DRI UPDATE

SIMA

Sponge Iron Manufacturers Association

Indian voice for the ore based metallic & steel industry

November 2025

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Deependra Kashiva
Editor, Director General,SIMA

Dear Industry Colleagues,

I am pleased to share that **Sponge Iron Manufacturers Association (SIMA)** is bringing out a special edition of its in-house magazine, **DRI UPDATE**, on the occasion of the **7th India International DRI & Steel Summit 2026, scheduled for 16th January 2026 at Hotel Le-Meridien, New Delhi.** This year's theme, **"Navigating the Sustainable Growth of the Indian Steel Industry,"** reflects our resolve to lead the sector toward cleaner technologies, enhanced efficiency, and long-term sustainability.

Today, the Indian steel industry stands at a defining moment. With increasing emphasis on low-carbon pathways, technological advancement, and responsible resource utilisation, our sector has an opportunity to set global benchmarks in sustainable growth. SIMA continues to play a pivotal role by facilitating dialogue, promoting best practices, and strengthening collaboration among government bodies, raw material suppliers, technology providers, and DRI and steel producers.

It is a matter of great satisfaction that SIMA continues to be closely associated with the Government and leading technology partners in developing a compact gas-based DRI module. While we face challenges such as high capital costs and uncertainties in the pricing and availability of reducing gases like natural gas/syngas/biogas/green hydrogen, I am confident that our collective expertise will help us arrive at practical and innovative solutions.

The global geopolitical environment remains unpredictable, often creating uncertainties for our industry. Yet, India and its steel sector continues to demonstrate resilience and adaptability which is reflected to the fact that we have an impressive GDP 8.2% in Q2 and 8.3% surge in steel consumption in the first half of 2025. I remain optimistic that stability will return, enabling us to further accelerate our journey toward global industrial prominence.

This special issue of DRI UPDATE aims to provide meaningful insights and perspectives as we prepare for the 2026 Summit. We look forward to receiving suggestions and contributions from our readers for future editions.

MESSAGE

Rahul Mittal

Chairman,SIMA and MD Janki Corp. Ltd

Dear Readers,

Over the past decade, India has emerged as one of the world's most dynamic economies. Investments in infrastructure, urbanisation and rising consumption are reshaping our growth. As India aspires to join the ranks of developed economies, the need for reliable, high-quality and cost-competitive materials has never been greater.

At the heart of this story lies the Indian steel industry. Steel supports core pillars of national development—infrastructure, housing, engineering, capital goods and energy. The industry is steadily adding capacity and moving up the value chain with better quality, higher productivity and sharper customer focus. In a competitive global environment, our path forward is clear: strong fundamentals, disciplined operations and continuous modernisation.

Within this broader framework, the DRI and sponge iron sector plays a vital role. India has one of the largest DRI capacities in the world, supplying essential metallics to electric arc and induction furnaces. The sector supports a wide base of medium and small producers, generates employment and supports regional development.

At the same time, the DRI industry faces challenges in raw material security, energy costs, process stability, product quality and compliance. Large breakthrough technologies are still evolving worldwide, so overnight transformation is unrealistic. Yet there is ample scope to improve performance through practical, low-hanging opportunities—greater use of renewable power where feasible, efficient electrical systems, better automation and control, stronger data monitoring and renewed focus on process discipline and preventive maintenance. These steps are well within reach and can deliver visible gains in cost, reliability and competitiveness.

In this context, the **7th India International DRI & Steel Summit 2026, to be held on 16th January 2026 at Hotel Le-Meridien, New Delhi,** assumes special significance. With the theme **"Navigating the Sustainable Growth of the Indian Steel Industry",** the summit will bring together policymakers, industry leaders, technology providers and researchers to discuss how India can strengthen its position in the global steel value chain while steadily improving efficiency and responsible resource use.

This special edition of DRI UPDATE, released to coincide with the summit, captures perspectives on India's economic outlook, the direction of the steel sector and the opportunities and challenges before the DRI and sponge iron industry. I am confident that the articles and insights presented here will be informative and relevant for all our readers.

As we look ahead, our progress will be driven not only by new technologies but by the steady improvements we make in our plants and organisations. If we combine India's growth momentum with a strong culture of operational excellence and prudent resource management, the DRI-based steel sector can further strengthen India's position as a reliable, long-term partner in global steel supply.

My best wishes to all our readers.

MESSAGE

Gajraj Singh Rathore
Vice Chairman,SIMA and Whole time Director & COO,JSW Steel Ltd

Dear Readers,

The global economic environment today is characterised by geopolitical tensions, supply chain restructuring, energy security concerns, and rising climate-related disruptions. While these uncertainties continue to reshape global trade and industrial competitiveness, India has emerged as a rare bright spot. With GDP growth of 6–6.5%, strong domestic consumption, large-scale infrastructure investments, and steady policy reforms,

India's steel sector is now entering a decade of transformation. Domestic demand is expected to rise to 250–300 million tonnes by 2030, supported by rapid urbanisation, manufacturing expansion, housing, and infrastructure development. Government initiatives such as the PLI scheme, the National Green Hydrogen Mission, and targeted support for low-carbon technologies are shaping a more competitive and sustainable industry landscape. At the same time, challenges related to raw material security—such as declining iron ore output—and the need to balance import control with global competitiveness require coordinated industry–policy action.

In this context, the DRI sector holds strategic significance. The DRI route offers strong advantages in energy efficiency, flexibility, and emissions reduction, making it central to India's long-term green steel ambitions. With global emphasis shifting toward decarbonization and hydrogen-based ironmaking, the sponge iron industry is poised to play a defining role in shaping India's sustainable steel future.

For over three decades, the Sponge Iron Manufacturers Association (SIMA) has served as the collective voice of the DRI-based steel industry—championing policy reforms, enabling technology adoption, and fostering knowledge exchange across the value chain. **The 7th India International DRI & Steel Summit 2026, themed "Navigating the Sustainable Growth of the Indian Steel Industry,"** continues this mission by bringing together global experts, technology providers, manufacturers, researchers, and policymakers on a single platform. I take the opportunity to invite all stakeholders to attend this biannual summit.

SIMA's Forthcoming Event on 16th Jan.2026 Delhi

Organizer

SIMA
Sponge Iron Manufacturers Association
Indian voice for the ore based metallic & steel industry

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STEEL & METALLURGY
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BIGMINT

7th India International DRI & Steel Summit 2026

16th January, 2026

Hotel Le Meridien, New Delhi

Navigating the sustainable growth of Indian Steel Industry

Delegate Fee	Early Bird	Standard	On Spot
		Till 12.1.2026	
SIMA Member	NA	Rs. 8000/- + 18% GST	Rs. 10000/- + 18% GST
Non-Member	Rs. 10000/- + 18% GST,Till11.1.2026	Rs.12000/- + 18% GST	Rs.15000/- + 18% GST
Overseas Member	NA	US$ 500 + GST Till 14.01.2026	US$ 750 + 18% GST

Sponsorship

Principal	Platinum	Gold	Silver	Associate
Rs. 12,00,000	Rs. 10,00,000	Rs. 8,00,000	Rs. 5,00,000	Rs. 3,50,000

Focus Area

The 7th India International DRI & Steel Summit 2026 will bring together industry leaders, policymakers, researchers, and innovators to deliberate on critical issues facing the Indian steel industry.

Key discussions will revolve around

Sustainable and green steel production DRI capacity expansion and technological innovation. Policy frameworks and regulatory alignment. Trade competitiveness and global supply chain integration. MSME participation and development of secondary steel.

Registration ends on 12th January 2026. Join us!

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Role of Pellets in Decarbonizing the Indian Steel Industry

Sobhanbabu PRK, Senior Fellow; Mayank Agarwal, Fellow
The Energy and Resources Institute (TERI)

1 Introduction

India's iron and steel industry is one of the largest contributors to industrial CO_2 emissions, accounting for an estimated 350 million tonnes (Mt) of CO_2 annually, which translates to about 12% of the country's total emissions. As the sector aims to expand its crude steel capacity from nearly 200 Mt in 2024–25 to around 300 Mt by 2030, it faces the dual challenge of meeting the growing domestic demand while aligning with India's net-zero emissions target for 2070. The growth of the steel sector calls for effective utilization of domestic iron ore resources.

India's iron ore reserves are increasingly characterized by low-grade ore and high fines content, making beneficiation and pelletization essential for efficient resource utilization. Converting low-grade ore and fines into high-quality pellets enhances process efficiency, reduces waste, and lowers emission and thus serves as a vital link between resource optimization and India's low-carbon transition of steel industry.

Recognizing this necessity, the Ministry of Steel's roadmap, *Greening the Steel Sector in India – Action Plan and Roadmap*[1], identifies beneficiation of low-grade iron ore and pelletization as among the immediate and impactful strategies to enhance raw material efficiency and reduce sectoral emissions. As highlighted in TERI's recent study, *Decarbonization of the Iron Ore Pellet Manufacturing Industry* (2024), pellets not only enable efficient utilization of India's abundant low-grade ore reserves but also supports low-emission ironmaking in both Direct Reduced Iron (DRI) and Blast Furnace (BF) routes, the two dominant pathways in India's steel production landscape.

2 Landscape of India's Beneficiation and Pellet Industry

2.1 Iron Ore Beneficiation

Beneficiation improves the quality of low-grade ore and makes it suitable for iron making process. It enhances the iron content of the ore by removing impurities and gangue materials, thereby enabling more efficient iron production. The process involves crushing and grinding, washing, screening, slurry concentration, and dewatering. Additionally, some plants employ advanced techniques such as magnetic separation.

There are 27 iron ore beneficiation plants in India with a combined installed capacity of 136 million tonnes per annum (Mtpa). The estimated production from these plants was 94 Mtpa in FY2024. Odisha and Jharkhand dominate the landscape, together accounting for over half of the country's total beneficiation capacity.

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

Image 1: Beneficiation unit in West Bengal

Beneficiation operations require electrical energy. The average specific energy consumption (SEC) of the plants is 17 kWh per tonne of beneficiated ore, of which grinding operations alone contribute nearly two-thirds. The industry's total annual energy use is estimated at around 400 million kWh, equivalent to 34,350 tonnes of oil equivalent (TOE). This results in approximately 2,80,000 tonnes of CO_2 emissions per annum, with an average emission intensity of 12.5 kg CO_2 per tonne of beneficiated ore.

2.2 Pellet Industry

Pellet making involves agglomeration of beneficiated iron ore fines with binders (such as bentonite) and additives to form green pellets, which are then indurated at high temperatures (1200–1300°C) in a furnace to achieve the required strength, porosity, and metallurgical properties.

Image 2: Pellet classifier in pellet manufacturing unit

The total installed capacity of the pellet industry in India is 145 Mt with a production of about 94 Mt during 2023–24 representing a capacity utilization of 65%. Pellet plants in India are predominantly situated close to iron ore mining regions to optimize logistics. There are 53 pellet manufacturing plants spread across mining rich states. Five states namely—Odisha, Karnataka, West Bengal, Jharkhand, and Chhattisgarh account for 82% of total capacity with Odisha alone accounting for one-third of the total capacity.

2.3 Manufacturing Process and Technologies

The key steps of the pelletization process are (i) batch preparation, (ii) formation of green pellets, (iii) screening, (iv) pre-heating of green pellets, and (v) induration (Figure 1). Batch preparation step comprises mixing of beneficiated ore, coal, coke, dolomite, and a binding agent such as bentonite in required proportions.

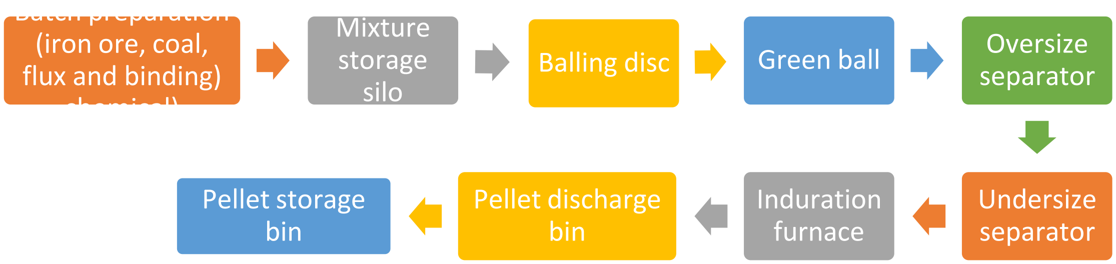


Figure 1: Pellet manufacturing process

Induration is a key thermal treatment process in pellet production to impart better mechanical and physical properties to pellets such as tumbling index, abrasion index, and porosity. It is the most energy and emission intensive process within the pellet making process where green pellets are gradually heated to a temperature of 1200–1300^{o}C. In India, pellet manufacturing predominantly employs two types of induration technologies, namely, the straight travelling grate (developed by Lurgi Metallurgie) and the grate–kiln (developed by Allis Chalmer) while the circular pelletizing technology (CPT) is a new technology, currently adopted by only one unit in Odisha. When compared, the straight travelling grate system offers superior pellet quality and greater fuel flexibility. Straight travelling grate plants are suitable for large-scale operations of up to 9 Mtpa, whereas grate–kiln systems cater to smaller capacities of up to 6 Mtpa.

2.4 Energy Consumption and Emissions

Pellet-making process is thermal energy intensive, with thermal energy constituting nearly 90% of the total energy consumed, primarily in the induration process. A diverse mix of fuels are used in pellet making, including coal, furnace oil, producer gas, and coal bed methane (CBM), the choice of which is largely dependent on cost and availability of fuels. Electrical energy is primarily used for grinding and screening operations and auxiliary systems.

The study conducted by TERI shows that SEC of pellet production process varies significantly, due to various factors including induration technology employed, type of fuel, and capacity utilization. The overall SEC is the lowest for straight travelling grate as compared to grate kiln or circular grate (Table 1).[2] The total energy consumption of the Indian pellet industry is estimated at 2.86 million tonnes of oil equivalent during 2023–24.

Table 1: Average specific energy consumption and emission intensity of the Indian pellet industry

Induration technology	SEC-thermal (GCal/t)	SEC-electrical (kWh/t)	Overall SEC (GCal/t)	CO_2 emission intensity (kg CO_2/t)
Grate kiln	0.32	43	0.36	178
Straight travelling grate	0.27	33	0.29	127
Circular pelletization technology	0.28	67	0.34	152

The emission intensity of pellet production varies across technologies with straight travelling grate having lowest emissions. The average emission intensity of the industry is 134 kg CO_2 per tonne of pellet. The total emissions of the pellet industry are estimated to be 12.6 Mt CO_2 during 2023–24.

While the emission share of pellet industry is modest as compared to the downstream iron and steel making processes, their significance lies in how pellets enhance energy efficiency and reduce emissions during both routes of iron production viz., DRI and BF route.

2.5 Benefits of Pellets Utilization in Iron Making

Pellets provide significant advantages in both production routes, enhancing efficiency, quality, and environmental performance, as outlined below.

Image 3: Grate kiln technology-based pellet manufacturing unit

[2] SEC includes grinding, green pellet making, and induration

a) DRI Route

India's DRI industry is predominantly coal-based contributing nearly 35% of the country's total crude steel output during 2023–24. A recent study by TERI confirms that iron ore pellets, as feedstock for DRI production, offer both economic as well as environmental advantages, including lower emissions and higher process efficiency. The key benefits of the usage of pellets in the DRI route include:

- *Higher product quality*: Low levels of impurities such as sulphur and phosphorus in pellets result in superior-quality DRI, which is essential for producing high-grade steel.
- *Improved reduction kinetics*: The uniform structure, high porosity, and better reducibility of pellets enhance gas flow and reactivity, leading to faster reduction rates.
- *Greater thermal efficiency*: The spherical shape of pellets promotes efficient heat transfer and minimizes thermal degradation, improving overall productivity.
- *Reduced furnace accretion*: Lower gangue content minimizes accretion formation and ensures smoother gas flow within the furnace.
- *Resource circularity*: Pelletization enables the productive use of low-grade fines, improving material efficiency and reducing environmental impact.
- *Better material efficiency*: Pellet use lowers the ore requirement per tonne of DRI. About 1.4–1.6 tonnes of pellets are needed as compared to 1.8–2.0 tonnes of lump ore per tonne of DRI.

These advantages contribute to lower coal consumption and reduced CO_2 emissions as compared to lump ore–based DRI production, reinforcing the role of pellets as a cleaner and more sustainable raw material for India's steel industry.

b) Blast Furnace Route

Pellets offer a range of metallurgical, operational, and environmental advantages over other raw materials such as lump ore and sinter in blast furnace route. Some of the key benefits include:

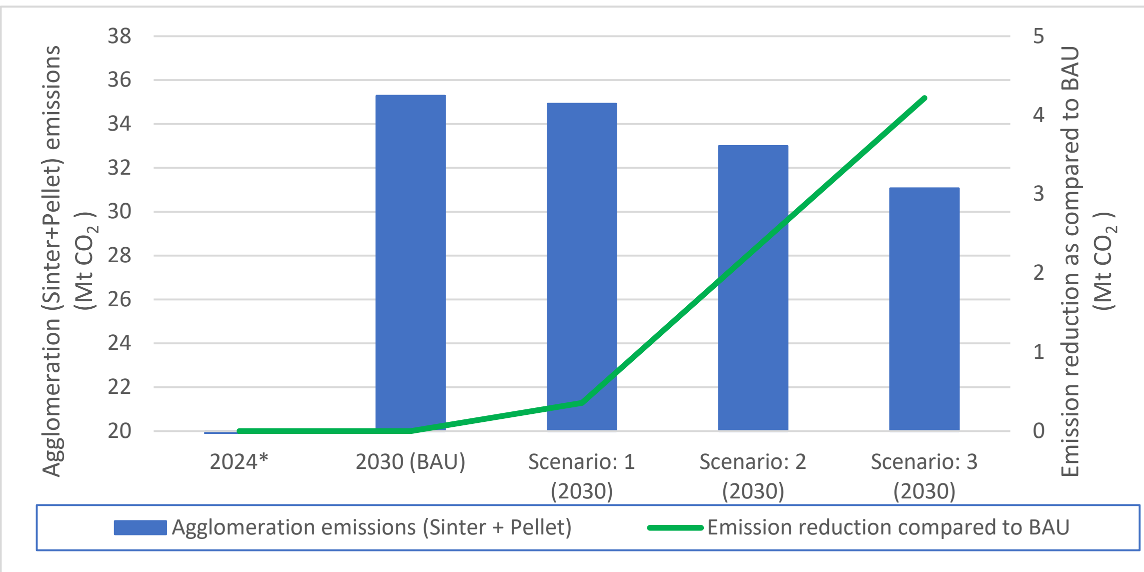
- *Higher productivity and lower coke rate*: The use of pellets enhances blast furnace efficiency, leading to higher output and reduced coke consumption. On average, every 1% increase in the iron content in the ore improves blast furnace productivity by about 2% and reduces coke consumption by around 1%.
- *Superior physical and chemical properties*: Pellets have lower gangue content (silica and alumina), uniform size (8–16 mm), high porosity (25–30%), high tumbling index, and low abrasion index as compared to lump ore and sinter. These properties ensure better bed permeability, efficient gas flow, and lower energy requirements for both heating and reduction.
- *Lower energy use and emissions*: Pellet production is significantly cleaner than that of sinter, emitting about 134 kg CO_2 per tonne of pellets as compared to 216 kg CO_2 per tonne of sinter, a 38% rise in case of the latter.

Overall, the use of pellets in the blast furnace route supports energy efficiency, productivity gains, and reduced carbon footprint, making them a key enabler of sustainable iron making in India.

2.6 Emission Reduction by Increasing Pellet Share in the Blast Furnace Burden

In India, for blast furnace route, sinter currently accounts for 60–70% of the total burden mix, with the remainder comprising pellets and iron ore lumps. Pellets offer considerable potential to substitute sinter in the charge mix, primarily due to their lower carbon footprint as compared to sinter. The TERI-PMAI study shows that increasing the pellet share in the blast furnace burden mix can result in significant emission reductions by 2030 (Figure 2). Three alternative scenarios were evaluated by progressively increasing the proportion of pellets. In scenario-1, with a burden mix of 30% pellet, 20% lump, and 50% sinter, the CO_2 emissions decreased marginally, resulting in an emission reduction of about 0.35 Mt vis-à-vis BAU scenario. In Scenario-2, with a burden mix of 40% pellets, 20% lump, and 40% sinter, CO_2 emission reduction was about 2.29 Mt. The analysis indicates that raising the pellet share to 50%, compared with the base case of 15%, could achieve an emission reduction of about 4.22 million tonnes of CO_2 by 2030. These findings underscore the critical role of pellet substitution in decarbonizing the iron-making process and achieving CO_2 reductions.

Figure 2: Emission reductions for different iron burden mix



2.7 Decarbonizing the Pellet Industry

The decarbonization of India's pellet industry can be achieved through a combination of technological, operational, and policy measures. Key levers include:

1) Enhancing energy efficiency across various steps and utilities to minimize specific energy consumption.
2) Transitioning to low-carbon fuels such as producer gas, biomass, or green hydrogen to replace fossil fuels during induration.
3) Electrifying thermal processes where feasible, supported by clean and reliable power supply.

4) Promoting circularity through increased recycling and utilization of by-products such as mill scale and dust.
5) Adopting renewable electricity for plant operations and auxiliary systems.

Further, domestic and international technology collaborations, targeted R&D for low-carbon process innovations, enabling policies and financial incentives, and robust infrastructure support altogether will be critical to accelerate the transition of the pellet industry towards a low-carbon future.

2.8 Challenges and Constraints for the Pellet Industry

The pellet industry in India faces several technical, financial, and policy-related challenges that hinder its growth and competitiveness:

- *Ore characteristics*: The complex mineralogy and variable particle size of Indian iron ores make beneficiation and pelletization processes more challenging, affecting product consistency and quality.
- *Tailings management*: Inadequate systems for the disposal and recovery of tailings pose environmental and operational challenges for the beneficiation plants.
- *High capital investment*: Pellet plants require high capital investment, around ₹250–300 crore per Mt of capacity.
- *Cost competitiveness*: High production costs, fluctuating market demand, and stringent quality standards affect overall profitability and market stability.
- *Affordability for small producers*: For smaller DRI units without economies of scale or long-term contracts, pellets remain costlier than lump ore, thereby limiting their adoption.
- *Logistical constraints*: Transport and connectivity issues between the beneficiation plants and pellet units increase costs and disrupt supply chains.
- *Lack of policy and incentives*: There is a lack of targeted policy support or fiscal incentives to encourage pellet use, especially in coal-based DRI plants.
- *R&D and technology gaps*: Limited research and innovation hinder the development of advanced and cost-effective technologies for beneficiation and pelletization.

3 Way Forward

To enhance the efficiency, competitiveness, and sustainability of India's pellet industry, a coordinated approach involving industry, policymakers, and research institutions is essential. The following measures can help address key challenges and unlock the sector's full potential:

- *Ore quality and process optimization*: Promote advanced beneficiation techniques (such as selective floatation, dry beneficiation, and sensor-based sorting) to handle complex ore mineralogy and improve feed quality for pellet plants

- *Technology development and R&D*: Strengthen R&D collaborations between industry, academia, and institutions to develop low-carbon, energy-efficient pelletization technologies and utilize alternative fuels.

- *Financial and policy support*: Introduce policy incentives such as interest subsidies, viability gap funding, or explore carbon credits to promote pellet-based DRI production and offset higher initial investment costs.

- *Infrastructure and logistics*: Develop integrated beneficiation–pelletization hubs near mining regions with improved rail and port connectivity and adopt slurry pipelines to reduce transportation bottlenecks and energy use.

- *Cost competitiveness and market development*: Facilitate long-term offtake agreements between steelmakers and pellet producers to ensure demand stability and enhance financial viability.

- *Capacity building and awareness*: Conduct targeted training and knowledge-sharing programs for plant operators and MSMEs to raise awareness about best practices in energy management and process optimization.

- *Circular economy integration*: Promote the reuse of low-grade fines and waste materials through pelletization to reduce waste, improve raw material utilization, and support India's low-carbon steel transition.

Conclusion

The iron ore pellet industry is at a crucial juncture as India wants to accelerate its transition towards low-carbon steel. Strengthening beneficiation, enhancing pellet quality, expanding capacity, and integrating emerging low-carbon technologies will be central to improving resource efficiency and reducing emissions across the iron and steel value chain. The findings from the TERI–PMAI study emphasize that increasing the share of pellets in the burden mix, optimizing process energy use, adopting renewable energy, and preparing for future hydrogen-based pathways offer actionable opportunities for near and medium-term decarbonization. Going forward, coordinated policy support, technology partnerships, and industry investments will also play a key role in unlocking the full potential of India's pellet sector in contributing to national climate goals while ensuring competitiveness and sustainable growth.

This article draws insights from the joint TERI-PMAI research study and the resulting publication 'Decarbonization of the Indian Iron Ore Pellet Industry'[3]. It synthesizes the key findings, analyses, and recommendations from this collaborative work.

[3] https://teriin.org/files/Technical-Report-on-Decarbonization-of-Iron-Ore-Pellet-Manufacturing-Industry.pdf

Energiron Technology: A Strategic Enabler for Green Steel in India

Soumyodeep Ghosh; Massimiliano Zampa

Danieli Group, www.danieli.com

Abstract

The steel industry contributes approximately 7–9% of global CO_2 emissions, making decarbonization a critical challenge. India, the second-largest steel producer aims to target 300 mtpy by 2030, faces the dual imperative of meeting growing demand while adhering to sustainability targets using local resources. This journal explores the role of Energiron technology in enabling green steel production, emphasizing its flexibility, technical advantages, and integration into India's decarbonization roadmap.

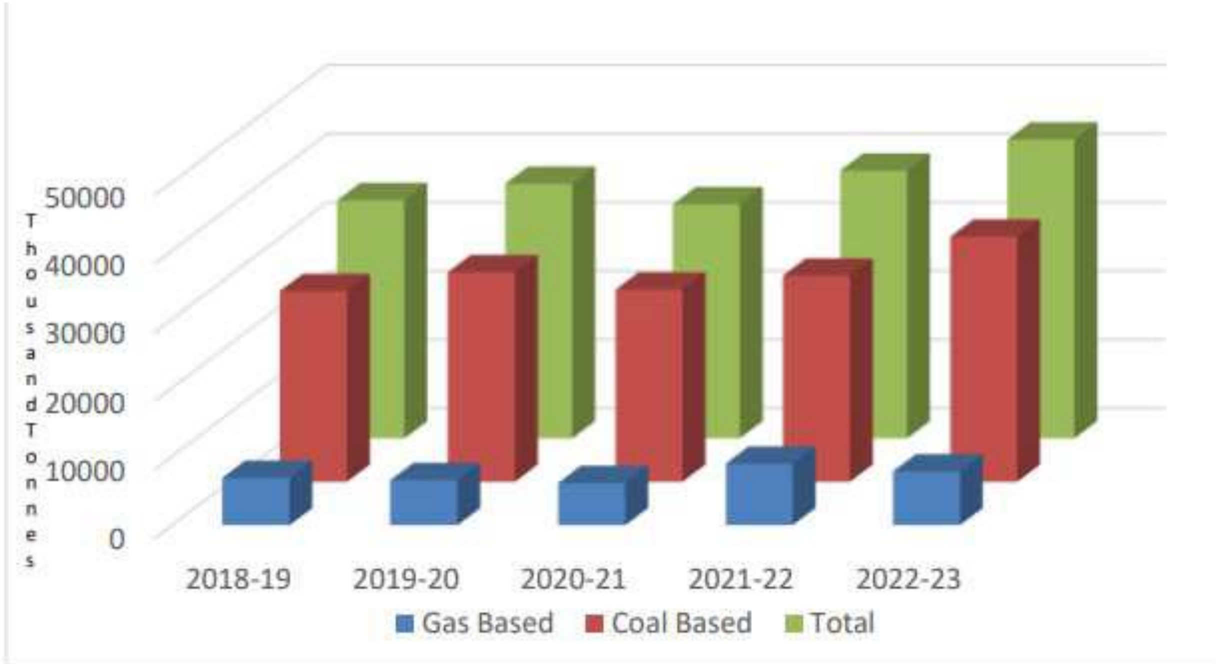
Introduction

Steelmaking is a cornerstone of industrial development but remains one of the most carbon-intensive sectors. With India's steel production expected to surpass 300 million tonnes by 2030, the need for low-carbon technologies is urgent. India relies on traditional blast furnace (BF) – Basic Oxygen Furnace (BOF) covering 43% of the production base with heavy reliance of coal, creating significant emissions. Direct Reduced Iron (DRI) processes, particularly those leveraging hydrogen, offer a viable pathway to reduce carbon intensity that could feed either to EAF (22% of market share) and IF (35% market share)

PROCESS ROUTE	% OF SHARE 2019-20	% OF SHARE 2023-2024
BASIC OXYGEN FURNACE (BOF)	44.5	42.7
ELECTRIC ARC FURNACE (EAF)	26.0	21.9
INDUCTION FURNACE (IF)	29.5	35.4
TOTAL	100.0	100.0

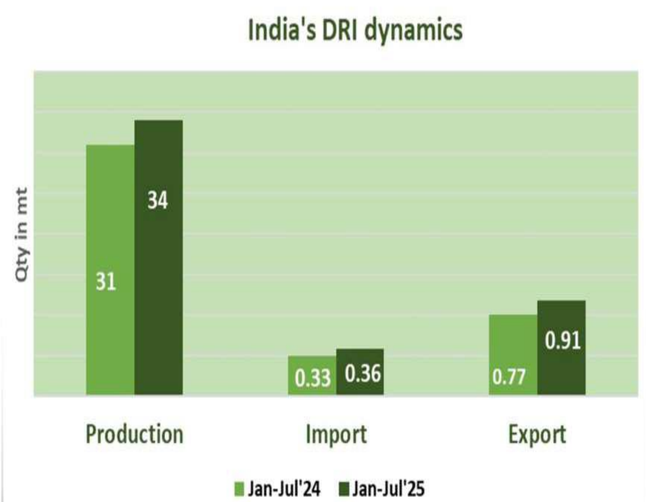
India's Steel and DRI Landscape

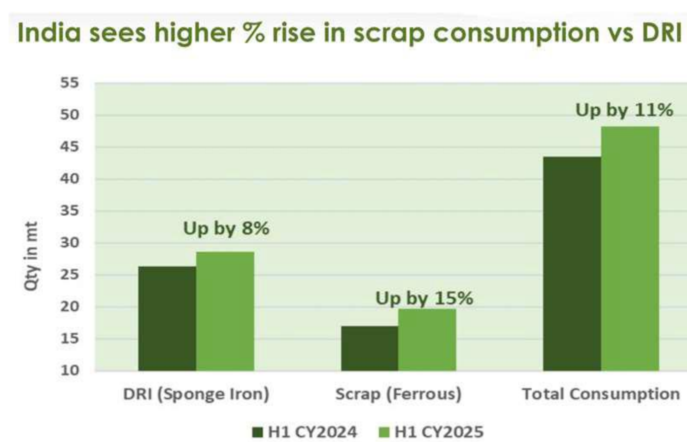
India's steel production has grown almost linearly over the past 25 years, reaching ~150 million tonnes in 2024 and projected to hit 200 million tonnes in 2025. By 2030, the target is 300 million tonnes. Current CO_2 emissions are around 2.5–2.6 tCO_2/t steel, which is 40% higher than the global average of 1.9 tCO_2/t. India is the world's largest DRI producer, primarily coal-based (80%), with production forecasted at 55 MT in 2025 and 80 MT by 2030.



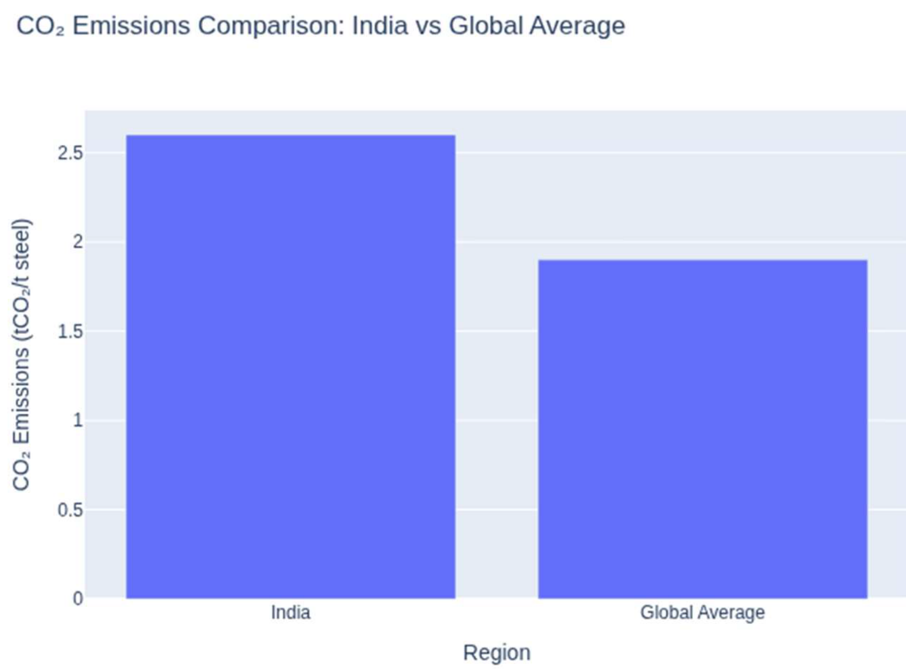
Government initiatives like the National Green Hydrogen Mission aim to integrate hydrogen into steelmaking, reducing reliance on coal.

DRI production in India saw a significant increase during the 2024–2025 period. This growth was accompanied by a noticeable rise in DRI imports, reflecting the country's expanding demand for metallics. A marked increase in scrap imports compared to the previous year, further emphasizing the growing reliance on alternative iron sour





With the global steel industry under increasing pressure to decarbonize, and with the rising demand for both DRI and scrap, it's clear that India's DRI future must evolve—embracing more flexible, sustainable, and efficient technologies to meet both domestic and international expectations.



Green Steel Rating System

India has introduced a star rating system for green steel, thereby defining the term:

- 0 stars: Emission > 2.2 tCO_2/t finished steel
- 3 stars: Emission between 2 and 2.2 tCO_2/t
- 4 stars: Emission between 1.6 and 2 tCO_2/t
- 5 stars: Emission < 1.6 tCO_2/t

From 2027 the Government of India, mandates include 20% green steel (3 stars), 4% (4 stars), and 1% (5 stars).

Public sector is using today 22% of the total steel production, and it foreseen to increase to 28% in 2030

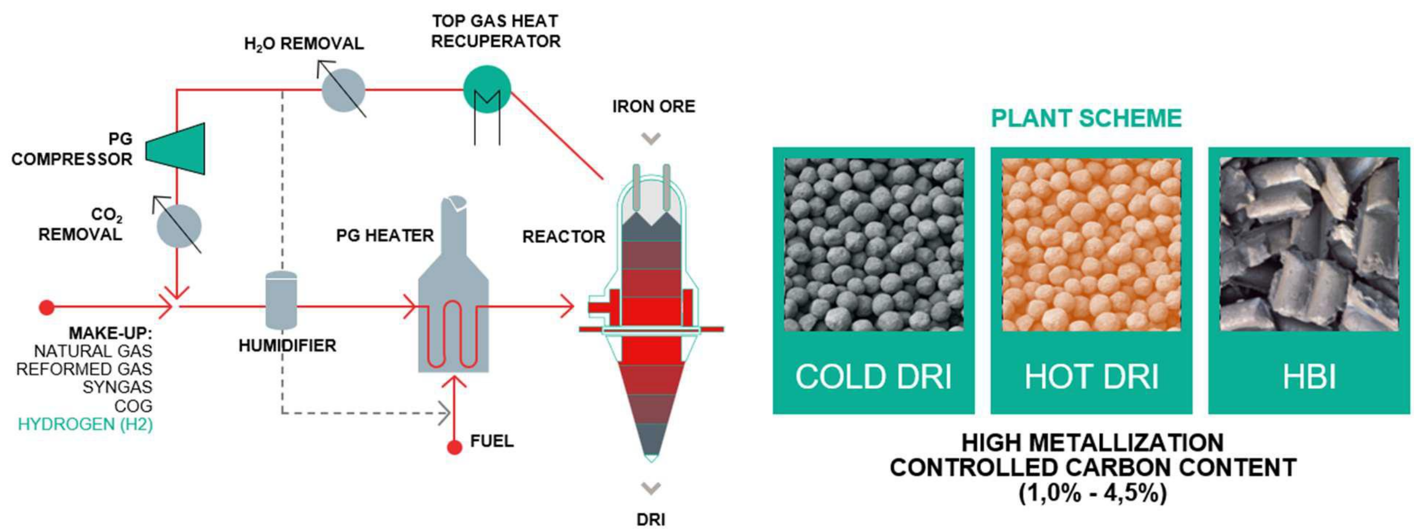
Means around 20 MTY (in 2030, considering 25%) need to be green steel

Energiron Technology: Flexibility for a Green Future

Energiron DR process offers unmatched flexibility in feedstock, operating efficiently with natural gas, syngas, coke oven gas, and up to 100% hydrogen. This adaptability ensures resilience against resource volatility and supports a phased transition to green hydrogen. The process accommodates both DR-grade and BF-grade ores, reducing dependency on premium raw materials.

Energiron DR process adjusts to demand without sacrificing efficient or quality.

Energiron DR process enhances supply chain resilience, supporting sustainability goals without sacrificing efficiency or availability.



High-Pressure Operation: Technical and Economic Benefits

Operating at high pressure (6–10 barg vs 1–2 barg) enhances compressor efficiency, reducing energy consumption to 60–75 kWh/t DRI compared to 100–120 kWh/t at low pressure.

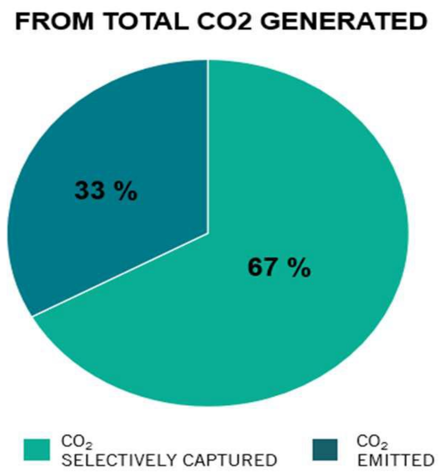
Improved yield minimizes iron ore losses, optimizing resource utilization. Integrated CO_2 removal systems enable carbon capture and commercialization, with up to 60% sequestration (67% captured, 33% emitted).

A CO2 removal unit is embedded in the ENERGIRON process scheme.

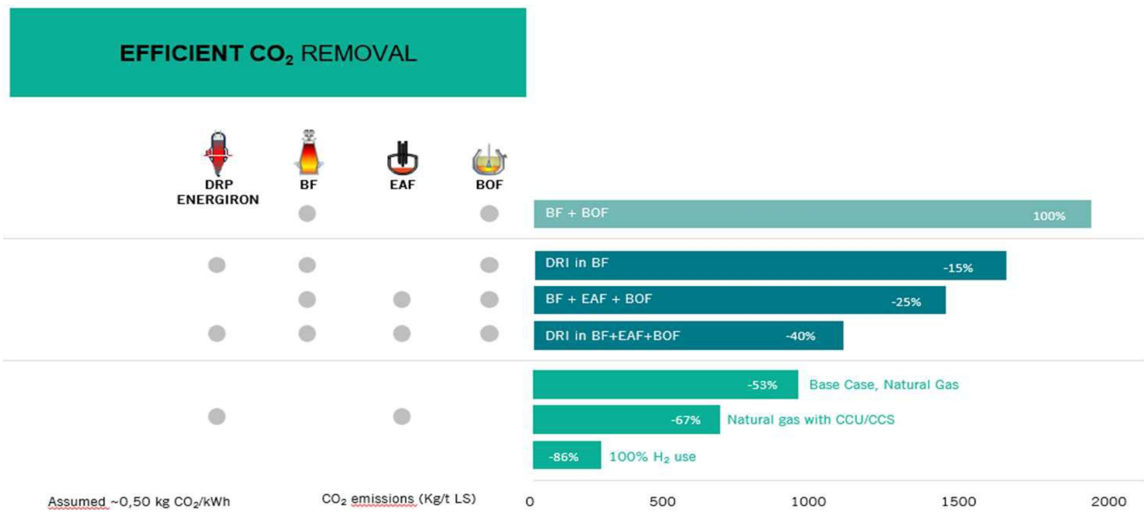
The efficiency of this system is maximised at high pressure and low temperature.

That's why in Energiron plants the CO2 can be sequestrated, without any additional CAPEX or OPEX.

Up to 60% of the generated CO2 can be captured, for its subsequent use or geo-storage.



Decarbonization scenarios range from NG base case to NG + CCU to 100% H_2, achieving up to 86% CO_2 reduction.



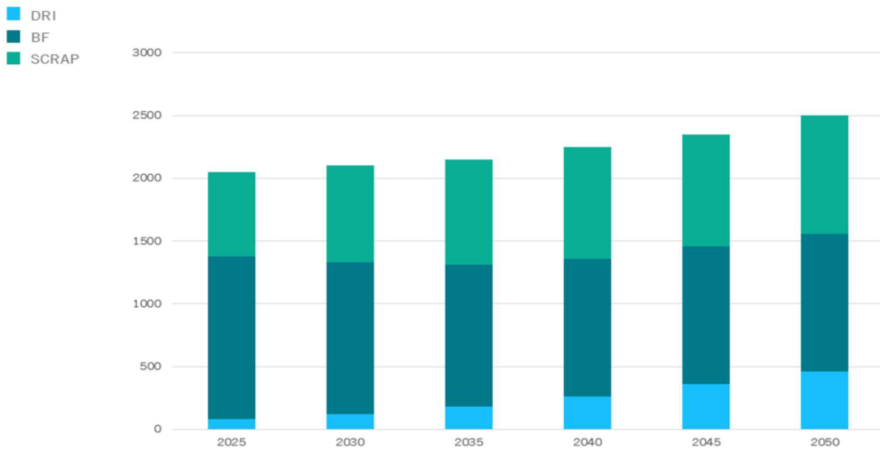
Flexibility of gas feed and Cold DRI

The possibility of Energiron to work with different reducing gases is an asset that allows a path for implementation in Indian steel industry. Cold DRI is infact a product already used, and it can be produced in EnergIron DRP's already with a high content of carbon, that may be an asset for primary metallurgy afterwards.

The flexibility means that the plants can be fed using a blend of available gases, likewise natural gas and syngas, and that such blend may be in future be adapted to partial (or full) se of hydrogen when it will be available at quantities and affordable costs.

HBI Market and Global Case Studies

Global HBI market is projected to grow significantly, with DRI production increasing from 80 MT in 2025 to 460 MT by 2050.



Energiron ZR process ensures hot DRI discharge at ~700° C and metallization >93%, supported by advanced thermal lining and process control systems. Market Implementation and the preferred choice in Jindal Steel in Oman highlights such benefits.

Conclusion

Green iron is no longer aspirational—it is a strategic imperative. Energiron's flexibility, efficiency, and integration capabilities position it as a cornerstone for India's green steel ambitions and a model for global adoption.

Its advanced technology, environmental benefits, and adaptability make it a valuable asset for steelmakers seeking to align with global decarbonization efforts. The integration of Energiron into steelmaking processes enables significant reductions in CO_2 emissions, improved product quality, and enhanced operational efficiency.

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IRON REDUCTION OPERATIONAL ASPECTS- Midrex Process
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IRON ORE

World-wide reserve of iron ore resources is estimated at 800 Billion Tons which makes 230 billion Tons of Iron. Australia, Brazil, Russia, India, China & Ukraine are having the largest iron ore deposits.

Recoverable Iron Ore deposits in India are 20 Billion Tons and the major iron ore deposit states are Orissa, Chhattisgarh & Karnataka. Pure Fe_2O_3 contains 69.94% iron & 30.06% oxygen.

The feed mix should have high iron content at economical cost, ability of the ore/pellets to resist degradation due to impact & abrasion during transport, reduction & product handling. Physical & Chemical behaviour of the oxide during reduction at elevated temperatures play a crucial role in suitability.

There are mainly 3-types of DRI furnace- (a) **Vertical Shaft Furnaces** of varying mega capacities which are gas based, deriving reductants from natural gas by reforming, partial oxidation of coal, corex export gas by removing cabon dioxide, part use of coke oven gas or latest under construction by use of green hydrogen (H_2 production with no harmful green-house gases emission). Major technologies are of Midrex, VAI, HYL/Energiron & Pered. The Midrex process is widely accepted across the globe for its large capacity plants, high annual running days (on-stream) of 330 to 340 days, production of consistence highly metallized product as per requirement and exceeding the rated capacity year on year. The low pressure stable operation invites less break downs & easier maintenance of plant.

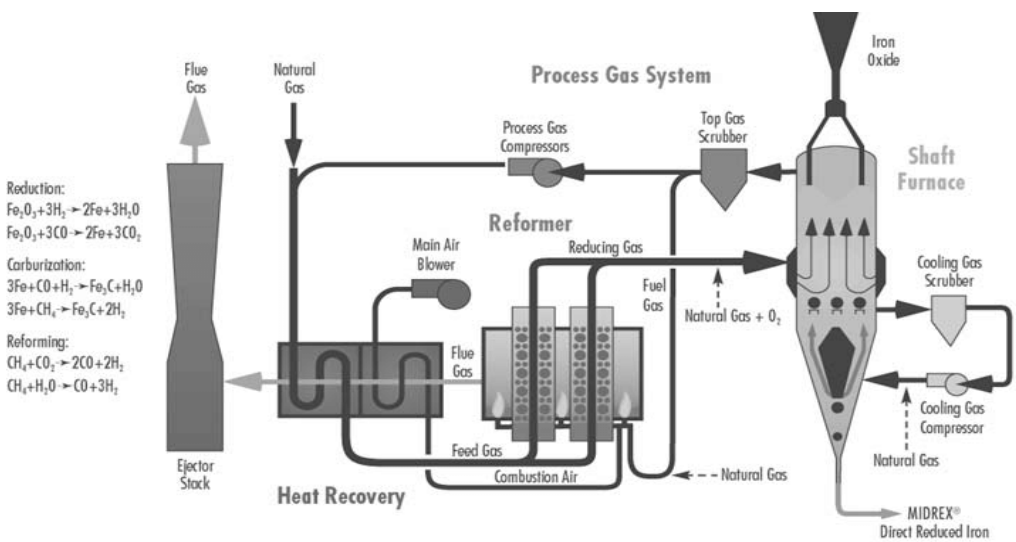
(b) **Rotary Kilns** which are coal based are comparatively of low capacity plant requiring calibrated lump ore (iron content of 63 to 67%) or pellets feed of sizes 5 to 25 mm. Over the years these rotary kiln are widely adopted in our country due to local availability of iron ore & non-coking coal. Quality of ore & coal plays important role in productivity & quality of DRI produced. Random formation of accretion, ring & boulders inside the kiln reduces the Kiln campaign life cycle. Also metallization levels & carbon content remain low in coal based DRI. Environmental management of dust emissions in plant areas remains a challenge. Dust settling chamber cleaning & safe removal of accretions are major safety concerns. It is quite simple plant as compared to other gas based processes.

C) **Finex Process of POSCO** & **Primetals** Technologies utilizes a cascade of Fluidized Bed Reactors in series for DRI production where Ore fines (having mean grain sizes of 1 to 2 mm) in suspension are reduced by coal gasified reducing gases which are hot compacted & transferred directly to a melter-gassifier, thus avoiding the necessity of pellet or sinter plant in producing melt steel. Both, coal and coal briquettes are charged to a Melter Gassifier to generate necessary heat for melting & reducing gas generation. The Finex export gas is used for combined cycle power plant. Since DRI produced are mostly fines offering large surface area, its compacting is necessary to avoid re-oxidation. The first plant set up in Pohang with a capacity of 2000 Mt per day is in operation since Year 2003.The reduction reaction is very efficient due to large surface area offered by ore fines & its intimate contact with the reducing gas. Gaseous emissions from this process is also lower. Two other Finex Modules of 1.5 Mt & 2 Mt annual capacities are in operation in Pohang since 2007 & 2014 respectively. A modified process of Finex called 'HyREX is being developed to use 100% hydrogen gas as reductant in making of DRI which is a positive step towards green steel production. This process can use ore with high alumina content. Though Finex process looks attractive, it is still within POSCO.

d. MIDREX DIRECT REDUCTION PROCESS IN BRIEF

The Midrex moving bed shaft furnaces are of large height of about 40 meters & their diameters vary as per capacity requirements. Oxide Feed Mix can be a blend of pellets & lumps in this process. Pellet size of 9 mm to 16 mm (falling in range of minimum 95%) of 67% iron content is preferred. Calibrated lump ore of size 10 mm to 35 mm (falling in range of minimum 85%) of > 67% iron can be used. The feed mix may contain 20 to 30 % of good quality lump ore having high iron content & with low decrepitation rate. Lower percentage of lump lubricates the burden flow and minimizes cluster formation. The more iron in the feed mix, the more DRI tonnage & less slag formation in SMS. Pellet feed of 100% with high iron content will give maximum tonnage. Only lump ore of Bailadila origin was found suitable and other Indian sources were decrepitating more in the furnace with low iron content affecting product quality because of fines segregation in furnace. The feed mix selection is done on economic consideration of cost, tonnage & quality.

Reducing Gas Generation of hydrogen & carbon monoxide required for reduction in furnace, is done in an air-tight refractory lined welded large box (called Reformer) having multiple rows & bays of catalyst filled reformer tubes (450 nos. of size 10 inches) and nozzle mix burners (total 270 nos.) of varying heat release capacities. The preheated natural gas of specified composition is mixed with recycled process gas containing required moisture (H2O) and carbon dioxide for stoichiometric reforming. The reformed gas temperature is maintained at 930℃ & the pressure is about 1.5 bar. A simple process flow diagram is given below.



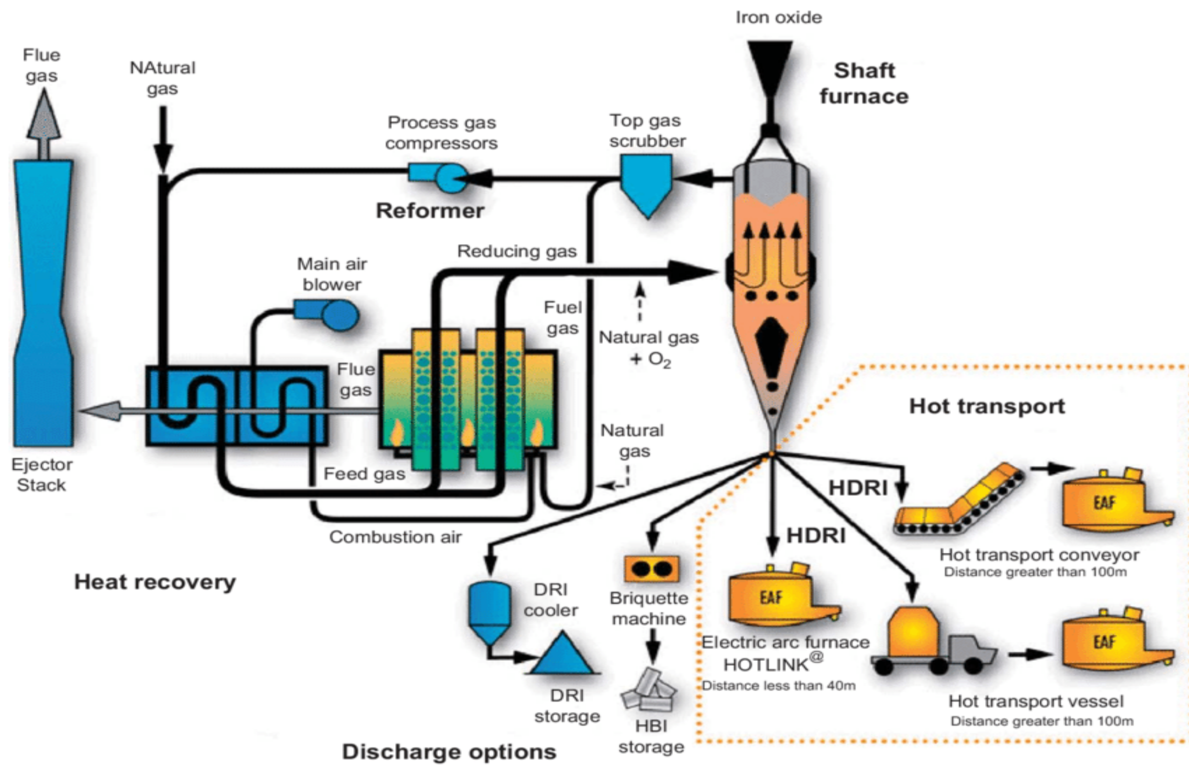
The reformed gas which is 95 % H_2 + CO is further conditioned as bustle gas, after controlling its temperature & adjusting methane percentage, which enters the furnace moving bed near the bottom of the reduction zone

through numerous peripheral ports via a distribution bustle. The screened feed mix is charged to the top of the furnace at about 91 m height by a flexowall conveyor in a charge hopper through riffler for proper distribution over the furnace burden. The feeding system consists of charge hopper, upper seal leg, proportionating hopper and multiple feed pipes. The furnace system operates under positive pressure of 0.350 bar to 0.5 bar. The furnace internals are having multiple feed pipes, various thermo-couples in reduction, transition & cooling zones, double bustle ports, sets of burden feeders and cooling gas injection device called Xs-Tree.

The reformer box operates at a high roof temperature of maximum 1130℃ & the floor temperature of 1070℃. The box pressure is maintained at minus 5 mbar through a power (ejector) stack fan. The preheated Feed Gas, which is a preheated mixture of compressed process gas & natural gas, enters at the bottom of the multiple catalyst filled tubes. The preheated hot air at 700℃ is supplied to main burners which are provided on the floor of the reformer box in different rows. Heat is recovered (about 80%) from the reformer flue gas by preheating reformer feeds like combustion air, feed gas, top gas fuel & natural gas before being vented to atmosphere through an ejector stack fan which maintains the desired vacuum in reformer box.
Having designed cold discharge, the reduced DRI is cooled to about 43℃ at the bottom portion of furnace by circulating cooling gas. The cooling gas enters the cooling zone of the furnace through a gas distributor having multi layered multiple holes called Xms Tree which is centrally located to minimize channeling & give plug flow of material. The furnace exit cooling gas is water cooled & scrubbed of dust before recycling through cooling gas compressors.

The cold DRI having possibility of overheating is screened of dust & fines and stored in product silos for 48 hours passivation before internal use or export. The separated fines are cold briquetted & sent to SMS. Part of the reformer flue gas is cooled, compressed and used as seal gas in top & bottom seal legs of furnace and some seal gas is conditioned to be used as inert gas or passivation gas in product silos after controlling its oxygen content to less than 3% & moisture removal.

The DRI quality can be maintained consistently to desired levels of 92 to 95% metallization and up-to 2.0 - 2.5% carbon without much process stress. One percent increase in metallization decreases production rate of DRI by 2% whereas it increases EAF yield by 0.3 – 0.5% and its productivity by 0.6 – 1.2%. To minimize thermal shock to reformer tubes & reduce plant re-startup time after any stoppage the plant has been designed to be in **4 states** by providing suitable instrumentations & interlocks : (a) **Cold Condition**: when reformer & furnace both are cold. (b) **Extended Idling**: When reformer is hot at 850℃ & furnace is cold. Only reformer is kept in hot condition. (C) **Idling**: When reformer & furnace both are hot but no production. Shut down conditions requiring maintenance to attend leaks, or plant trip, raw materials supply limitation or upsets (d) **Operating**: When plant is making normal production.



Heat Consumption by the Process

Heat of reaction to reduce ore = 62 %, consumed in furnace.

a. Net heat loss in reformer flue gas stack which depends upon designed heat recovery units = 20%
b. Heat loss in top gas scrubber = 11% due to cooling of furnace top gas for recycling as process gas & as a fuel to reformer.
c. Heat loss in Cooling Gas scrubber to cool DRI = 3%.
d. Heat Loss in Reformed Gas Cooler = 2%, a provision to control bustle gas temperature, mostly during start-up, plant normalization, abnormal operating conditions & shut down.
e. System refractory heat Losses =2% from vessel shells, headers & pipe lines, reformer box etc.
f. Out of 34 % heat in reformer box exit flue gas: 14 % of the heat is recovered i.e., in recuperators (8%) & Heat Recovery Tube Bundles (6%) which of-course depends upon designed heat recovery system in a particular DRI plant.

Theoretical Concept of Reduction & Material Balance

Reduction Reactions with Carbon monoxide

All reactions are reversible & for forward reactions to proceed the ratio of reductant to oxidant (H_2+ CO)/(CO_2+H_2O) must be greater than an equilibrium value of 2.

Reduction by CO occurs in 3- stages at temperature >570°C.

a. $3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$ - 12.6 Kcal
b. $Fe_3O_4 + CO = 3FeO + CO_2$ + 8.66 Kcal
c. $FeO + CO = Fe + CO_2$ - 4.13 Kcal
d. $\frac{1}{4} Fe_3O_4 + CO = \frac{3}{4} Fe + CO_2$ - 0.93 Kcal

The relative partial pressure of CO, CO_2, H_2 and H_2O in the reducing gas and the presence of inert gas like N_2 have an effect on the rate of reduction in the furnace.

Reduction by Hydrogen Gas also takes place in 3- stages at temperatures above 560℃ and 2- stages below 560℃.

a. $3Fe_2O_3 + H_2 = 2\,Fe_3O_4 + H_2O$ - 2.8 Kcal
b. $Fe_3O_4 + H_2 = 3Fe0 + H_2O$ + 18.5 kcal
c. $FeO + H_2 = Fe + H_2O$ + 5.7 Kcal
d. ¼ $Fe_2O_3 + H_2$ = ¾ $Fe + H_20$ + 8.9 Kcal

The overall reduction reaction is endothermic (system absorbs heat) & the heat is supplied by the sensible heat of the reducing gas.The reduction of wustite to iron is the longest step of the whole reduction process. In the final stages of reduction i.e., 85 % and above, the reaction rate decreases drastically showing that some very slow determining process is taking over control. This slowing down of reduction rate is attributed to the sintering & re-crystallization (reduction in porosity) of the newly formed metallic iron which occurs readily above 650℃.

The final stage of reduction i.e., FeO to Fe^{++} is accomplished by the richest gas in the system i.e., reduction gas entry at bottom most bustle of the furnace.

Material Balance of oxide Reduction by Hydrogen

Ore Input for 1mt Iron Production:

a. Fe% in ore = 68.5
b. As Fe_2O_3 weight of ore = (160/112) *68.5= 98 kgs.
c. Iron Ore for 1 t DRI = (100/68.5) *1000= 1460 kgs.
d. O_2% = (98-68.5) = 29.5
e. Gangue % = (100- 68.5-29.5)= 2

Total Input in - Kgs

a. Iron produced = (1460 * 0.685) = 1000
b. Gangue = (1460 *0.02)= 30
c. Oxide weight without gangue = 1460-30 =1430
d. Oxygen =(1460-1000-30) = 430

Material Balance of Reduction with Pure H_2 Gas

Gaseous Input:

$3H_2 + Fe_2O_3 = 2Fe + 3H_2O$

a. Pure H_2 for 1t DRI conversion of 95% total iron
= 3 moles of H_2 *1430* 0.95/160
b. = 51 Kg of H_2 which equals to 22.4 Nm3/2 * 51 = 571 Nm3 of gas. However the conversion of H_2 is limited by the equilibrium conditions and therefore the actual circulation of H_2 gas is much more than the stoichiometric value shown above.

c. For 95 % total iron in DRI, The quantity of O_2 transfer = 430 * 0.95 = 408 kg.

Gaseous Output

d. H_2O Vapour = 408 + 51 = 459 Kg

= 571 Nm3

Solid Output

DRI = 1000/0.95 = 1052 Kg

e. Gangue= 30 Kg
f. Iron = 1000 Kg
g. Oxygen =1052-1000-30 = 22 Kg

Product Analysis:

h. Total Fe % = 95
i. Metallic Fe % = 88
j. Degree of Reduction = 408/430 = 95 %
k. Degree of Metallization = 88/95 = 92.6 %

Raw Materials Selection Criteria

A. Oxide: Raw materials selection is done to suit the requirements of both DRI Plant & SMS. Raw materials physical, chemical & reduction characteristics are evaluated properly before buying.

The presence of certain common impurities in the ore may have a negative effect on the rate of reduction & the process.

a. Lime has been found to accelerate the reduction process. Cao increases the basicity (Cao + Mgo)/ (SiO2 + AlO2).The lower the silica, the less CaO is required to decrease swelling of pellets. Basicity of 0.70 to 1.0 % is desirable for pellets.
b. MgO content of 0.4 to 0.7% in the feed material is desirable as it increases reducibility & improves the strength of the pellets. Magnesium minimizes swelling phenomenon in pellets.
c. Silica forms ferrous silicate & hinders the reduction process. However optimum silica is required for strength. About 2 to 3% silica is enough for strength.
d. Alkali oxides (sodium/potassium) in the feed promote swelling & degradation during reduction. Maximum allowable concentration is 0.1%.
e. Phosphorous has no effect on reduction of DRI. Up to 0.35% P2O5 is acceptable to SMS.
f. Sulfur has negative effect on the reformer Catalyst activity when gets liberalized in the system through top gas. Its limit in feed mix is 0.01%.
g. Zinc is not desirable.
h. TiO2- Influences the material swelling behaviour & causes cluster formation in furnace. Its limit is 0.15%.
i. Alumina: It is hard to reduce & generates thick slag in SMS. Silica + Alumina content may be 2.0 to 3.5 %.
j. FeO content limit is 0.8% in pellets because it is in magnetite form & not indurated properly.
k. The presence of free water & LOI are undesirable because they require extra heat load & give increased volume of gas. Extra water vapor reduces the reduction rate.

(B) **Natural Gas Quality for Reformer**

On line Natural Gas Analyzer is recommended to know the quality variation for timely corrective process actions like increasing moisture in process gas, load reduction or even plant stoppage. Safe-guarding the catalyst activity is of paramount importance for sustained economic operation of the plant.

C. Desirable Oxide Qualities for higher production:

- Higher iron content of more than 67 % TFe, with low FeO of <0.5%. However higher iron content in oxide increases sticking tendency in furnace.

1. Pellets having large pore diameter, higher porosity, higher external surface to volume ratio and smaller particle diameter will increase metallization. The time for reduction is proportional to the particle size for phase boundary reaction control and to the square of the particle diameter (size) for gaseous diffusion control.
2. Higher reducibility, Limited Silica in the Ore/Pellets
3. Uniform CCS of 300 kgs for pellets for less fines generation during reduction & product handling.
4. Able to tolerate higher bustle gas temperature operation.

Maintaining Optimum Operating Parameters For Sustained Operations

(a) **Reformed Gas Quality** should be as follows:

a. Reformed Gas CO_2 = 2.5 %
b. Methane slip in reformed gas= 0.5 to 1.5 %
c. Reformed Gas Temperature = 930 to 940℃
d. H_2/CO Ratio of reformed gas = 1.5 to 1.6 : 1
e. Reduction Potential $(H_2+CO)/(H_2O + CO_2)$ = 11.5

Factors Affecting Reformed Gas Quality are

a. Prevailing Catalyst Activity & Natural Gas Supply Quality.
b. Other Reformer Limitations like: High Box temperature, positive Pressure in Box, High Reformer differential pressure, carbon built-up in catalyst or catalyst degradation, higher load plant operation, No additional Capacity in Main Air Blower, Red Hot Reformer Tubes, Moisture control in process gas, High Sulfur in feed gas, Power Stack Fan capacity limitation also play roles on quality of reformed gas production.

Required Bustle Gas Quality

a. The Ratio of Reductants (H_2 + CO) to Oxidants (CO_2 + H_2O) in bustle gas is termed as B.G. Quality (also known as Reducing Potential) The optimum ratio is about 11- 12 without O_2 injection.
b. Operations below 10 is un-desirable.
c. Gas Quality must exceed the minimum ratio of 2.0 before reduction to Fe will occur.
d. Drop in BG quality ratio from 11.3 to 10.0 if O_2 Injection is increased from 0 to 8 nm3/mt of DRI.
e. Drop in BG quality ratio from 11.3 to 9.0 if O_2 Injection is increased from 0 to 16 nm3/mt of DRI.
f. Optimum Ratio of H_2/CO = 1.5 to 1.6 in reformed gas. Higher ratio pushes $C + H_2O = CO + H_2$ reaction i.e., towards decarburization in reformer.
g. Oxygen Injection System lowers Bustle Gas Quality & the maximum quantity to be optimized with increase in production.
h. Maintaining 3 % CH_4 in B.G. is a safe limit at normal H_2/CO ratio to avoid methanation reaction in furnace which is exothermic runaway reaction.

Effects of High H_2/CO Ratio in Reformed Gas

a. Increases fuel consumption in reformer.
b. Lowers burden temperatures as reduction by H_2 is endothermic.

c. Has lower carburizing potential in furnace.
d. Reduction is faster because of high H_2.
e. High ratio decreases CO_2 in Reformed Gas Significantly.
f. Generates additional Top Gas Fuel.
g. High ratio increases the methane content of reformed gas or reformer needs to be operated at higher temperature.
h. will vary H_2/CO ratio in reformed gas. The stoichiometric ratio varies as per variations in natural gas quality and CO_2 & Moisture % in Process Gas.

Effects of Process Gas Flow

a. Increasing reducing gas flow through furnace will improve metallization by lowering CO_2 partial pressure which is one of the reaction products.
b. Increasing process gas flow will increase reformer load.
c. Specific process gas flow depends upon the operating bustle temperature. Minimum specific flow achieved at Imexia is 850 NM3/M.T. at 990°C bustle temperature.
d. When Process Gas CO_2 goes beyond 21.5 %, Specific Process gas flow needs to be increased.
   The amount of reducing gas required varies with the composition of the gas, the reduction temperature & gas utilization. A high ratio of process gas flow per ton indicates low gas utilization.

Importance of Furnace Bed Temperature indicators

a. Burden temperatures are useful indicators for evaluating bed movement, gas distribution and detecting furnace up-set conditions.
b. Whenever bustle temperature is raised & bustle methane is kept constant, there will be rise in furnace burden temperatures. In a normal moving bed the temperature difference between bustle gas & wall temperature at lower thermocouple will be around 50 to 80°C.
c. Sudden drop or rise in bed temperatures indicates sluggish bed movement.
d. The center bed temperature drops gradually with increasing discharge rate even though bustle temperature is raised .This is improved by taking cooling zone bleed to Reformed Gas Duct or Process gas compressor suction.
e. In no case the bed temperatures should be allowed to cross the clustering temperature of the selected feed mix. The bustle temperature is therefore increased gradually @ 5°C every 12 hrs.
f. The highest burden temperature of 900-1000°C has been practiced. Any abnormal high bed temperature is controlled by raising quickly the bustle methane (up to 6 - 8 %), lowering the bustle temperature and or making more discharge from the furnace to avoid clustering.
g. High moisture carry over from Reformed Gas Cooler or leaky hot valve can raise bed temperatures because of re-oxidation.
h. The highest bustle temperature, tolerated by the bed, is attained by optimizing the oxygen flow if in use & bustle methane adjustment.

Burden Feeders Speed Calculation as per Discharge Rate

a. UBF- Minutes/ Stroke = 704.8 / T/hr
b. MBF- = 49.14 / T/hr
c. LBF = 5.825 / T/hr
   T/hr is the furnace discharge rate.

Minutes/ Stroke is the time required for the burden feeder to travel one direction only.

Importance of Double Bustle Ports in Mega Modules

a. Its function is to reduce the bustle gas flow velocity through tuyers to less than 70 m/sec.
b. Reduce burden pressure drop to less than 170 mm wc/m of bed.
c. To eliminate "Bubble formation" in the descending burden at the tuyers.
d. To minimize funnel flow i.e., to maintain a uniform temperature & pressure gradient within the shaft furnace resulting in uniform product quality.
e.

Various Operational & Maintenance Problems, their Symptoms & Corrective Actions

Most of the below mentioned problems are faced in all vertical moving bed shaft furnaces having reformers to generate reducing gases.

1.(a) Premature Loss of Reformer Catalyst Activity & its Symptoms

he reformer operation is the most critical along with oxide start-up operation of the plant. The SOP of reformer & maintaining its suggested operating parameters are very rigid & non-flexible. Any deviations & short-cut in procedures may pay heavy penalty to the plant. The catalyst may crumble to dust due to boudouard reaction ($2CO \quad C + CO_2$) if it occurs and which may lead to permanent high reformer dP. Complete adherence to oxide start-up procedure is required to avoid carbon formation in the catalyst & cluster formation in furnace. Heavier HCs or excess sulfur present in NG may lead to carbon deposition in the catalyst & subsequent red hot reformer tubes & unbalanced box temperatures. Such problems may result in under performance of reformer for a long time, low load operation, frequent carbon burn-out leading to production loss & remet (off-grade) generation and cutting short the expected lives of reformer tubes & catalyst in addition to operational handicaps. Continuous operation at low level of catalyst leads to premature failures of reformer tubes at roof level of the box. Catalyst filling procedure to be followed strictly along with differential pressure measurement of individual catalyst filled reformer tubes.

B. Corrective Actions: a. Adequate manning of DCS Control Panel by qualified experienced engineers is a must who know about the theory involved, understand the process & its control logics, PLC operation, various process interlocks, detecting, diagnosing & correcting any abnormal situations at the earliest, fully knowing reformer lining up, heating, enrichment & reforming steps. They need to have alertness and good communication skills. They should be fully convergent with the normal operating data which need to be maintained and also capable enough to handle abnormal operating conditions with direct communication to field operators.

b. The stoichiometric ratio of feed gas mole ratio ($H_2O + CO_2$) / (total C in hydrocarbons) should always be above 1.4 to avoid carbon deposition in catalyst. The floor & roof temperatures to be maintained at 1040 & 1130°C respectively. The feed gas temperature to be maintained as 540/560°C as per design.

c**.** Carbon formation from CO to be avoided by not initiating any reforming at low bottom temperatures.

d. Whenever rich NG is entering the plant the process gas temperature to be raised to improve stoichiometric ratio which is possible once you have on-line fixed natural gas analyzer. A guideline to be made about reformer operation when the NG is having more than the prescribed limit of heavier hydrocarbons i.e., possible load reduction or plant stoppage to avoid carbon deposition in catalyst.

e. Catalyst loading profile in reformer tubes to be judiciously decided as most of the plants use low active & high active catalysts as per expected NG quality.

f. The catalyst loading in reformer tubes should be done by using vacuum loading or sock loading or rubber flapper method to get homogenous dense loading. The tubes should be vibrated while loading & hammered occasionally by a wooden hammer.

g. During annual shut down the tube catalyst levels should be checked randomly & if found low level, catalyst top-up may be required in all the tubes. Prior gasket arrangement is necessary before opening the top flange of reformer tubes.

h. The counter weight or spring supports of reformer tubes needs to be adjusted when heated to take care of expansion.

i. Any leaky tube needs to be blinded early to avoid nearby tubes damage & heavy loss.

j. From minor to mild carbon deposition there is a carbon burn out procedure to wipe out the carbon.

k. If there is severe or heavy carbon deposition in catalyst, it may need dumping, segregation, re-screening & top up with fresh catalyst. The fresh catalyst requirement may be 30% of total charge.

l. Densely filled catalyst tubes with broken pieces will raise skin temperature & loosely packed will limit the capacity of the reformer.

The care & precautions required in reformer operations have already been discussed in the aforesaid paragraphs.

HYL Reformers operate at 7.0 bar pressure with RG out let temperature between 800-850℃. It is a steam reforming process having steam/carbon ratio of 2.4 & therefore its H2/CO ratio is 5.0. It uses high nickel based catalyst has a maximum limit of 0.5 ppm sulfur in feed gas. Because of excess steam use & using higher active catalyst, reformer is operated at low temperature without carbon deposition. Even though, problem of Carbon deposition is faced in this reformer catalyst also and the precautions required are similar to Midrex reformer as mentioned above.

2. Variations in Metallization: Normally, the DRI quality remains stable unless there is a change in feed-mix or its screening quality. The reformer operation is very stable and the operating conditions are not changed frequently. Every 2- hourly sample is analyzed for the quality. However, there are various factors which may bring quality variations.

Maintaining_furnace bed permeability is the single most important parameter in vertical shaft furnace. Homogenous bed mass & uniformity in solids & reducing gases contacts in furnace is essential for more tonnage & consistence quality production. Feeding of specified sizes of pellets & lumps is essential for good permeability in furnace bed.

Maintaining Reducing Gas (Reformed Gas) Quality, Bustle gas quality, Flow rate of burden (Furnace Discharge Rate or Residence Time), Specific flow rate of process gas/ reducing gas, Operating Bustle gas temperature, Uniformity in Furnace burden temperatures, Natural Gas additions in Transition zone(added for in-situ reforming & iron carbide reaction) & Cooling Zone (to improve surface carbon in DRI & to lower C.G. temperature) and in Carburizing Bustle of furnace in case of HBI plant are, all having effects on metallization degree.

Other parameters like Burden feeders speed, Cooling gas temperature, Cooling zone up-flow (gas flow from cooling zone to reduction zone), Cooling gas flow in circulation & its quality, Cluster Formation in furnace if bigger & in appreciable numbers, Free moisture in the oxide feed & Furnace operating pressure also have roles in achieving the required metallization degree**.** The panel engineer has to find out the specific changes that have taken place either process or physical condition of feed mix which is responsible for quality variation & take timely corrective actions.

3.Controlling Carbon in DRI

The Carburizing potential of the gas is dependent upon its temperature (500–900°C) & partial pressures of H_2, CO, CH_4, CO_2 & H_2O in the gas. The carburizing reactions in furnace (Reduction/Transition & Cooling Zones) are:

- $3Fe + CO + H_2 = Fe_3C + H_2O$
- $3Fe + 2CO = Fe_3C + CO_2$
- $3Fe + CH_4 = Fe_3C + 2H_2$

Because of the large surface area of DRI, the carburization is mostly a surface process. Little carburization occurs below 500°C because of slow reaction kinetics.

a. Decreasing bustle temperature increases the carburizing potential however it is more desirable to operate at high bustle temperature to maximize production.
b. Increasing the methane concentration in bustle gas increases the carburizing potential in reduction zone in addition to in-situ reforming. As the methane cracks it cools the bed but reacts with iron to form iron carbide. The methane concentration in B.G. is optimized by desired discharge rate which in turn will fix the required bed temperatures, injected oxygen flow & the quality of bustle gas required to achieve a particular product quality.
c. Transition Zone (furnace zone below reducing zone & above cooling zone) natural gas addition in low gas flow zone of furnace utilizes the sensible heat in the burden to crack & to do in situ reforming. It cools the bed and increases carburizing potential. Reforming of 35 Nm^3 of CH_4 per ton DRI, reduces the bed temperature by 115°C. The heat loss is partially compensated by raising the bustle gas temperature so that the reaction kinetics does not suffer adversely. This transition zone natural gas cracks to H_2 & solid Carbon than reform to H_2 & CO.
d. The methane rich cooling gas carburizes in the upper portion of the Cooling Zone & transition zone.
e. Other things being equal the Feed Mix affects the carbon content of DRI.
f. Increase in CO_2 concentration in B.G. will lower carbon in DRI.
g. In HBI Plant the carbon content is controlled by carburizing gas flow & natural gas addition in it.

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4. **Lower Gas Utilization in Furnace**

It is a measurement of how efficiently the reducing gases react within the reduction furnace. The ratio of the calculated minimum flow requirement to the actual flow of reducing gas supplied is called utilization. Utilization is 100% when the actual consumption attains the chemical equilibrium value. The higher the utilization, the lower the quantity of reducing gas requirement per ton of DRI. The gas utilization of 80 – 90% is considered optimum. There are many factors which affect furnace gas utilization:

a. The Reductant-to-oxidant ratio (H_2 + CO)/(H_2O +CO_2) of the reducing gas. Higher ratio will increase furnace utilization**.**
b. The H_2/CO Ratio of the reducing gas. Decrease in ratio favours the gas utilization.
c. The higher temperature of the reducing gas will favour utilization but to be below softening temperature of oxide.
d. The methane content of the reducing gas. Higher value will increase carbon in DRI & will lower bed temperature. This is optimized (3 to 5%) with bustle temperature operation.
e. The reducing gas distribution in furnace.
f. The oxide feed material- low oxide quality results in lower utilization.
g. The uniform burden permeability: The furnace burden must have uniform permeability to ensure good gas distribution. Channeling of the reducing gas in the furnace will lower furnace utilization.

Symptoms of Material bridging in top seal leg and/or in feed pipes due to excessive undersize particles, large size materials or foreign objects entry in the feed mix:

a. A gradual decrease in top gas CO_2 concentration.
b. A gradual increase in top gas temperature.
c. Rapid change in top seal leg differential pressure
d. Increase in proportionating hopper temperature.
e. Warm or hot feed pipes on touching. No material flow sound.
f. High Carbon Mono- oxide level in Charge Hopper floor. Don’t bent over charge hopper.

Remedial Actions to overcome top seal leg bridging

a. Hammering of the upper seal leg & feed pipes**.** Clean upper slide gate pocket.
b. Lowering system pressure & decreasing top seal gas flow without losing seal.
c. Run fire water pump. Water flushing of charge hopper lower cone/seal leg. Clean upper slide gate pockets. Correct the screened oxide quality if it is the cause. Change feed mix if required.
d. Open & close upper slide gate periodically by ensuring top seal differential pressure.
e. Maintain PG CO_2 above minimum required (16%) by adjusting process natural gas flow to reformer i.e., load reduction.
f. Maintain high level in charge hopper to take care of heavy material fall once bridge breaks. Take care of top seal differential pressure.

5. **Cluster or Agglomerate Formation Symptoms in Furnace**

Cluster formation (bonding of metallized materials in the burden) is governed by bed temperature, oxide-particle strength & its surface characteristics and to some extent by the degree of metallization. Clusters below the size of a helmet are characterized as insignificant. The reduction zone temperature is influenced by bustle gas temperature & its composition. The maximum operating temperature attainable with various types of lump ore & pellets are dependent upon their physical & chemical properties. Some of the common causes are sudden surge of oxide fines or wet material or change in ore chemistry, uneven flow of materials in furnace resulting in gas channeling, keeping furnace in idling condition for extended duration. Clustering seriously affects the furnace operation & it should be avoided all the time otherwise it may halt production for quite some time.

Prevention of Cluster Formation

a. Maintain reduction zone temperatures below the clustering temperature of the oxide feed at all time. Increase bustle methane and/or CO_2 %age in reformed gas to cool the bed. Lower bustle temperature gradually till clusters disappear.

b. Maintain appropriate speeds of burden feeders so as not to pack the burden. Increase the % of proven non-clustering oxide (pellets) in the feed mix if available. Be care-full while feeding new shipment.

c. Ensure adequate & uniform lime coating of feed mix if operating at high tempt.

d. Restrict undersize % age in the charge hopper feed.

f. Avoid multiple jerking in furnace discharge rate & system pressure which is sometimes given to arrest funneling flow

g. Avoid free moisture carry over to charge hopper & try to feed dry oxide in the furnace.

g. If clustering not under control cut lump %age in the feed mix and increase pellet percentage gradually.

h. Continuous hammering of lower cone of furnace & lower seal leg may be necessary, in case of heavy clusters, to get smooth discharge.

i. Take care of lower seal differential pressure & don't jumper bottom seal & top seal interlocks. Be careful while standing near furnace discharge due to the possibility of seal loss when big size clusters are falling down.

j. Take steps to control product temperature if rising by increasing C.G. flow. If temperature rises above 55°C product gets diverted to remet bunker which may need spreading to cool & avoid fires.

k. Increase T. Z. Natural Gas flow if low & increase H_2/CO ratio of reformed gas to cool the bed.

l. Try to keep running the plant till bigger clusters are out of the furnace.

m. Optimizing specific Process Gas flow may be helpful.

This is a specialized operation & should be done by experienced panel operator only.
Always remember: Your timely action to control clusters, will save a lot for the company.
Problems of **agglomerate or cluster formation in HYL reactors** are similar to Midrex process where optimizing process parameters & maintaining uniform feed mix quality are utmost important. Chances of agglomerate formations & clogging of reactors are reported more in HYL reactors due to comparatively high temperature reduction & different discharge system due to high pressure reduction.

6. Reformer Tube Failures: These reformer tubes of HP-Nb-micro alloyed with Ti, Zr, W are designed to withstand maximum continuous operating temperature of 1150°C (roof) at 2 bar pressure for 11.5 years with limited thermal shocks. However due to operational upsets like un-scheduled plant stoppages/trips, carbon deposition in tubes, unbalanced box temperatures & operation with low catalyst levels, premature failures of reformer tubes take place. Many plants are getting reformer tube life of more than 11 years & may need catalyst replacement once in-between. Attending leaky reformer tubes need short shut down for blinding at inlet & outlet while reformer remains hot. Careful observation is required to identify the leaky tube. Some plants have suffered heavy damages because of prolonged operation with leaky reformer tube & delay in taking corrective actions. The floor & roof of reformer box are provided with more than 20 numbers of thermocouple for monitoring temperatures.

7. De-dusting Systems Cleaning: Wet scrubbing de-dusting systems are installed for Furnace Discharge, Screen House and Product Silos. Depending upon the oxide feed quality, planned cleaning of these scrubber venturies, pump suction piping & de-dusting fan impellers are required for efficient operations or whenever suction vacuum drops. The fan impellers are cleaned with hose water or by hydro-jets depending upon the coating i.e., loose or hard and the pumps are cleaned of slurries.

8. Hot Discharge from Furnace: Reasons for Hot discharge are the formation of large size clusters, gas channeling in the furnace, carry-over of water from Reformed Gas Cooler or water ingress from burden feeder shaft leakage or extended idling of plant.

Symptoms: Furnace discharge conveyor will detect the rise in temperature which can be checked physically also. Cooling zone skin temperature will also rise.

Handling Hot Discharge: Hot DRI will get diverted to remet on exceeding set value of 55°C. Protect furnace discharge conveyor by spraying sufficient water if red hot clusters are coming. The diverted product in remet needs to be spread to avoid burning. The contributing reason for hot discharge needs to be identified for corrective actions.

Technological Up-Gradations in Midrex Process

Larger capacity shaft furnace up to 7.65 m dia. for large production volume, high temperature reduction by Oxygen Injection in bustle duct, generation of additional reducing gas by Partial Oxidation of Natural Gas, Higher In-situ reforming in transition zone of furnace to reduce reformer load, increased Heat Recovery to conserve energy, integrated hot discharge system for SMS, Combo discharge system for simultaneous discharge of CDRI, HDRI & Briquettes, thin wall refractory design in furnace, providing double bustle ports, reformer capacity enhancement options, oval shape top gas opening in furnace to increase reduction volume & providing degasser upstream of Clarifier to increase clarifier pH & improving clarification and DRIPax Process Automation System to optimize process parameters, predicting product quality & timely adjustment of process parameters to minimize quality deterioration are some of the up-gradations already done.

Bibliography:-

Various Publications of- Midrex, HYL & Others related to DRI.Working experiences in various fertilizer plants- operations & technical services. Gas based DRI/HBI plants & also coal based DRI Plant.
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Smart Metallurgy Approach in the Secondary Steel Sector

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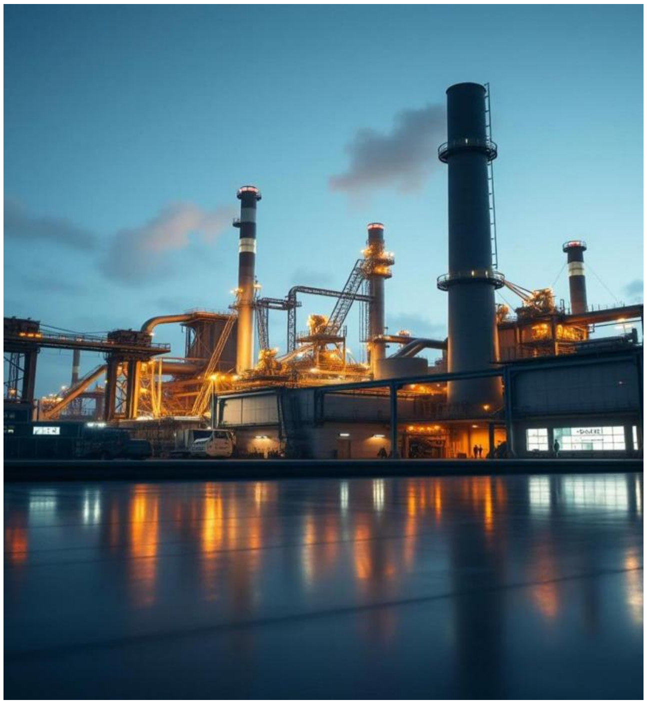


SMART Metallurgy Approach in the Secondary Steel Sector

This presentation explores the transformative potential of SMART metallurgy in the secondary steel sector. We will delve into how sensing, modeling, automation, refining, and transformation can revolutionize steelmaking.

The Genesis & Necessity

METAL & Metallurgy is deeply associated with the Human Evolution . One can directly corelate the advent : a) The Metal of SATYA YUG was GOLD - this was available in it's purest form so no refining was needed and such was the quality of Human Being in his age - no VIKAR - purity in it's highest form. b) Thereafter in Treta Yug the need of purification in the Human Being was sought for & so SILVER became the METAL of TRETA YUG. c) Thereafter in DWAPAR YUG as we all know, how the Human Character got deteriorated , so with this advent the METAL prominent in this YUGa became COPPER - as you all know , coincidently Copper also need much more refining than Silver. Finally the present era is KAL YUGA where the Human Being needs endless refinement ,therefore, the METAL now is STEEL which also needs endless refinement.

As our Era's Metal is STEEL . it has to undergo through massive Metallurgical Process of Refinement which is highly dependent upon Human Competency . Today with the triggered Rising Needs compatible to Industry Norms & Needs viz. Super fast Trains, Cars, EV, Aerospace, Defense , Submarines etc , the Specifications are highly Stringent & demands for the need of Consistency, Repeatability, Accurate & Customised. As per the era's requirement already the Primary Steel making is now supported by Secondary Steel Refining . However, as the world demands high precision in the metallurgical properties , only Technological Development will not be adequate - one needs to adopt a new PHILOSOPHY which is driving the Shift Toward Ai - Driven Metallurgical Processes.

NEEDs TO MAP THE MAKING

The secondary steel sector is at a critical juncture, facing increasing pressure for efficiency, sustainability, and superior product quality. This necessitates a fundamental shift towards more intelligent and adaptive processes.

Resource Optimization

Addressing the intensive energy consumption and variability of recycled raw materials inherent in secondary steelmaking.

Environmental Imperative

Reducing carbon footprint, emissions, and waste generation to meet global climate goals and regulations.

Evolving Market Demands

Producing high-performance steel with stringent quality and precise specifications for advanced applications.

Competitive Landscape

Enhancing operational cost-effectiveness and productivity to maintain a competitive edge in a global market

Understanding the Secondary Steel Sector

Primary Steelmaking

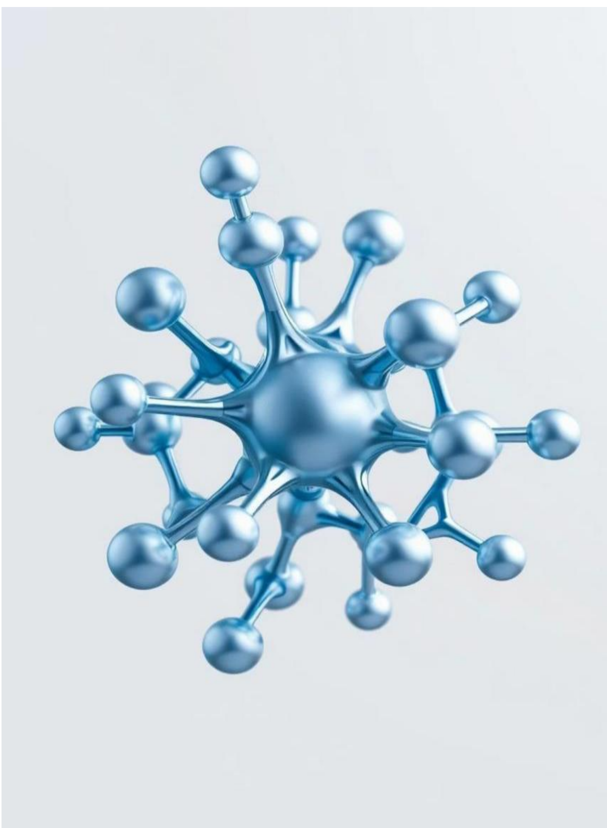
Involves production from iron ore. This is a resource-intensive process.

Composite Steelmaking

Combines primary and secondary routes. This offers a balance of cost and quality.

Mini Mills (Secondary)

Uses recycled scrap steel as feedstock. This is an environmentally conscious approach



The Metaphysics of Steel

Before diving into the SMART approach, let's consider the fundamental nature of steel. Its properties dictate its applications. Understanding this is crucial for advanced metallurgy.

Decoding SMART Metallurgy

1 Sensing

Real-time monitoring of steel composition and temperature.

2 Modeling

Advanced simulation to predict steel properties and optimize processes.

3 Automation

AI, machine learning, and robotics for increased efficiency.

4 Refining

Advanced technologies like VD/Ems/AMLC/ESR/VIM for quality enhancement.

5 Transformation

Transformation of technology with new Philosophy of Pradigm Shift to Digitalisation/ AI adaption to Real Time Decision Making

SMART Applications in the Steelmaking Process

Scrap Melting (EAF)

Efficient melting of scrap using electric arc furnaces.

Predictive Modelling: AI Algorithms analyse historical data, scrap quality & furnace parameters to predict the optimal mix of scrap & sponge iron for efficient melting

EAF Parameter Insights

Data-driven insights to optimize EAF process parameters.

Energy Optimisation: AI Systems adjust energy input in real - time to minimize energy consumption while maintaining the desired temperature & chemistry.

Temperature Prediction: AI-powered models predict temperature fluctuations, enabling precise control over the melting process.

Arc Length & Foamy Slag Practice: The Real Time Data will declare the Arc Length & guiding for the Flux Usage.

LRF: The Heart of Refining

Synthetic Slag

Custom-designed slag for precise control of steel chemistry

AI-Based Tools

Slag Optimisation: Intelligent selection of slag composition, guiding dispersion deoxidation & removal of impurities.

Controlled Operation: On Line Arc Length & corresponding Slag Volume, Fluidity & Foamyness.

Refractory Life Opimisation: Guiding Refractory Erosion based upon Arc Exposure, Real Time Temperature etc.

Customized Properties

Precise prediction & tailoring to achieve desired mechanical properties in the final steel product.

VD: Vacuum Degassing Advancements

VD Optimization

Advanced control systems for vacuum degassing. AI System precisely control vacuum Pressure to ensure optimal Degassing & removal of impurities.

Hydrogen Removal

Sensors and machine learning to control hydrogen levels.

Steel Quality

Techniques to improve overall steel quality.AI monitors temperature changes during vacuum treatment, ensuring precise control over the process

Caster Smart Metallurgy Approaches

Continuous Casting Control

Optimize continuous casting processes - **Mold Flow Control** : AI optimizes mold flow & solidification rates to minimize defects & improve cast quality.

Casting Speed Control : AI adjusts casting Speed & Negative Strip Time on real-time basis to ensure consistent quality & minimise waste.

Solidification Modeling

Simulate solidification processes and casting conditions

Defect Detection

Detect and prevent defects in the cast product. AI- powered Models predict potential defects & quality issues enabling early intervention & correction.

AI Assisted few Steel Plants

In order to address different problems & improvements many Plants have initiated this SMART approach, to name a few :
1) Arcellor Mittal group 2) Tata Steel 3) POSCO 4) Nippon Steel 5) US Steel 6) JSW Steel 7) Bao Steel (Baowu Group) 8) SSAB (Swedish Steel) 9) Hyundai steel 10) ThyssenKrupp steel

Conclusion: The Future of Steel

The Indian steel industry is at a nascent stage. Adopting the SMART framework requires energy, focus, and collaboration between metallurgists and AI Experts.

By leveraging AI & Smart Metallurgy Approach, Steel Plants can match the most stringent requirements of Enhanced quality, Improved Efficiency, Predictive Maintenance & Sustainability to the satisfaction of Industry needs.

To thrive in this era, we must refine steel more effectively and at a competitive price to face global competition.

STATISTICS

Item	Performance of Indian steel industry		
	April 2025 - September 2025* (Mt)	April 2024 - September 2024 (Mt)	% change*
Crude Steel Production	82.065	73.227	12.1
Hot Metal Production	47.211	43.991	7.3
Pig Iron Production	4.310	4.041	6.6
Sponge Iron Production	29.464	27.003	9.1
Finished Steel (alloy/stainless + non-alloy)			
Production	78.445	70.721	10.9
Import	3.345	4.735	-29.4
Export	2.810	2.311	21.6
Consumption	78.860	72.797	8.3
Source: JPC; *provisional; Mt=million tonnes			

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