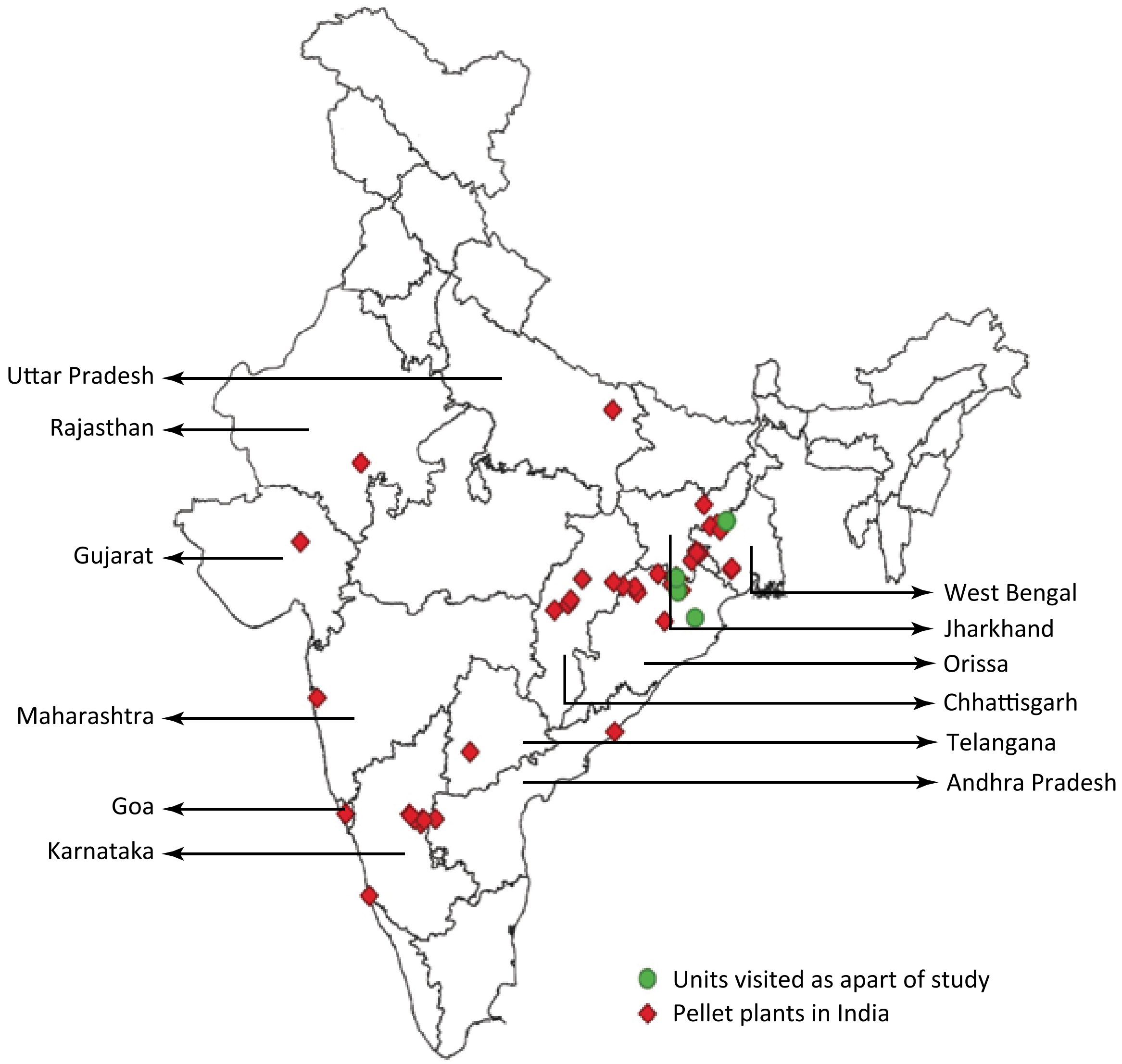
(As of April 2024)

S. No.	Company Name	Location of the plant	Capacity Mtpa	Captive Share (%)	Merchant Share (%)
Odisha					
1	Bhushan Power & Steel Works Ltd	Sambalpur, Jharsuguda	3.9	70	30
2	Shyam Metallics and Energy Ltd Sambalpur	Pandloi, Sambalpur	3.0	50	50
3	MSP Metallics Ltd	Marakuta, Jharsuguda	0.6	50	50
4	Sree Metaliks Ltd -Keonjhar	Barbil, Keonjhar	0.6	-	100
5	Ardent Steel Ltd	Keonjhar	0.85	-	100
6	Arya Iron & Steel Company Pvt. Ltd	Barbil, Keonjhar	1.2	-	100
7	Brahmani River Pellets Ltd	Khurunti, Jajpur	4.0	-	100
8	ArcelorMittal-Nippon Steel India Ltd	Paradeep, Jagatsinghapur	12.0	50	50
9	Jindal Steel and Power Ltd	Angul	5.0	50	50
10	Jindal Steel and Power Ltd	Barbil, Keonjhar	10.0	50	50
11	MSP Sponge Iron Ltd	Haldiaguna, Keonjhar	0.75	50	50
12	Rungta Mines	Kamanda, Sundergarh	3.0	NA	
13	Essel Mining & Industries Ltd	Barbil, Keonjhar	1.0	-	100
14	Shri Jagannath Steels & Power Ltd (KJS Group)	Barbil, Keonjhar	1.2	50	50
15	Shri Mahavir Ferro Alloys Ltd	Rourkela, Sundergarh	0.9	-	100
16	Enviro Care Infra Solutions Pvt Ltd	Rourkela, Sundergarh	0.9	-	100
		Total	**48.9**		
Karnataka					
17	Kudremukh Iron Ore Co Ltd (KIOCL)	Mangalore, Dakshin Kannada	3.5	-	100
18	MSPL Limited	Halavarthy, Koppal	1.2	-	100
19	NMDC Limited-Karnataka	Bellary	1.2		100
20	Xindia Steels Ltd	Kuniere & Hirebaganal, Koppal	0.8		100
21	BMM Ispat Ltd	Hospet, Vijaynagar	2.4	80	20
	JSW Steel Ltd	Vijaynagar, Bellary	17.2	100	-
23	Janki Corporation Ltd	Sidiginamola, Bellary	0.6	-	100
24	Minera Steel & Power Pvt Ltd (KMMI Steel)	Yerabanahally, Bellary	0.8	40	60
		Total	**27.7**		

S. No.	Company Name	Location of the plant	Capacity Mtpa	Captive Share (%)	Merchant Share (%)
West Bengal					
25	Rashmi Metaliks Ltd (Rashmi Group)	Kharagpur, Paschim Midnapur	0.9	50	50
26	Orissa Metaliks Ltd (Rashmi Group)	Kharagpur, Paschim Midnapur	3.6	50	50
27	Rashmi Udyog Private Ltd (Rashmi Group)	Paschim Midnapur	1.2	50	50
28	Orissa Alloy Steel Pvt Ltd (Rashmi Group)	Kharagpur, Paschim Midnapur	3.6	50	50
29	Shakambhari Ispat & Power	Madandi, Purulia	2	NA	
30	Super Smelters Sponge Pvt Ltd	Jamuria, Paschim Bardhman	1.2	100	-
31	Bravo Sponge Iron Pvt. Ltd	Purulia	0.9	NA	
32	Shyam Sel and Power Ltd (Jamuria)	Jamuria, Paschim Bardhman	3.0	-	100
33	Ankit Metal and Power Ltd	Bankura	0.6	50	50
		Total	**17**		
Jharkhand					
34	Tata Steel Ltd – Jamshedpur Works	Jamshedpur, East Singbhum	8.0	100	-
35	Tata Sponge Iron Ltd Main Plant - 1&2	Gamharia, Saraikela Kharsawan	1.2	NA	
36	Rungta Mines	Chaliyama, Saraikela Kharsawan	3	NA	
37	Amalgam Steel Private Limited (Formerly Adhunik Alloys)	Gamharia, Saraikela Kharsawan	1.2	30	70
38	Atibir Industries Co. Ltd (Unit I)	Giridih	0.3	100	-
		Total	**13.7**		
Chhattisgarh					
39	Jayaswal Neco Industries Ltd	Siltara, Raipur	1.5	50	50
40	Godawari Power and Ispat Ltd	Siltara, Raipur	2.7	50	50
41	MSP Steel and Power Ltd	Raigarh	1.25	50	50
42	JSW Ispat Special Products Ltd (Raigarh)	Raigarh	2.2	100	-
43	Raipur Power & Steel Durg	Durg	0.6	NA	
44	Sarda Energy and Minerals Ltd	Siltara, Raipur	0.9	70	30
45	Rashi Steel and Power Ltd	Bilaspur	0.4	-	100
46	Shri Bajrang Power and Ispat (Tilda)	Tilda, Raipur	1.4	50	50
		Total	**11.0**		

S. No.	Company Name	Location of the plant	Capacity Mtpa	Captive Share (%)	Merchant Share (%)
Goa & Gujarat					
47	Mandovi Pellet	North Goa	1.8	-	100
48	Sal Steel Ltd (Shah Alloys Ltd)	Gandhinagar	0.6	NA	
		Total	**2.4**		
Andhra Pradesh					
49	Arcelor Mittal-Nippon Steel India Ltd	Vishakhapatnam	8.0	50	50
		Total	**8.0**		
Maharashtra					
50	JSW Steel Ltd – Dolvi Unit 1 & 2	Dolvi, Raigad	13.3	100	-
		Total	13.3		
Rajasthan					
51	Jindal Saw Ltd	Village Pur, Bhilwara	1.5	-	100
		Total	**1.5**		
Telangana					
52	Vinayak Steels Ltd	Mahboob Nagar	0.07	NA	
		Total	**0.07**		
Uttar Pradesh					
53	Gallantt Ispat Ltd	Gorakhpur	0.8	NA	
		Total	**0.8**		
Grand total			**144.3**		

Source: BigMint, PMAI



Section of map of India showing pellet manufacturing plants

Annexure 4: Methodology for estimating GHG emissions and energy consumption

GHG emissions

For estimating GHG emissions, the World Steel Association (WSA) methodology is used along with standard emission factors from the IPCC 2017 calculation tool. The Scope 1 emissions in pellet manufacturing are from fuel used in the form of coal, coke, furnace oil, tar, producer gas, coal bed methane (CBM), blast furnace gas, off-gases from the other units of Integrated Steel Plant, or any other fuel used for making pellets. The locked CO_2 emissions from raw materials like dolomite or lime, which are released during pelletization process are also considered in Scope 1. Apart from mentioned sources, the fuel used to generate power or any other processed energy form, used in pelletization process is considered in Scope 1 emissions. The grid emission factor is taken into account in Scope 2 emissions for the power drawn from the grid. The electricity generated through diesel generators has been accounted for in Scope 1 emissions. Credits have been accounted, in case RE generated is used for plant operations.

Energy consumption

Energy consumed in the form of fuels including coal, coke, furnace oil, tar, producer gas, CBM, and blast furnace gas for thermal energy has been accounted. The calorific value of various fuels has been shared by the manufacturing units. In case, calorific value is not available, default values have been considered from IPCC 2017 calculation tool.

The electrical energy consumed from all the sources including grid, solar photovoltaic and diesel generators has been accounted for electrical energy. The conversion factor for KWh to GCal has been referred from IPCC 2017 calculation tool.

Annexure 5: Comparative characteristics of coal with bio-products

Property, unit	Wood	Wood pellets	Torrefaction pellets	Charcoal	Coal
Moisture content, wt%^{db}	30–45	7–10	1–5	1–5	10–15
Calorific value, MJ/kg	9–12	15–16	20–24	30–32	23–38
Volatile, wt%^{db}	70–75	70–75	55–65	10–12	15–30
Fixed carbon, wt%^{db}	20–25	20–25	28–35	85–87	50–55
Bulk density, kg/l	0.2–0.25	0.55–0.75	0.75–0.85	0.2 ~	0.8–85
Volumetric energy density, GJ/m^3	2–3	7.5–10.4	15–18.7	6–6.4	18.4–23.8
Dust	Average	Limited	Limited	High	Limited
Hydroscopic properties	Hydrophilic	Hydrophilic	Hydrophobic	Hydrophobic	Hydrophobic
Biological degradation	Yes	Yes	No	No	No
Milling requirements	Special	Special	Classic	Classic	Classic
Handling properties	Special	Easy	Easy	Easy	Easy
Product consistency	Limited	High	High	High	High
Transportation cost	High	Average	Low	Average	Low

Note: db – dry basis

Annexure 6: List of technology suppliers

Technology/Equipment	Technology supplier	Contact details
Straight Grate Kiln	Primetals Technologies	Primetals Technologies India Pvt Ltd 5th Floor, Tower – C, DLF IT Park-I Major Arterial Road, New Town (Rajarhat), Kolkata 700156, West Bengal Tel.: +91 (33) 6629 1000
	Metso India Pvt. Ltd	1st Floor, Building No.: 10, Tower A DLF Cyber City Phase II, Gurugram, Haryana, 122002 Tel: +91 124–3336666
	Lloyds Engineering Works	Plot No.: A-5/5, MIDC Industrial Area, Murbad, District Thane – 421401 Maharashtra
Circular Pelletization Technology	Primetals Technologies	Primetals Technologies India Pvt Ltd 5th Floor, Tower – C, DLF IT Park-I Major Arterial Road, New Town (Rajarhat), Kolkata 700156, West Bengal Tel.: +91 (33) 6629 1000
Grate Kiln	Metso India Pvt Ltd	1st Floor, Building No. 10, Tower A DLF Cyber City Phase II, Gurugram, Haryana, 122002 Tel: +91 124–3336666
	Lloyds Engineering Works	Plot No. A-5/5, MIDC Industrial Area, Murbad, District Thane – 421401, Maharashtra
	Andritz- BrainWave®	Andritz Technologies Pvt Ltd Sattva Galleria 20/1, First Floor Kashi Nagar, Bellary Road, Byatarayanapura, Bangalore 560092, Karnataka automation-sales@andritz.com
Mineral processing equipment	Weir Minerals India	NCC Urban Windsor, 1st Floor New Airport Road, Opposite Jakkur Aerodrome, Bengaluru 560064, Karnataka Tel: +91–80–46177666
Gasifiers	Cosmo Gasifiers	Cosmo Powertech Pvt Ltd. Near Jain Public School, Devpuri, Raipur – 492015, Chhattisgarh Tel: +91–8839409473 / 9229132400 / 9893030085 cosmo_powertech@yahoo.co.in Website – www.cosmo-energy.in
Separation and pump technologies	Andritz Separation and Pump Technologies India Pvt Ltd	S. No.: 389,400/2A & 400/2C Padur Road, Kuthampakkam Village, Poonamalle, Taluk, Tiruvallur, Kuthambakkam, Tamil Nadu 600124 Tel: 044–4399 1111

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