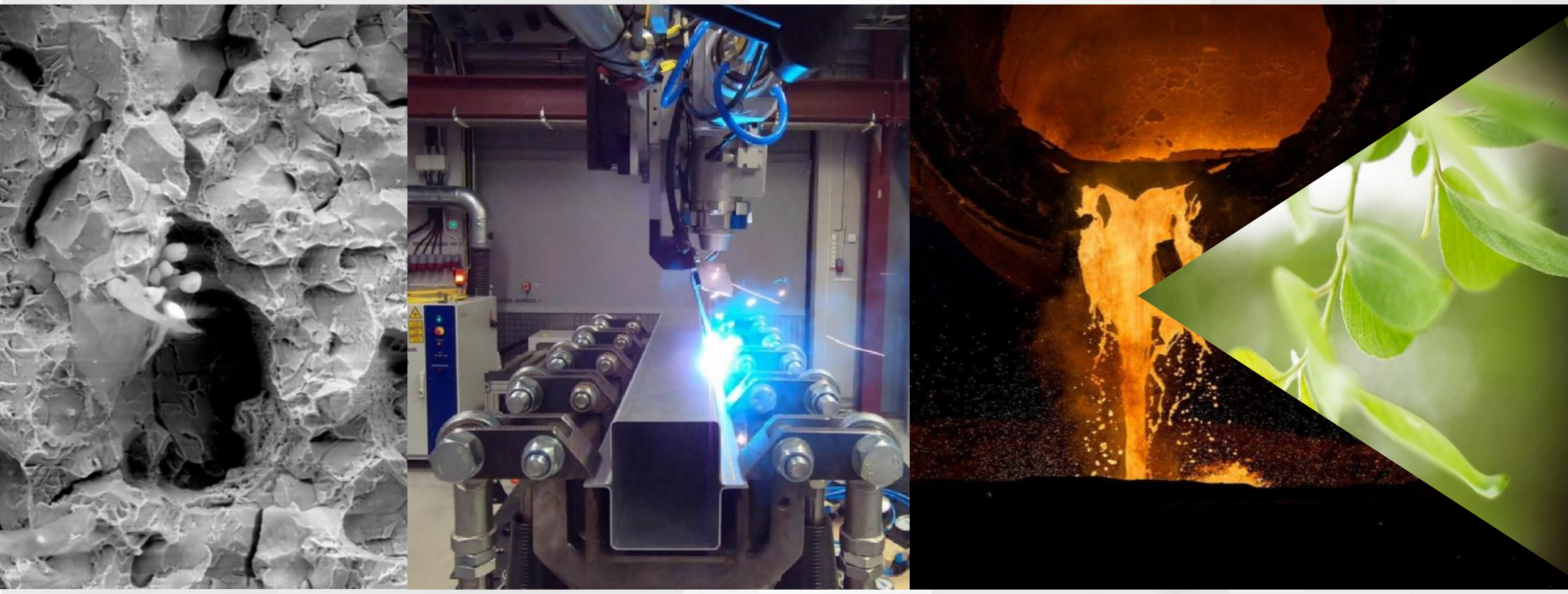

Study of the conditions for Swedish-Indian cooperation in the steel sector

2024-10-30

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Open contract work report

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Investigator:	Mikael Larsson, Paul Cobden, Elsayed Mousa	2025-05-22
Our Ref. No.:	Swerim-2024-350	X Mikael Larsson
Project number:	104101	
Your reference:	Lisen Stenberg	Signerat av: Mikael Larsson
Your Ref. No.:	2024-2432	

Study of the conditions for Swedish-Indian cooperation in the steel sector

Summary

The primary objective with this report is to identify gaps and opportunities for collaboration between Sweden and India, particularly in the steel industry, which is a significant contributor to CO_2 emissions.

India's emissions have risen with economic growth, with the iron and steel sector contributing significantly. India's steel industry is the second largest in the world and a significant contributor to CO_2 emissions. The goal is to achieve net-zero emissions by 2070. The industry predominantly uses blast furnace/basic oxygen furnace (BF/BOF) and coal-based direct reduction (DR) methods, relying heavily on domestic iron ore and coal. However, this growth comes with high CO_2 emissions, averaging 2.5-2.7 tons of CO_2 per ton of steel, compared to Sweden's 1.6 tons.

Potential pathways for reducing these emissions include the adoption of process efficiency improvement, green hydrogen, renewable energy sources, and carbon capture technologies. These measures are crucial for aligning with global decarbonization goals and improving the environmental footprint of the steel industry. Major players in the Indian steel industry, such as Tata Steel, JSW Steel, and SAIL, are identified as key stakeholders. These companies face several challenges, including low-quality iron ore, high CO_2 emissions, and limited availability of scrap and natural gas. Addressing these challenges is essential for enhancing the sustainability and efficiency of the steel sector.

The European Union's Carbon Border Adjustment Mechanism (CBAM) is expected to impact Indian steel exports, creating a strong incentive for reducing emissions.

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Recommendations:

- **Process Efficiency**: Enhance the efficiency of existing production processes, particularly in coal-based BF/BOF and DR operations. Improve ore beneficiation processes to enhance the quality of raw materials.
- **Renewable Energy**: Implement long-term waivers on open access charges for the steel industry to encourage the use of renewable energy. Utilization of bioresources in metallurgical processes to reduce emissions.
- **Carbon Management**: Develop a robust carbon capture and storage (CCS) ecosystem in India. Collaborate on carbon capture, utilization, and storage (CCUS) projects to manage emissions effectively
- **Research and Development**: Foster an inclusive R&D ecosystem to drive innovation across the industry. Experimental Facilities: Support the establishment of experimental blast furnace and hydrogen-based DR pilot projects.

The importance of Swedish-Indian collaboration in addressing the challenges faced by the steel sector. By leveraging Swedish expertise and technology, India can accelerate its transition to a more sustainable and efficient steel industry. The recommendations and potential collaborations outlined in the report aim to create a pathway for achieving

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1 Introduction

The Swedish Energy Agency has been working, via Business Sweden in India, since 2009 to create conditions for development, collaborations, technology exchange, and business. For many years, the agency has run the market introduction program India-Sweden Innovations Accelerator, which supports Swedish small and medium-sized enterprises in introducing energy solutions with new value in India. Since 2022, the work has been further developed to also include larger companies. With this, the agency's mission and goals within climate work have become even more guiding.

A key part of this work is the agency's role as an implementing party within the India-Sweden Industry Transition Partnership (ITP), a bilateral collaboration within the broader work under the Leadership Group for Industry Transition (LeadIT).

On December 1, 2023, during COP 28, India's Prime Minister Modi and Sweden's Prime Minister Kristersson agreed that the countries together will take measures for industrial transition and net-zero emissions by 2050. This will be done within the framework of ITP, which will work proactively to support the development of concrete examples that can contribute to the transition work within the steel and cement sectors. The work will be industry-focused and aimed at pilot and demonstration projects.

In the ITP (Industry Transition Partnership) policy document, four areas of work are described:

1. Strengthening institutional framework
2. Unlocking conditions for technology demonstration projects
3. Fostering innovation, research and development, and capacity building
4. Mobilisation of finance and investments

The Swedish Energy Agency has been designated as responsible for point 2 and to engage in creating conditions for cooperation within the framework of Article 6 of the Paris Agreement under point 4. Initially, ITP will focus on the transition within the steel and cement sectors.

Swerim is a Swedish industrial research institute which conducts industry-related research in the metal and steel industry. Swerim was established in 2018 to support the industry in its transition to fossil-neutral production. Swerim has been an active research partner from the pre-study work on hydrogen-based steel production (Hybrit) to the pilot phase of the project. Swerim has extensive experience working closely with the industry in industry-related research, which is considered to be of outmost importance in India's transition work.

During 2023 Swerim was contacted to carry out a fact-finding study to identify different opportunities for the Sweden – India collaboration and support the Swedish Energy agency in its assignment. This report concerns preparatory work related to point 2 and the steel sector. Given this focus, the study may indirectly also touch on aspects that can contribute to parts of the other points.

1.1 Purpose/goal

The purpose of the work is to study the conditions for India's transition based on Swedish experiences. This involves identifying gaps and overlaps between the countries, in a direction that can outline the conditions for a function in India that can be cohesive, a function to rally around. In addition to identifying conditions, the study should also contribute to anchoring with relevant stakeholders.

Goals for 2024:
- Identify gaps through physical visits and study trips
- Conduct a workshop with stakeholders in India to present conclusions and proposals for further work

1.2 Implementation

The work was carried out through dedicated fact-finding trips and workshops. During 2024 three dedicated fact-finding trips were carried out. In addition to the fact-finding trips, a final workshop in India is planned to present the findings from the present study.

1.3 Investigation

To identify gaps and overlaps between Sweden and India regarding actors and opportunities, local anchoring and presence are required. The different trips investigated different aspects of the Indian steel industry and research and innovation landscape. The purpose of the visits were also to capture the need for joint development from an Indian perspective and to understand the Indian transition philosophy.

The GAP analysis was carried out in regards to following sub-areas:

- Mapping of India's steel production - dominant steel manufacturing routes
    - Raw materials (ore, alloys, recycling/recirculation, etc.)
    - Energy (available energy carriers in general and local conditions prevailing in the Indian steel industry)
    - Logistics
    - Emissions (environmental emissions and legal requirements, exposure to CBAM, the EU Commission's upcoming CO_2 burden/tariff for steel sold on the European market, and other drivers)
    - The current technical lifespan of the industrial park (current processes, need for technology shift, maturity level, etc.)
    - Competence
- Market actors
    - Industry: composition of actors, possible pioneers in the transition
    - Research environment: academia, institutes, testbed activities/lab infrastructure
    - Government actors: Principal Scientific Advisor, etc. The need for actors across the entire value chain may require cooperation with several ministries
    - Others: Associations (Ministry of Steel, etc.), think tanks
- Incentives and drivers
    - National governance mechanisms
    - Legislation

- Business culture: the relationship between the state and industry, experience of joint research, transparency, dissemination of results, etc.

2 Results

Totally three fact-finding trips were carried out during the period March – September 2024. The final workshop in India planned to be carried out in November were postponed to January/February 2025.

1. Fact-finding trip 1 – 11-19/3 2024 (Swerim-2024-205)
2. Fact-finding trip 2 – 21-28/5 2024 (Swerim-2024-217)
3. Fact-finding trip 3 – 22/7-2/8 2024 (Swerim-2024-322)

The main findings from the trips have been reported in dedicated travel reports. Based on these trips the following results have been derived.

2.1 Mapping of India's steel production

The steel production in India have been increasing with an annual growth rate of 7% since 2000 which makes the Indian steel industry the one of the largest growing regions in the world. India is currently the second-largest steel producers in the world. The steel industry plays an important role in the county gross domestic product.

The Indian steel industry has developed in line with the large domestic reserves of iron ore and coal. The availability of these raw materials has been a driver for the industry's growth. Today, most of the production is ore-based, using either the blast furnace/basic oxygen furnace (BF/BOF) or coal-based direct reduction (DR) routes. The small amount of scrap available is used either in the BOF process or in electric melting furnaces (EAF/IF).

The blast furnace operations are generally large production units. Normal production capacity of 2 Mton/a but also larger and smaller units are present. Looking at the development from early 2000 it can be seen that the production has increased from ~20 Mton/a to ~90 Mton/a. The increased production is mostly done in newly installed capacity. DR capacity increased during the same time from ~6Mton/a to 30 Mton/a. Most of the DR capacity is coal based in small (<0.05 Mton/a) to medium (0.05-0.15 Mton/a) sized kiln type units. Hence the number of units in DR-based operations is significantly higher (+300 units) and the production sites are normally close to ore and/or coal mine. There are some installations of gas-based DR processes and also linked coal gasification to gas based DR units.

<u>Main Iron Production Routes:</u>

- Blast Furnace (BF): Primarily used in large integrated steel plants, accounting for 66.4% of India's iron capacity.

- Direct Reduced Iron (DRI): Used by around 300+ units, making up 33.6% of iron capacity. A majority of these (80%) are coal-based kilns, while the rest use gas.

<u>Main Steel Production Routes:</u>

- Basic Oxygen Furnace (BOF): Mainly uses liquid iron and scrap to produce steel, representing 48% of steel capacity.
- Electric Arc Furnace (EAF) and Induction Furnace (IF): Primarily use sponge iron and/or scrap. EAF accounts for 23% and IF for 29% of steel capacity.

The steady growth rate of the Indian steel industry from early 2000 also indicates that there has been a significant increase in steelmaking assets. In 2002 the steel production was at approximately 30 Mton/a and has steadily increased to 134 Mton/a in 2023. During the Covid-19 pandemic in 2020, there was a temporary decrease in production.

The lifetime of steel in society depends on the different applications where the steel is being used. For construction and infrastructure, the lifetime is generally longer 50-100+ years while consumer goods have a much shorter lifetime 1-5 years. A general average lifetime is estimated to 35-40 years in a developed steel market. In a market with significant growth, this can be expected to be longer (more infrastructure). With an assumption that the lifetime of steel in India is 40 years and with a well-developed scrap market, this means that the potential scrap available for steel production is the amount produced 40 years earlier. Of course, this is a simplified model, since both import and export need to be taken into consideration. However, analysing the growth rate as illustrated in Figure 1, the steel consumption and domestic steel production is in balance. Hence, it is reasonable to assume that the scrap available for new steel production can be correlated to the steel production some 40 years earlier. Since the steel production have shown a steady growth increase, therefor most of all new production capacity over the last 20 years have been made as ore-based production.

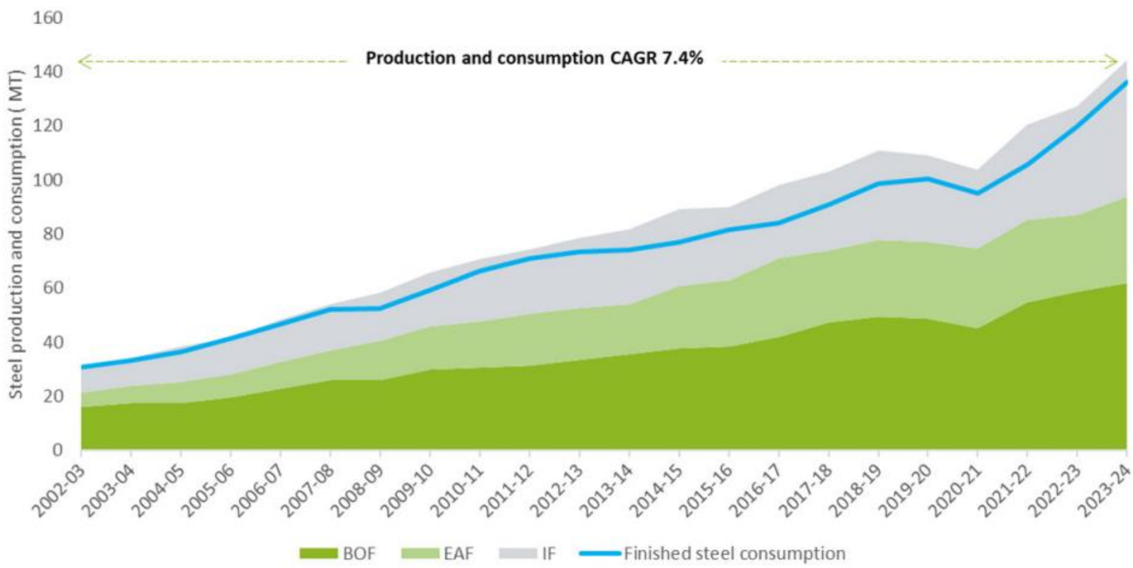

Figure 1. Annual production of steel in India. [CGI report – Greening the steel sector in India]

A few big steel companies and state-owned companies hold a share of around 65 per cent of the current steel production in India. In order to fulfil the capacity and production goals announced these steel companies are expected to expand their capacities as much as possible.

A majority of the companies have been expanding and are planning to expand through the BF-BOF route. Technologies like EAF/IF emits lesser CO_2 compared to BF-BOF, but still the big players of the sector are hesitant to invest in such technologies.

Some reasons for this are:

1. Large-scale production capacity of BF-BOF: In order to increase production beyond a certain level, it is important that the technology being adopted enables large-scale production. BF-BOF is a proven existing technology that enables carrying out production at that scale. The raw material situation has not allowed for the development of the EAF based production.
2. Poor quality and non-availability of scrap: EAF/IF technologies are dependent on scrap as a raw material, but the availability of scrap is currently an issue in the country. The steady increase in domestic production cannot be met with scrap-based production due to the availability. Even the scrap available is not of the best quality, which can result in poor quality steel production, especially in induction furnaces. This has forced EAF/IF plants to use direct reduced iron or sponge iron in combination with steel scrap.
3. Non-availability and high prices of natural gas. Some steel companies are and have been setting up gas based DRI plants (as they have lower emissions), but natural gas pipelines are not available in many parts of the country where these plants are located. Alternatively, co-investments with coal gasification have been explored as an option.

2.2 Energy and CO_2 emissions.

Since the Indian steel industry is mostly based on BF/BOF and coal based DRI production, the coal intensity is high. An average CO_2 emission of the steel sector is 2.5-2.7 ton/t steel. In comparison with Sweden the BF based steel production emits 1.6 ton/t steel. The possibility to explore these differences are a key for the future work.

There are multiple technology pathways that could help in the transition from traditional methods to low emission intensity technology like green hydrogen, renewable energy, carbon capture, usage and storage technology with Blast Furnace (BF)/Basic Oxygen Furnace (BOF) or Direct Reduced Iron (DRI)-Electric Arc Furnace (EAF), scrap-based Electric Arc Furnace (EAF) etc.

3 Main steelmaking production routes

Iron ores provide the majority of the iron used to make steel at integrated steelmaking sites. They are delivered as fines, lump ore and pellets. The sinter plant processes the fines to sinter which is charged to the blast furnace together with lump ore and pellets.

3.1 Blast furnace operation

The reduction of iron oxides in the blast furnace is the most energy intensive step in iron production. The blast furnace consists of a shaft oven where coke and ferrous materials are charged via lock hoppers into the top of the furnace where iron oxides are heated, reduced and melted by ascending reducing gas. Figure C10 shows a schematic of the blast furnace layout. Blast air which is preheated in hot stoves, oxygen and fuels are injected through tuyeres in the lower shaft together with heated air. Hot stoves are used to preheat blast air for injection through the tuyeres, described below. The blast generated at the tuyeres through combustion of the fuel and particles of coke to CO provides thermal energy and reduction gas. Coke, which is charged in layers, allows the gas to distribute and continue ascending. The molten iron, called hot metal, and slag drip through a bed of coke below the cohesive zone and are tapped intermittently from one or several tap holes in the furnace hearth. Slag is easily separated from hot metal in the runner by density difference and sent to either slag slow-cooling or granulation. Granulation of slag is common, via rapid quenching with water. The hot metal, at about 1500^{o}C, is poured into refractory-lined ladles or torpedo cars and transferred to the steel factory for desulphurization and further refining.

Due to the nature of the chemical equilibrium of the reactions in the furnace, the gas exiting the BF is only partially oxidised to CO_2 and H_2O. There is remaining CO and H_2 in the top gas which is used to preheat the air injected at the tuyeres and the remaining used as fuel in the power plant, coke ovens or elsewhere.

The hot stoves are regenerative heat exchangers used for preheating of blast air. Combustion fuels, typically BF gas and COG, are combusted with air to flame temperatures of about 1300^{o}C – 1500^{o}C. The gas transfers heat to refractory checker bricks. Once the desired brick temperature is reached, the combustion is stopped and blast air is heated by passing counter-currently to the direction of combustion gas. There are typically 3 or 4 hot stoves operating in a sequence of gas firing and blast heating to maintain constant blast temperature. Blast temperatures of 1000-1300^{o}C are common. The hot stoves are the main source of CO_2 emissions from the blast furnaces as well as the recovered blast furnace gas from the system, usually used internally on site as main heating fuel.

There are a wide variety of burden compositions depending on sourcing. Some of the Indian Iron ores are high in Fe content while other are lower in Fe content. Typical western burden charge is shown in the table.

Table 1 Typical blast furnace burden

Burden materials	**Unit**	
Sinter	kg/thm	1120
Pellets	kg/thm	344
Lump Ore	kg/thm	119
Additives		
Quartzite	kg/thm	10
Limestone	kg/thm	12
Solid fuels		
Coke	kg/thm	348
PCI	kg/thm	152

Indian reductant rates are generally higher due to lower Fe content in the burden feed material and higher slag rates.

3.2 Direct reduction production

The common principle for all direct reduction (DR) processes is that solid sponge iron as DRI (Direct Reduced Iron) or HBI (Hot Briquetted Iron) is produced by the removal of oxygen from the iron ore, which remains in solid form. In the 70s direct reduction was regarded as a real alternative to the conventional BF route. The interest in direct reduction has resulted in the development of many different processes, natural gas-based (HYL/Energiron, MIDREX, PUROFER, Ironcarbide, FINMET/Fior, etc.) and coal-based (SL/RN, Krupp-CODIR, DRC, Kinglor Metor, ACCAR, etc.), from which only some survived or got industrial size relevance. The real production capacity did not increase as quickly as initially believed. One reason for this being the availability of cheap natural gas. During the last decade, the production capacity has been increasing significantly and also development for carbon neutral production such as H2 based DR production.

For the Indian market, the kiln-type process is the dominant production process used. However, gas-based production units are available.

3.2.1 Kiln processes

The kiln process uses lump ore, pellets, and solid carbon to produce hot or cold DRI. The coal acts both as a reductant but also supplies the required energy to maintain the temperature profile within the kiln. The process operates at high temperature and at atmospheric pressure. The rotary kiln operates on the counter-current principle, gas moves in the direction opposite of the flow of the solid. The rotary kiln is inclined downward from the feed to the discharge end, Figure 2.

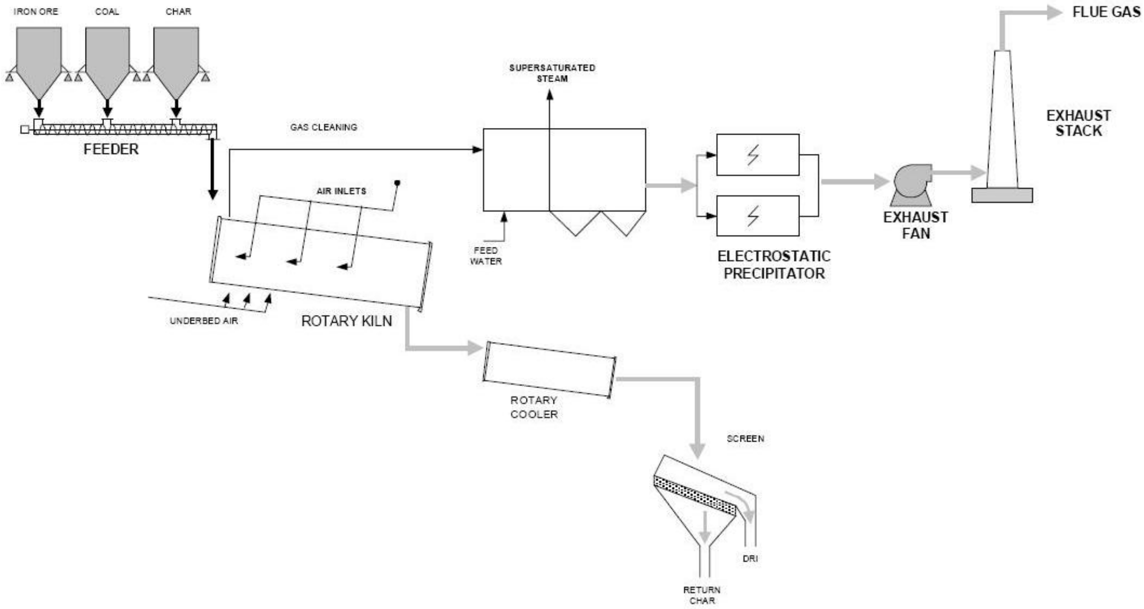

Figure 2. Schematic process layout of the SL/RN process

The kiln is divided into two sections, preheating and reduction zone. In the preheating section, the charge is heated to approximately 1000 °C. As the reductant is heated the volatile compounds are released. Combustion of the volatiles takes place in the freeboard above the bed. The charge is heated directly by radiation from the post-combustion above the bed as well as by conduction from the kiln lining. The bed is normally very well mixed. In the reduction zone the temperature is maintained at 1000 – 1100 °C where the final reduction takes place. For an iron ore charge the metallization is around 93% and carbon content is 0,1-0,2% in the DRI product.

The most critical factor in the operation of the rotary kiln process is controlling the combustion of coal and its conversion to CO. In case the CO generation is insufficient additional coal can be combusted. The volatile matter in the co-current feed is released in temperatures to approximately 600 °C. Part of these volatiles are combusted to preheat the kiln while or leaves the kiln with the waste gas without doing any reduction work. The utilisation of the volatiles in the coal is of highest importance. Unless they are utilised effectively the specific coal consumption will be high.

The SL/RN process was developed for the Indian market, designed for direct use of non-coking coals. The reactor is a refractory lined cylinder rotating on an inclined axis, continuously charged with the feed material (lump, pellet, ore fines, coal limestone, and return char). The product discharged is cooled in an external cooler, passed through magnetic separators and screens to separate sponge iron, coal ash and char. The waste gas from the furnace contains combustible gases which are burned off. Sensible heat can be recovered to generate electricity. The SL/RN process is well proven technology for producing DRI from iron ore with direct use of non-coking coal. The process has since its commissioning demonstrated flexibility regarding the use of iron ores and the use of a wide range of fuels.

Table 2. Typical Consumption figures[1] for SL/RN DR process

Raw material:	Ore fines, lumps, and pellets
Reductant:	non-coking coals, low sulphur
Energy:	19.9 GJ/t
Limestone:	50-70 kg/t dri
Power:	55-70 kWh

(Coal consumption included in the energy requirement)

3.3 Market actors

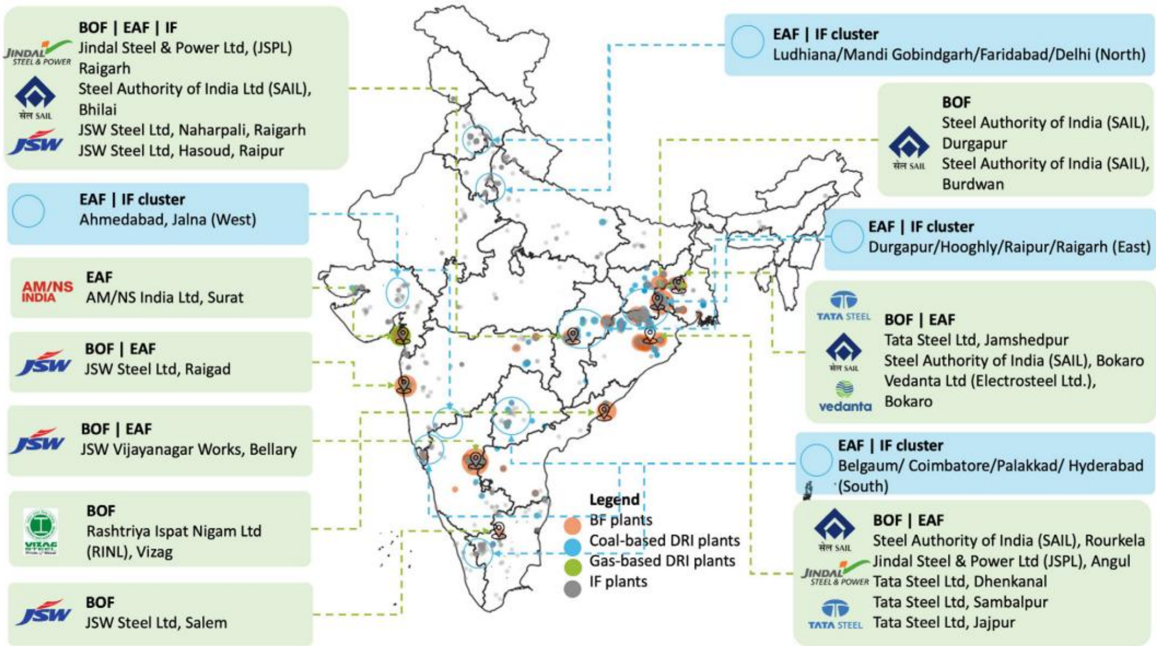

Figure 3. Indian steelindustry

The main steel producers visited

- **Tata Steel Limited** - Founded in 1907, Tata Steel is one of the oldest and largest steel companies in India. Annual crude steel production of ~35 Mton/a. Main integrated steel plants in Jamshedpur and Gamharia in Jahrkland and Kalingangar and Meramadali in Odisha. Tata will continue to base their steel production around the BF as primary ironmaking unit for next 3-4 decades.

  Projects showcased by TATA, such as synthetic graphite production from coal tar and iron powder production, have gotten significant interest. TATA also expressed interest in maximizing resource efficiency through enhanced recycling, which aligns well with expertise and ongoing projects in CCUS in Sweden. Another potential area of

[1] Chatterjee, A. (2010). Sponge Iron Production by Direct Reduction of Iron Oxide. PHI Learning Pvt. Ltd.

collaboration involved incorporating a H_2-based Direct Reduction (DR) unit within TATA's integrated steel plant to utilize the COG (Coke Oven Gas) for Direct Reduced Iron (DRI) production. Tata also shows great interest in experimental blast furnace collaboration possibilities.

- **JSW Steel** – Belongs to the Jindal group. One of India's second-largest private steel companies, providing steel products used in the construction and automotive sectors. Total production of approximately 28.5 Mton/a. Goal to increase production to 50 Mton/a by 2050, utilizing both blast furnace (BF) and direct reduction (DR) processes, including 5Mt capacity this year.

  In 2030, they plan to implement H_2-gas-based DR technology, similar to that of Stegra. Starting with 4Mt capacity using natural gas and transitioning to H_2 when available. Potentially, they will reserve their new DRI steel site for European exports because of CBAM, giving less stringent timeline for decarbonization of other Indian assets.

  JSW currently has 7 GW of energy production, with 60% of this energy coming from renewable sources. They have 3 thermal coal assets, but these will keep operating, and growth will come from renewables. Their target is to reach 20 GW by 2030, with 80% of the energy being generated from solar, wind, and hydro-based power.

  One of the major challenges is the low quality of ores, as they work with iron ore containing 50% Fe and upwards.

  The Carbon Border Adjustment Mechanism (CBAM) will be implemented on Indian export materials from 2030, and the current allowances will be removed. Therefore, it is crucial for JSW to focus on decarbonization. They plan to reduce CO_2 emissions by 1.7% annually. India intends to continue using BF/BOF alongside coal-based DR units.

- **Jindal Steel and Power Limited (JSPL)** – Within the Jindal group. JSPL is a major player in the Indian steel industry,

- **Jindal Stainless –** is one of India's leading stainless steel producers established in 1970, part of the larger Jindal Group. The company aims to reduce its carbon footprint by investing in cleaner energy sources, such as solar energy, and enhancing energy efficiency across its operation.

- **Steel Authority of India Limited (SAIL)** - SAIL is India's largest state-owned steel company and holds a significant market share domestically

- **AM/NS India Ltd** - ArcelorMittal/Nippon steel joint venture

- **SAIL –** is one of the largest state-owned steel-making companies in India. Established in 1954, SAIL operates and owns five integrated steel plants and three special steel plants.

SAIL expresses a strong interest in decarbonization and sustainability, with a particular focus on valorizing all residues, hydrogen (H_2) injection, biomass utilization (including biochar, biogas, and biocoke) for decarbonization, digitalization, carbon capture, utilization, and storage (CCUS), as well as internal utilization of all available off-gas streams.

One of the major challenges highlighted by SAIL is the use of low-grade ores, which results in high emissions. SAIL currently employs ores with a Fe content ranging from 58% to 62%. The feasibility of utilizing these low-grade ores for H_2-based direct reduction and the potential challenges might include disintegration after reduction in the shaft due to the relatively high silica content, as well as higher energy consumption in steelmaking due to increased gangue oxides are important areas for future collaboration and research.

Kalyani Steel - is a manufacturer of forging and engineering quality carbon and alloy steels in India. Established in 1973 and belongs to the Kalyani group. Kalyani Steel operates three small BFs with total annual production of 0.65 Mton/a and one small EAF (35 ton/heat) using scrap collected from Bharat Forge, a part of the Kalyani Group. Kalyani does not undertake any beneficiation processes as they import high-grade ores with Fe content exceeding 60% (up to 64-65% was mentioned).

Bharat Forge is a global provider of high-performance and critical components used in various sectors such as automotive, railways, defense, construction, aerospace, marine, and oil (mainly European and N. American markets). After acquiring the Swedish forgings manufacturer Imatra Kilsta AB, Bharat Forge established a presence in Sweden. Approximately 60-70% of Kalyani's products are supplied to Bharat Forge, which specializes in manufacturing special steel for export, and send scrap back to Kalyani. The EAF at Kalyani emits approximately 100 kg of CO_2 per ton of crude steel

DR based steel plants visited

- HIRA
- SARDA

Both companies have the SL/RN kiln type DR plant.

Ore industry

- Lloyds Metals and Energy- Lloyds is primarily a mining company. Their main steel products are lump ore and fines, which are currently sold on the market. Lloyds plans to diversify into pellet production in the future.

  In collaboration with Metso, Lloyds plans to commission their first iron ore beneficiation plant in September/October 2024. The goal is to upgrade the iron ore from 30-35% Fe content to a high-grade 67% Fe concentrate. This particular source of Iron Ore is Banded Hematite Quartz (BHQ). Preliminary tests conducted at Metso and with Chinese partners have shown promising results. Lloyds aims to invest in this beneficiation approach to produce around 15 million tons of high-grade iron ore. This will be in 3 steps, processing a total of 55Mt/yr on completion.

Pellet Production Plans:
Lloyds plans to commission their first pelletizing plant for direct reduction (DR) pellet production in March 2026. The DR pellets will be exported to the Middle East until the market is available in India. They will be the first to market with DR grade in India.

Tailings and Critical Raw Materials:
Lloyds is seeking partners to investigate the potential for rare earth elements or critical raw materials in their tailings. Lloyds is working with BRPL (Brahman River Pellets Limited), one of the largest merchant pellet manufacturers in India.

Other Industries

- IMFA (Ferro chrome): IMFA utilizes an electric arc furnace powered by a captive coal-based power plant, relying on a blend of reductant coke (85%), anthracite, and around 15% other materials. Major clients include Posco (Korea) and Jindal Stainless, with approximately 85% of their products exported. IMFA is expanding its production capacity from 270,000 to 370,000 tons per annum, with plans to move underground within the next five years. The company aims to reduce carbon monoxide emissions in its plant for various uses, such as ore drying, targeting a reduction of 50% CO, 20% N_2, and 30% CO_2. Additionally, IMFA plans to install 60 MW of solar energy. There is ongoing discussion about utilizing Lanzatech technology to produce ethanol, though progress has been slow after three years of development.
- Hindalco: Hindalco primarily operates in the production of copper (Cu) and aluminum (Al) metals, as well as carbon black and cement. They import ores from Chile and other South American countries as well as Australia. Their product range includes Cu tubes, high-alloyed Cu metals, Al for electric vehicles and battery manufacturing, and carbon black for anodes. Hindalco boasts large facilities for gray cement production, totaling approximately 100 million tons. The expectation is an expansion to 200mt. Swerim and KTH have been talking to Hindalco and have submitted a proposal with CETP-EU funding together with them and Stegra (formerly H2GS) from Sweden amongst others for use of H2 in copper production.

Research institutes/universities

- **TERI** is a highly equipped research institute that has several advanced laboratory facilities – we were introduced primarily to equipment and projects focused on agriculture-related characterization, analysis and valorization. The expansive 100-hectare site had much more to offer than the technology we were exposed to.

  The institute is actively contributing to the decarbonization roadmap for the steel sector and is involved in 8 dedicated taskforces exploring various decarbonization strategies. They are the lead knowledge partner for MoS in LeadIt 2.0, including:
    a. Pilot or demo green steel
    b. Biochar- supply, production and availability
    c. Role of CCUS

  TERI's research spans a wide range of areas, including sustainable agriculture (e.g., developing bio-fertilizers, bioleaching, water treatment, and mapping the geographical distribution of agricultural residues), climate change, energy, the environment, and sustainable resource utilization.

- **SIMA:** The Sponge Iron Manufacturers Association (SIMA) in India is a pivotal organization representing the DRI producers. In recent years, the association has prioritized decarbonization efforts by advocating for the adoption of cleaner production methods and the use of renewable energy sources in DRI manufacturing. The majority of members are using coal and not a gas-based products. Therefore, the association helps the members to implement efficient processes that reduce carbon emissions, such as utilizing natural gas instead of coal and integrating CCUS technologies. The roadmap of SIMA decarbonization is as follows:
    - 2024-2030: low-hanging fruits, efficiency
    - 2030-2047: syngas, natural gas
    - 2047-2070: catch up to western technology

- **The National Institute of Secondary Steel Technology (NISST)** is an organization in India dedicated to the development and promotion of secondary steel technology. Established in 1982, NISST focuses on research, training, and consultancy services to enhance the productivity, quality, and cost-effectiveness of secondary steel production. NISST´s focus is primarily on the downstream aspects of steel production, with an emphasis on laboratory characterization of slabs, forging, chemical, mechanical, and metallographic properties.

  The institute supports the steel industry by providing feasibility studies, industrial consulting, and recommendations on energy efficiency, dust and gas monitoring, process development, and safety inspections. They also offer training programs for young engineers from the industry.
- **Council of Scientific and Industrial Research (CSIR)** is one of the largest and most diverse publicly funded research and development organizations in India. Established in 1942, CSIR operates under the Ministry of Science and Technology and is headquartered in New Delhi
- The **Nordic Centre in India (NCI)** is a consortium of leading universities and research institutions from Denmark, Finland, Iceland, Norway, and Sweden. Established in 2001, NCI aims to facilitate cooperation in research and higher education between the Nordic countries and India.
- **IIT Bombay** is one of India's premier public technical and research universities. IIT Bombay has 15 academic departments, including Aerospace Engineering, Chemical Engineering, Computer Science & Engineering, Electrical Engineering, and Mechanical Engineering. Areas of interest among others are modelling and research capabilities with 37 full-time faculty; Undergraduate program-120 students per year; Total 231 PhDs and 37 Postdocs. Courses are split over Material Science, Process Engineering and Steel Technologies.
- **IIT Dhanbad** (formerly Indian School of Mines) is working on mineral processing and beneficiation, which is a key challenge for reducing coke consumption and CO_2 emissions from low-grade ores.
- **ITT Dehli:** They are promoting their own solutions for CC(U)S and have established a small CCUS unit with a capacity of about 1 ton per day for a methanol pilot project, dedicated to developing technologies that reduce carbon emissions from steel production.

- **Institute of minerals and materials technology (IMMT)** is a premier research institute located in Bhubaneswar, Odisha, India. It is a constituent laboratory of the Council of Scientific and Industrial Research (CSIR) and focuses on the development of sustainable technologies for the minerals, metals, and materials industries. IMMT conducts advanced research in metallurgy, mineral processing, chemical synthesis, and materials engineering.

State actors

- **Ministry of steel (MoS)** - is an executive branch agency of the Government of India responsible for the development and regulation of the steel industry in the country.
- **Ministry of Power - Bureau of Energy Efficiency (BEE)** is an agency under the Ministry of Power, Government of India. Established in March 2002 under the provisions of the Energy Conservation Act, 2001, BEE's primary objective is to promote energy efficiency and conservation across various sectors of the Indian economy (BEE)
- **Indian Steel association (ISA)** is a prominent industry body representing major public and private sector steel enterprises in India. Established to promote the interests of the Indian steel industry, ISA plays a crucial role in policy advocacy, industry development, and fostering innovation
- **Confederation of Indian Industry (CII)** is a prominent business association in India. Established in 1895, CII works to create and sustain an environment conducive to the growth of industry in India, partnering with industry, government, and civil society through advisory and consultative processes
- **Ministry of New and Renewable Energy (MNRE)** is the nodal ministry of the Government of India responsible for all matters relating to new and renewable energy. The Green Hydrogen Mission is an initiative under MNRE
- **Ministry of Mines (MoM)**
- **Directorate General of Hydrocarbons (DGH)** is the Indian governmental regulatory body under the ministry of petroleum and natural gas. The primarily objective is to promote sound management of India's oil and natural gas resources. Future carbon capture and storage possibilities In depleted oil and gas fields will be managed by DGH.

3.4 Incentives and drivers

Developed countries are increasingly looking at policies that penalise carbon emitters in order to protect and promote green technologies. On 14 July 2021, the European Commission released a package of regulatory proposals as part of its "Fit for 55" initiative that aims to achieve the European Green Deal target of 55% net reduction in GHG emissions by 2030. The package includes a proposal for a Carbon Border Adjustment Mechanism (CBAM) and revisions to the EU's Emission Trading System (ETS). CBAM will apply to steel products imported into the European Union (EU), affecting steel exports from India. Either direct exports to the EU or through indirect export through raw materials (DRI, Ferroalloys, Steel) exported to other countries with exports to the EU.

Between 2023 and 2025, non-EU steel producers will need to report both direct and indirect emissions. From 2026, importers will need to declare and purchase CBAM certificates to cover GHG emissions associated with the production of imported steel products.

3.5 Potential collaborations

Research organisations and Universities:

Swerim

Potential areas of collaboration: Research and development within metallurgy area

At Swerim, the research mission is to create, improve, and convey research results for the metallurgical industry. The experimental part of Swerim includes several large-scale pilot equipment that can be accessed on-site.

Luleå University of technology, Ltu

Potential areas of collaboration: Research within energy and metallurgy

Luleå University of Technology experiences rapid growth with world-leading expertise within several research domains. We shape the future through innovative education and ground-breaking research results. Drawing on our location in the Arctic region, we create global societal benefit. Our scientific and artistic research and education are carried out in close collaboration with international, national, and regional companies, public actors, and leading universities. Luleå University of Technology has an annual turnover of SEK 2.0 billion. Today, we have around 1,900 employees and close to 17,900 students.

Royal Institute of Technology, Kth

Potential areas of collaboration: Research within energy and metallurgy

Since 1827, KTH has grown to become an international leading technical university. As the largest institution in Sweden for technical education and research, we bring together students, researchers, and educators worldwide. Our activities are grounded in a strong tradition of advancing science and innovation, focusing on contributing to sustainable societal development

Companies;

LKAB

Potential areas of cooperation: Experimental blast furnace operation, Ore processing and Beneficiation, H_2 DRI demonstration plant

LKAB is an international group that sells sustainable iron ore pellet, minerals and special products. We are leading the green transformation of the iron and steel industry by developing carbon-free processes and products like sponge iron.

Hybrit development (LKAB/SSAB/Vattenfall)

Potential areas of cooperation: Experimenetal H_2 DRI operation and research

The HYBRIT technology has the potential to reduce Sweden's total carbon dioxide emissions by at least ten percent. This is equivalent to one third of the emissions from the industry and may, in the future, help to reduce emissions from iron and steel production globally. The Hybrit technology have been developed as a joint venture between SSAB, LKAB and Vattenfall.

SSAB

Potential areas of cooperation: BF operation praxis (worlds lowest CO_2 emission from BF operation), Setting up greenfield H_2 DRI based Steelmaking plant, transitioning from BF /BOF to H_2 DRI based steelmaking (minimill type)

SSAB is a global steel company with a leading position in high-strength steels and related services. SSAB aims to be the first, in 2026, to offer fossil-free steel to the market and largely eliminate carbon dioxide emissions from our own operations in around 2030. SSAB has taken a policy decision to transform all our sites to fossil-free steel production. SSAB's transformation of its Nordic production system is the first true steelmaking transformation in centuries. All five blast furnaces in Sweden and in Finland will be replaced by more flexible and cost-efficient mini-mills that run on electricity.

Stegra (former H2 green steel)

Potential area of interest: Setting up new greenfield H_2 DRI based steelmaking plant (minimill type)

Founded in 2020, Stegra was created with the purpose to decarbonize hard-to-abate industry. Abatement refers to reducing carbon emissions – while still producing the same products. Hard-to-abate industries rely heavily on fossil fuels, making emissions cuts more challenging. The first plant is under construction in Boden in northern Sweden. We're on track to produce green steel by 2026, using green hydrogen and green iron to slash emissions by up to 95%.

GreenIron

Potential areas of interest: Technology for H_2 reduction in bell furnace (smaller sized plant)

GreenIron's vision is to become the global metals and mining sectors most respected and innovative CO2-free company. By leading our industry´s transformation from a linear to a circular economy. After a few years of successful testing, GreenIron are now ready to industrialise GreenIron's hydrogen-based technology, for fossil-free and energy-efficient recycling of metals and minerals. A technique that also enables the processing of raw materials, such as iron ore. The first full-scale production facility is being erected during 2024 in the Sandviken Industrial Park.

Ferrosilva

FerroSilva's sponge iron production method generates a carbon sink of 845 kg of CO2 per tonne of steel if the biogenic carbon dioxide is recovered and turned into new products or e-fuel. FerroSilva's business concept is based on using residue from the forest industry that is gasified into a biogenic syngas to reduce high-value iron ore pellets to sponge iron, known as DRI. The resulting carbon dioxide is captured and sold to become products or fuels that would otherwise require fossil fuels.

Ovako

Potential area of interest: Large-scale H_2 production, Hydrogen combustion in heating applications

Ovako is a leading European manufacturer of engineering steel for customers in the bearing, transportation and manufacturing industries. Environmental aspects have always been a fundamental part of Ovako's business. Ovako has reduced it relative carbon emissions with 56 % since 2015 (base year) through efficient processes, the use of fossil-free electricity and dedicated investments such as conversions to fossil-free fuels for heat treatment resulting in a carbon footprint 80 % lower than the global average. Ovako's goal is to achieve zero-carbon emission steel.

Höganäs

Potential area of interest: Bioresources in DRI production, Energy efficiency

Höganäs is the world leader on the market for iron and metal powders. Höganäs objective is to become a net-zero company by 2037. This is a huge challenge but it is necessary. To minimize our climate footprint, we need to utilize both established and newly developed methods. Focussing on transitioning to renewable energy in production and transport, replacing fossil process coals, improving energy efficiency, and rethinking our materials supply.

Envigas

Potential area of interest: Biocoal production, Bio oil utilisation

Envigas utilize intermediate pyrolysis technology. The system feeds the pyrolysis furnace with forest waste. With a precision control of residence time and a pyrolysis temperature (< 600°C), our main output product is high quality BioCarbon (approximately 90% C-fix) free of nearly all polycyclic aromatic hydrocarbons. The process also produces an energy rich pyrolysis Syngas that can either be condensed to pyrolysis oil, combusted to heat or upgraded to bio-methane or hydrogen.

Envigas goal is to have large scale production by **2025** and by **2030** reach a production capacity of **150,000** tons of high quality BioCarbon. This corresponds to a significant part of the Swedish steel industry's need, in order to reach the goal of fossil free steelproduction.

Bioshare

Area of interest: Biogas and biocoal production

BioShare is a technology provider specializing in combined thermochemical processes such as combustion, pyrolysis, and gasification. With BioShare's technologies, high-value products including SNG, fuel gas, methanol, hydrogen, pyrolysis oil, and biochar can be produced. These products play a key role in decarbonizing industries, while waste streams from different sectors such as agriculture, forest and the plastics industry are chemically recycled to foster a more sustainable and circular economy"

Kanthal – Technology provider

Area of interest: Electric heating technology (solid materials, gas)

Kanthal is a world-leading brand for products and services in the area of industrial heating technology and resistance materials. Kanthal is experts in industrial electric heating technology and resistance materials, providing products and solutions to a wide range of industries on a global scale. Our extensive investments in R&D and eagerness to collaborate ensure that we remain in the forefront of technological development.

Linde gas – Technology provider

Potential area of interest: Oxygen application, H_2 burners, H_2 production

Linde gas is leading in global industrial gases and engineering company, serving a variety of end markets such as chemicals and energy and metals and mining. Industrial gases and technologies are used in countless applications including production of clean hydrogen and carbon capture systems critical to the energy transition, life-saving medical oxygen and high-purity and specialty gases for electronics. Linde gas also deliver state-of-the-art gas processing solutions to support our customers.

Outotec – technology provider

Potential area of interest: H_2-based DRI production, melting, Ore beneficiation, Pelletising

Metso is a frontrunner in sustainable technologies, end-to-end solutions and services for the aggregates, minerals processing and metals refining industries globally. We improve our customers' energy and water efficiency, increase their productivity, and reduce environmental risks with our product and service expertise.

4 Discussion

In response to the escalating demand for steel within India's burgeoning infrastructure landscape, several companies have expressed keen interest in investing in large-scale blast furnaces in the immediate future (2025-2030). In this context, prioritizing the beneficiation of low-grade Indian iron ore, alongside the strategic deployment of carbon capture utilization and storage (CCUS) technologies, as well as the harnessing of hydrogen (H_2) gas and renewable energy sources are major approaches for mitigating fossil CO_2 emissions. Additionally, the prospect of either moving or establishing an experimental blast furnace (EBF) in India has emerged as a promising avenue for potential collaboration between Sweden and India.

The key takeaways from the discussion concluded the complexity of the decarbonization process based on green H2, the need for collaboration, technological advancements, and investments. It highlights the urgency of addressing the challenges posed by low-grade ores and the potential impact of natural gas and renewable energy sources in reducing CO2 emissions.

4.1 Unlocking conditions for technology demonstration projects

From the visits, it is clear that the industry realises the need to find new solutions for CO_2 reduction. In order to find suitable candidates for demonstration projects:

1. Look at the dominant Indian processes for steel production, with respect to raw materials, energy, logistics, emissions, sunk costs and competence
2. Understanding the main concerns/issues of Indian Steel industry with respect to decarbonization efforts especially with respect to Blast Furnace Operation and possible effects of CBAM or other drivers on decarbonization efforts.
3. Understand the drivers for Sponge-Iron manufacturers.

India have seen significant expansion of the industry the last decades. The majority of the large steel producers have made new investments in BF based production. It is likely that this production capacity will stay in operation another 1-2 investment cycles. Hence BF based technology improvements are needed. With expected growth of the Indian steel production to 300 Mton by 2030 this means that there are significant additional production capacity to be added. Several steel producers visited already have expansion plans decided, new production capacity being installed and new investments being decided. Most of the new production will be based on their existing technology, adding efficiency improvements. Some companies are investigating the possibility with H2 based steelmaking, however it is not likely that this will be the majority of new installed production until 2030.

4. Identify synergies between the approach of Sweden metallurgy industry to research, and how this could potentially be implemented in India.

Sweden has long tradition of research and development. Technology development such as oxyfuel applications, electric heating, pellet development, waste handling, new hydrogen-based reduction processes. There are also several examples of process efficiency improvements that are possible candidates for collaborative projects. One area which have been identified by the Indian side is collaboration around the pilot research such as experimental blast furnace (LKAB), H2 DRI pilot (Hybrit development) and metallurgical pilots (Swerim). This is an area for future possibility collaboration.

Research efforts on renewable carbon resources and how these can be utilised in metallurgical industry can play a role for future Indian industry. This is an area where Swedish research could be assisting Indian industry.

Carbon capture and utilisation has been identified as an option of the Indian industry. There is a CCUS roadmap for Indian Industry authored by IIT Bombay, where there is knowledge on geographical locations and possibilities. Sweden have experience with large scale pilot testing, this could be another potential candidate for collaboration.

There are different ways to promote the collaboration. Either business to business collaborations or collaborative research with a combination of national and industrial funding. In both types of research, it is important to find partnerships where different actors are co-developing the research.

5. Understand the geographical distribution of different drivers for decarbonization: renewable energy, biomass and carbon sequestration potential.
    a. Raw Materials: Unlike the steelmaker, the operators of mines seem to have realised the need for upgrading of ore. Lloyds Metal are setting up pellet plant to upgrade iron ore from 35 to 67%, already with plans for the oft-cited problem around availability of water resources.
    b. Energy: The CO_2 associated with imported electricity footprint is gaining recognition with many independent actors buying renewable energy or setting up their own renewable energy systems. Storage of renewable energy is on the minds of the larger users.
    c. Emissions and CBAM: The high value steel companies visited showed two very different knowledge levels: from deep understanding to on-coming panic of understand CBAM.
    d. Sunk Costs: Remains the same with respect to BF route. Growing consensus that coal-DRI operations will need to change radically (to Natural gas) and also consolidate for economies of scale.
    e. Competence: More is available than initially identified by actors – especially with respect to IIT Bombay and Teri. NISST will not be used as the base for an Experimental Blast Furnace as tipped off by JSW.

4.2 Recommendations

Based on the different fact finding trips, as consensus is starting to form around six different potential activities of support:

1. Support for operation and setting up an experimental blast furnace facility dedicated to the Indian context, i.e. lower grade ores and coal.
    a. There could be several semi-commercial discussions going on (Tata and JSW), but these are not necessarily conducive to support the broad iron and steel industry in India.
    b. There already is an experimental facility that have been operated by SAIL up to 20
2. Support for operation and setting up H_2-based DRI pilot (or demonstration)
    a. Same discussion around the size and potential for support a broad range of actors is still necessary.

    b. H_2-electrolyser operations
3. Utilisation of bio-resources for metallurgical industry
    a. Potential resources from Indian perspective, pretreatment
    b. Developing bioresources for BF and DRI operation
4. Beneficiation is still an important action, although the miners are moving forward on this anyway, even though iron and steel companies see problems with respect to water use and tailings.
    a. Specifically, this could be translated in a wish to understand what to do with the tailings as apart from the beneficiation itself, which the operators are buying Finish-Swedish technology (i.e. Outotec-Metso)
    b. The disconnect may partially be because of falling under a different Ministry (i.e. Ministry of Mines)
    c. Courses and best practices
5. CBAM and emission scope
    a. Lack of understanding of many actors, is a great driver for Sweden-Indo Cooperations
6. Activities around CCUS haven't yet found a real footing in India
    a. Better interaction with IIT Bombay and Teri could be drivers of the research in this are
    b. Potentially, also an issue that CCUS is though of more in the Petrochemical industry – falling yet again under another set of state actors

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