DRI UPDATE

Sponge Iron Manufacturers Association

Indian voice for the ore based metallic & steel industry

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Editorial

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Dear Readers,

Presently, sponge iron manufacturers stand at a pivotal crossroad: riding a wave of global demand, facing price and supply turbulence, and navigating a fast-evolving green-energy and geopolitical lattice. Successful players will be those strategically investing in cleaner technologies, securing continuous raw materials flow at affordable prices.

India leads global production in DRI. As per World Steel Association in 2024, DRI production of India was 54.8 million tonnes vis-à-vis global production of 144.1 million tonnes (38.04%). Due to the current focus on decarbonization, it is expected that there will be a robust growth globally in sponge iron production. In India, we also envisage similar situation in view of the double digit growth in steel consumption and inadequate availability of recycled steel from domestic and international sources.

India heavily reliance on coal based DRI which is not so eco-friendly. Realizing this , under National Green Hydrogen Mission, Ministry of Steel has identified and providing financial support to the following projects:

* Hydrogen Based DRI
* Hydrogen + Natural Gas in DRI
* Hydrogen in Blast Furnaces

In addition of the above under their R&D scheme, Ministry of Steel has approved 5 projects to reduce carbon footprints in the existing coal based DRI industry and exploring the use of GH2.

Another issue impacting growth of this vital segment of the steel industry is raw material availability of desirable quality and quantity at affordable prices. It is a matter of grate satisfaction that Ministry of Mines and Ministry of Coal are working to augment availability of coal and iron ore. Availability of natural gas at affordable price continues to be a major stumbling block to reduce carbon footprints and to augment desirable DRI production through gas based route.

In view of the implementation of CCTS and CBAM, it is felt that all stakeholders should work together for cleaner energy subsidies, carbon credit frameworks, and CAPEX incentives for green DRI, enabling competitiveness against fossil-steel incumbents.

The present issue focus on Use of Hydrogen and Bio mass in DRI & Steel Making and continues use of DRI in electric arc furnace plants. We are sure our readers would find this issue informative.

Hydrogen in Iron and Steelmaking

Ore-Based Metallics & Carbon-Neutral Steel

This article is based on excerpts from IIMA White Paper 7: "Hydrogen in Iron & Steelmaking" by Neil Bristow, H&W Worldwide Consulting, and Chris Barrington, IIMA Chief Adviser, April 2024, reviewed and updated by Christian Boehm, Primetals Technologies Austria GmbH, and Chairman of IIMA Technical Committee.

INTRODUCTION

The global steel industry accounts for between 6-8% of carbon dioxide (CO_2) emissions. The majority of this is due to the reduction phase of iron ore in blast furnaces (BFs). While modern ironmaking systems have seen a sizeable reduction in emissions and an increase in energy efficiency in the past 20 years, to reach the targets of net zero emissions by 2050, a non-carbon, fossil-free reductant will be required. This will result in the large-scale use of hydrogen as the key reductant in ironmaking technologies.

This article outlines the different types of hydrogen, explores the costs of producing hydrogen, discusses the use of hydrogen in iron and steelmaking to Replace carbon reductants, and touches on future issues and uncertainties surrounding widespread adoption of hydrogen as the primary reductant in producing iron for steelmaking applications as the primary reductant in producing iron for steelmaking applications.

INTRODUCTION TO HYDROGEN

What is Hydrogen?[1]

Hydrogen is a colourless, odourless, tasteless, and non-poisonous gas under normal ambient conditions. It exists as a diatomic molecule, meaning each molecule has two hydrogen atoms (H_2). Hydrogen is the smallest, lightest, and the most abundant element in the periodic table.

Hydrogen can be stored and consumed as liquid hydrogen or compressed gaseous hydrogen. Liquid hydrogen must be kept at -253oC at 1 bar. Compressed hydrogen must be stored at 200 – 700 bar at ambient temperature. The boiling point of hydrogen at atmospheric pressure is -253oC, which is 20oC above absolute zero and far colder than the boiling point of nitrogen (-196oC) and liquefied natural gas (-162oC). This presents major challenges in adapting existing liquified natural gas infrastructure for liquid hydrogen storage and transportation use, even in the case of hydrogen being transported in the form of methanol or ammonia carriers followed by dissociation and separation.

While hydrogen may dissipate quickly in open, well-ventilated areas, confined spaces with little or no ventilation represent a significant hazard. Combustion may occur in some scenarios depending on the flammable air temperature, gas pressure, and location of a leak. These characteristics will require corresponding electrical equipment certification for application in hazardous areas.

Hydrogen has a wide flammability range compared to other commonly handled fuels and cargoes and a maximum experimental safety gap of 0.29 mm, having an assigned 11C gas group based on the international method of area classification developed by the IEC (International Electrochemical Commission.

Although the heating value of hydrogen is the highest of all potential fuels (120-142 MJ/kg), the energy density per volume is relatively low at standard temperature and pressure. This can be increased by storing hydrogen as a compressed gas or in liquified form, but even in these forms the energy density is significantly below that of other hydrocarbons and alternate fuels; e.g., ammonia, methanol, and liquefied natural gas (LNG).

THE HYDROGEN RAINBOW

Hydrogen is given different "colours" to differentiate the various production methods ***(see Table 1)***.

Although there are many ways to produce hydrogen to reach net zero emissions, green hydrogen will need to be produced in very significant volumes. This will pose major technical and commercial challenges and will require massive government and/or private funding to enable development of the volumes of green hydrogen needed for industry and power generation.

Pink hydrogen is something of a niche product in the current market but has significant longer-term potential to add to the supply of low emission hydrogen. Nuclear energy is used to generate the heat required for high temperature steam electrolysis, without the intermittency of renewable sources of wind and solar power. Of course, nuclear power brings its own challenges: although CO2 emission is not an issue, there are the attendant problems of long-term storage of nuclear waste, safety concerns and public acceptance. These challenges will have to be addressed if pink hydrogen is to fulfil its potential.

White hydrogen is experiencing an increased level of interest and visibility and has been referred to as "the white gold rush." There were 40 companies exploring for natural hydrogen deposits by the end of 2023, up from 10 in 2020. A key incentive driving this "gold rush" is that natural hydrogen would have a significant cost advantage over hydrogen produced from renewable energy or fossil fuels. Whereas grey hydrogen costs less than US$2/kg on average and green hydrogen currently is three times more expensive, white hydrogen could be extracted and purified at a cost of about US$1/kg. There is currently only one producer, Hydroma, a Canadian company, which operates a well in Mali at an extraction cost of US$0.50/kg. Recognising that it is at an early stage of development, white hydrogen could be a gamechanger for the low emission hydrogen sector, although reserves still have to be quantified and the issues of transportation, distribution, and storage have to be addressed as for all forms of hydrogen.3

HYDROGEN COLOURS H_2

GREEN

Made by the electrolysis of water by renewable energy sources. Defined as "carbon-free" hydrogen.

BLUE

Produced predominantly from natural gas via steam reforming. Heating steam and natural gas and produces carbon dioxide as a by-product, which is then captured. Defined as "low carbon" hydrogen.

GREY

Produced by methane and steam reformation but without capturing the greenhouse gases. Essentially the same as blue hydrogen but without carbon capture.

BLACK & BROWN

Using coal or lignite in the hydrogen making process. Used somewhat interchangeably this is the most carbon intensive way to make hydrogen.

PINK

Defined as hydrogen produced from nuclear energy. Also referred to as purple or red hydrogen.

TORQUOISE

Hydrogen made via methane pyrolysis at high temperatures, producing hydrogen and solid carbon. Yet to be proven commercially.

YELLOW

Hydrogen formed via electrolysis using solar power.

WHITE

Naturally occurring geological hydrogen found after fracking or from old mines. Not commercial yet, but experiencing an increasing level of interest.

NOTE: Green and blue hydrogen can generally be described as "low emission" hydrogen

TABLE 1. *The Hydrogen Rainbow*[2]

purified at a cost of about US$1/kg. There is currently only one producer, Hydroma, a Canadian company, which operates a well in Mali at an extraction cost of US$0.50/kg. Recognising that it is at an early stage of development, white hydrogen could be a gamechanger for the low emission hydrogen sector, although reserves still have to be quantified and the issues of transportation, distribution, and storage have to be addressed as for all forms of hydrogen.3

COSTS OF HYDROGEN

The two main routes for achieving net zero emissions by 2050 are likely to be electrolytic production of hydrogen and the addition of carbon capture, utilization, and storage (CCUS) to conventionally produced hydrogen from fossil fuels, green and blue hydrogen respectively. The key will be the production of hydrogen via the electrolysis route using ever larger and lower-cost electrolysers.

Based on existing proposed projects, low emission hydrogen could move from 0.7 Mtpa in 2021 to around 24 Mtpa by 2030. The future of many of these projects depends on improving electrolyser technology and the development of sufficient green electricity to power them. Australia is one of the leaders in the proposed use of renewable electricity-powered hydrogen production, with targets of electrolyser capacity of 50 GW by 2030. This equates to more-or-less the amount of power required to power all homes in Australia. One of the key features here is the continued reduction in the costs of renewable electricity and water, necessary to drive cost-effective hydrogen production. Larger capacity electrolysers are currently under construction in Europe (32%), Australia (28%), and Latin America (12%)2. Scale is predicted to exceed 260 MW by 2025 and >1 GW by 2030. To reach these targets significant additional funding will be required, which is proving a challenge. Electrolyser capacity is being expanded to meet future demand and planned capacity. If funded, it will be more than sufficient to meet projected demand. This will be extremely important if the global steel industry moves to high hydrogen use towards and beyond 2030[4].

Costs of electrolyser capacity will be a function of size and location. To produce green hydrogen an electrolyser will need to be powered by green electricity, which will pose major challenges and difficulties (e.g., renewable power is not continuously available from solar and wind and the limited expansion potential for hydropower) and will need significant expansion of renewable power generation feeding the grid. Estimated production costs vary from around US$4/kg hydrogen to >US$9/kg, depending on location9. The cost of hydrogen is predicted to come down as the efficiency of electrolyser technology improves, from <70% to approximately 85%, and targets of between US$2.3 to <US$4.0 have been forecast10. Current costs using steam reforming generation of hydrogen are in the order of US$1.00/kg.
Electricity cost is one of the key components to the overall cost of producing hydrogen, with estimates of between 50-55 kWh required per kg of hydrogen, equating to around US$3/kg at a power cost of US$0.06/kWh9. Typical costs for green electricity are higher than this and vary by location but are in the order of US$0.08-0.12/kWh. Costs in developing countries are higher than in regions with advanced electricity grids and will need to see major electricity grid advances to make hydrogen costs economically viable. More recently, the cost differentials between renewable power and fossil fuels have declined9,10 and further cost reductions are needed to continue this trend, particularly for solar and offshore wind power generation. It is expected that lower hydrogen production costs will enable large scale hydrogen generation facilities to come on stream in the next decade.
The cost of electrolysers is another major consideration. Current full costs are in the range of US$1,400 to US$1,800 per kW. Major reductions in costs of up to 70%2 are predicted by 2030, with a target of around US$400 per kW by 20309 and ~<US$300 per kW by 2050, as economies of scale and technology proceed2. A key uncertainty will be the cost of metals; e.g., platinum and rare earths, which are critical parts of both alkaline and membrane electrolysers.

CCUS coupled to use of fossil fuels could enable hydrogen production of 3 Mtpa by 2030 in Europe, with a similar level in North America. The key here is the successful, timely development of lower cost CCUS options. Although technically CCUS can work, the major issue will be can it become commercially viable, as this will require a continued reduction in costs. A major cost driver for CCUS is the steam requirement of approx. 1 tonne of low-quality steam per tonne CO_2 captured. The total potential CCUS project pipeline is as high as 80 Mtpa CO_2.
Another issue is the cost of storage of either electricity or hydrogen to buffer intermittent green electricity generation and steady industrial demand, both daily and long term. Storage of either is expensive and not available yet at industrial scale. The cost of CCUS is highly variable and depends on the levels of CO_2 in the gas streams. Typical costs for CO_2 capture from concentrated gas streams vary from around US$15-20/t CO_2 to US$40-120/t CO_2 for dilute gas streams. Indicative costs for CO_2 capture are shown in ***Figure 2***.14

To reach net zero emissions by 2050, most forecasting groups suggest that this will require the adoption of CCUS. Use of CCUS and/ or green hydrogen in the steel industry is the projected route most likely to enable such low or zero emission targets by 2050 in developed regions such as the EU, North America, and north Asia.

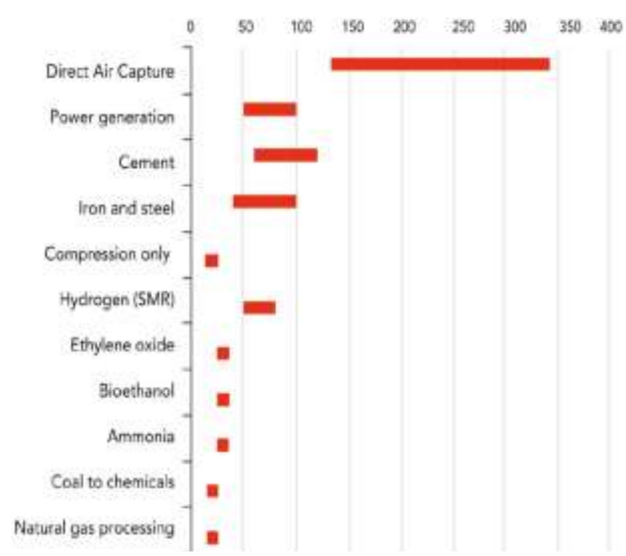

Figure-2 *Costs of CO_2 capture by sector (US$ per tonne)14*

HYDROGEN PRODUCTION

Hydrogen is not yet viable at scale. According to the IEA (International Energy Agency), green hydrogen will not be available at an industrial scale until after 2030 – currently less than 0.1% of global dedicated hydrogen production comes from water electrolysis. In the interim, blue hydrogen options are being explored. However, the main challenge will still be in producing hydrogen at scale to meet projected demands, not only from the iron and steel industry but also from the other industry sectors. Under IEA's Sustainable Development Scenario, global demand for hydrogen will increase to 287 Mtpa by 2050, which represents an increase of over 400% from 2020.[30]

The demand for hydrogen will increase strongly to 2030 and beyond. However, as yet there is no priority in the demand for hydrogen. It has not been determined which industry will receive the available green hydrogen as-and-when it becomes available. Potentially, this might come down to simple price/affordability criteria. There is a shift nowadays to favor industrial use vs. other sectors (such as transportation) that can better afford hydrogen.

Hydrogen production is nevertheless growing strongly, with numerous projects worldwide to produce the different forms of hydrogen. Production of green hydrogen is predicted to grow very strongly post 2030, as shown in ***Figure 3***, and will become the dominant form of hydrogen by 2050[14]. Blue hydrogen also will in crease while grey and brown hydrogen produced from fossil fuels will decline post 2030.

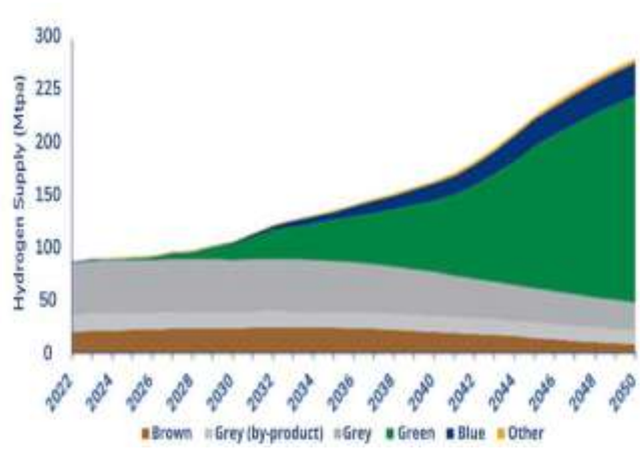

FIGURE 3. *Global hydrogen production by colour: 2022 to 2050 (Mtpa)*[15]

HYDROGEN IN IRON & STEELMAKING

The conventional route currently used in the production of steel is ~72% via the cokemaking/blast furnace/basic oxygen furnace (CO/BF/BOF) route and ~29% via the scrap/DRI/electric arc furnace (EAF) route, worldwide. The blast furnace route emits up to four times more CO2 than the EAF route. The major source of the CO2 via the blast furnace route is the sintering and iron ore reduction/ smelting processes ***(see Figure 4[8]).***

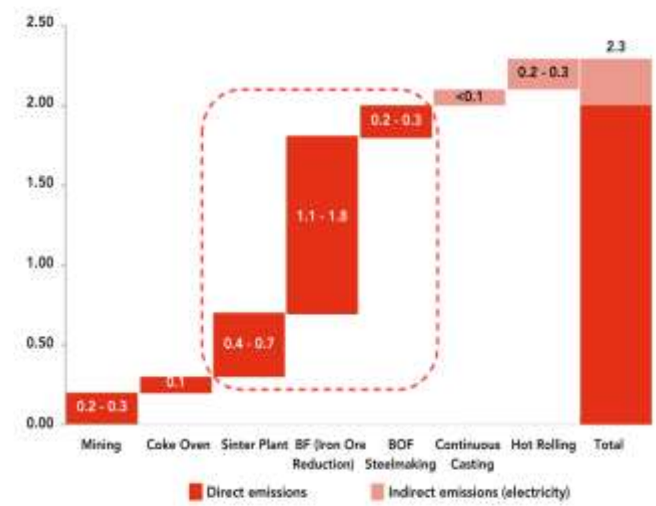

FIGURE 4. *CO_2 emissions during CO/BF/BOF steelmaking by stage (T CO_2/T HRC)*[8]

The direct use of hydrogen for iron and steelmaking is for heating purposes and for the reduction of iron ore oxide. Three main application fields for the utilization of hydrogen within the iron and steelmaking exist:

- **Hydrogen injection in blast furnaces:** here a partial replacement of coke or pulverized coal as PCI and/or the replacement of natural gas or other reductants with hydrogen is possible but limited. As hydrogen reduction is endothermic, it absorbs heat and results in a cooling effect in the blast furnace raceway, which needs to be compensated with additional heat added to the reduction and melting process inside the blast furnace. This reduces carbon emissions but does not eliminate them entirely.
- **Hydrogen Plasma Smelting Reduction (HPSR):** This is a process that uses hydrogen plasma to reduce iron ore, which is still in experimental stages but has certain potentials.

• **Hydrogen-based Direct Reduced Iron (H2-DRI):** Instead of using natural gas or coal, hydrogen can serve as a reductant to remove oxygen from iron ore. This process produces water (H_2O) instead of CO_2, making it more environ-mentally friendly.

Most major steel companies have published emission reduction targets, with the majority seeking to achieve 25-30% or more by 2030, while aiming for net zero emissions by 2050. As part of these ambitions to decarbonise the steelmaking process, the widespread use of hydrogen has been planned. This will be focused on technology seeking to replace natural gas with hydrogen in direct reduction processes and partially replacing pulverised coal injection (PCI) with hydrogen in the blast furnace. This will be undertaken in staged processes.
For hydrogen to be used in combination with CO in direct reduction shafts, significant planning has been done on moving to increased levels of hydrogen and then to full 100% hydrogen reduction. Where there is the practical option to store CO2 geologically, carbon capture and storage also can be added to the process to reduce the carbon footprint for existing direct reduction plants and/or blast furnaces. Partial use of captured CO2 already occurs in Mexico and Abu Dhabi, for example17. Most major European steelmakers have plans to add DRI capacity to their steel plants by or soon after 2030.

It is worth noting that HBI could also be seen as a form of energy transport. HBI manufactured in green or low emission hubs, for example in the USA, Middle East, Australia, etc. and shipped to countries with high energy cost and/ or limited potential for renewable energy, would be a much simpler and lower cost solution than transportation of hydrogen as liquid, gas, or ammonia.

Hydrogen-based Direct Reduction

Flowsheets for 100% hydrogen-based reduction have been developed for both the MIDREX® and ENERGIRON® processes. In addition to the established direct reduction processes, emerging direct reduction technologies, such as Primetals' Hyfor™ fluidised bed process and the POSCO/ Primetals HyREX fluidised bed process combined with a smelter will be hydrogen-based. Metso's re-emerging Circored™ fluidised bed process is also hydrogen-based.
Plans are also well advanced, especially by integrated steel companies in Europe (including SSAB, thyssenkrupp, Tata Steel Ijmuiden, voestalpine, Salzgitter and Saarstahl) for the transition from blast furnace-based to direct reduction-based iron production with the resultant DRI to be used to complement recycled steel in EAF steelmaking or, via an electric smelting step, as BOF feedstock. Similar plans are also underway in the Asia Pacific region, for example in Australia for replacing the blast furnace at Port Kembla works. There are also hydrogen-based direct reduction plants in China, albeit so far with hydrogen derived from coke oven gas.
H2FUTURE16,24 is a European flagship project for the generation of green hydrogen using electricity from renewable energy sources. Under the coordination of the utility VERBUND, steel manufacturer voestalpine, and proton exchange membrane (PEM) electrolyser manufacturer Siemens Energy, a large-scale 6 MW PEM electrolysis system is in operation at the voestalpine Linz steel plant in Austria.
In the near- to medium-term, most of the new direct reduction plants will be based on natural gas with a progressive shift to low emission hydrogen as it becomes economically available. Both the MIDREX and ENERGIRON processes have flexibility in the proportion of hydrogen in the reducing gas, as well as the ability to include carbon capture technology. However, using hydrogen produced from natural gas for DRI production emits more CO2 than using the natural gas directly.
A front runner in hydrogen-based direct reduction is HYBRIT (Hydrogen Breakthrough Ironmaking Technology) in Sweden, a joint venture of SSAB, LKAB, and Vattenfall25,26. Having successfully demonstrated the process at a pilot plant in Luleå, the next step is a demonstration plant to be built by LKAB and located at Gällivare, using green pellets from LKAB and green hydrogen based on green electricity from the Swedish grid. SSAB will utilise the green DRI to produce green steel at its Oxelosund works and eventually at its Luleå works, which will be converted to EAF steelmaking.

In Boden, Sweden, Stegra (formerly H2 Green Steel) is advancing toward a 2026 start-up of the world's first commercial-scale green steel mill powered by renewable energy and based on 100% hydrogen DRI. The state-of-the-art steel mill will have an initial production capacity of 2.5 mtpy fed by a MIDREX H2™ Plant supplied by Midrex and Paul Wurth, with an production capacity of 2.1 mtpy of hot DRI (HDRI) and hot briquetted iron (HBI). SMS group will provide the rest of the steel mill for the production of a broad product mix including advanced high strength steel and automotive steel grades.

Our journey towards 5 million tonnes of green steel

June 2023:
Full environmental permit approved - in record time

Beginning 2026:
Production start

2026-2028:
Ramp-up to full production of 2.5mt hot- and cold-rolled steel

2028
Expansion - ramp up to full 5mt capacity

2030 (earliest 2):
Yearly production of 5mt green steel

Stegra is pursuing a 5-step development plan for its lighthouse project, with the goal of producing 5 mtpy of "green" steel:

STEP 1: Giga-scale Electrolysis – using renewable electricity to decompose water into hydrogen and produce enough hydrogen to make 5 million tonnes of high-quality steel annually by 2030.

STEP 2: Hydrogen-based Direct Reduction – using green hydrogen instead of coal or natural gas to react with oxygen in iron oxide pellets to produce highly metallized direct reduced iron (DRI) for steelmaking with steam as the residual, thus reducing CO2 emissions by up to 95%.

STEP 3: Electric arc furnace (EAF) Steelmaking – using renewable electricity to heat DRI and steel scrap to create liquid steel, with contained carbon in the slag playing an important role in lowering electricity consumption and enabling the transformation of iron to steel.

STEP 4: Continuous Casting and Rolling – allowing energy consumption to be reduced 70% and replacing natural gas in the traditional process.

STEP 5: Downstream Finishing Lines – cold rolling, annealing, and hot-dip galvanizing for adjusting steel thickness, creating desired mechanical properties, and protecting against corrosion, respectively.

FUTURE ISSUES & UNCERTAINTIES

There are issues and challenges with respect to adoption and use of hydrogen as a carbon replacement in the steel industry. These include:

1. Rate of production of green hydrogen: there are numerous projects in the pipeline to produce green hydrogen, but these are wholly insufficient to meet the requirements, commitments, and targets of European steel companies. Tracking the development of such projects will provide a good indication of the feasibility and timeline for the steel companies to meet their stated targets. A key requirement to monitor will be the development of large-scale green power facilities and electrolysers capable of producing large volumes of green hydrogen at commercially viable costs.

2. Cost reduction of hydrogen production: aggressive hydrogen cost reduction targets are forecast to 2030.

The progress and realisation of these targets will provide good indications of the economic feasibility of reaching net zero emission by 2050.

3. Technical achievement of successful hydrogen use in steelmaking and DRI production: monitoring of the progress of large-scale hydrogen injection into large blast furnaces and the construction of hydrogen-based DRI facilities, for example, the HYBRIT demonstration plant and the Stegra industrial-scale plant due to start in 2026, will be a good guide as to the likelihood of European steel companies reaching their 2030 targets for emission reduction.

4. Development of ranking industries for hydrogen adoption: no such list is currently available. The assessment of industries for available hydrogen when available will allow steel companies to assess their place in the queue and plan accordingly.

5. Evolution of public opinion: current public opinion is strongly in favour of net zero emissions by 2050. However, the economic viability of achieving this target is being increasingly questioned. Many developing countries will not be able to do so. India and China are targeting 2060 and 2070, respectively, and countries in Africa with growing populations do not have targets. In some European countries there already have been some policy-driven slowdowns in the rate of progress towards achievements of key milestones along the pathway to net zero, even as they maintain their 2050 net zero emission goals. Monitoring progress in achievement of intermediate targets; e.g., in 2030, and any changes in public sentiment will assist in determining the rate of adoption of hydrogen use in the steel industry. Use of hydrogen in shaft furnace-based direct reduction processes will require some technical and operational changes including:

- **Energetics and cooling effect:** direct reduction based on hydrogen is different to that based on natural gas as the thermodynamics result in an endothermic reaction delivering a cooling effect inside the reduction shaft. For the case of hydrogen use, some adjustments of temperature and/or gas flow can overcome the cooling effect.
- **Condensation of water:** hydrogen reduction forms water. However, this is more of a problem for the blast furnace. Concerning direct reduction plants, if not properly designed and operated, there is the potential for water condensation in the upper regions of the reactor.

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Biomass as a Game-Changer for Decarbonizing the Steel Industry: Opportunities and the Way Forward

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The steel sector holds a pivotal role in powering the world's core industries—construction, infrastructure, automotive, engineering, and defense—making it an indispensable pillar of economic progress. India has rapidly ascended as a global leader in this field, now ranking as the world's second-largest steel producer with a crude steel output of 125.32 million tonnes (MT) and finished steel production of 121.29 MT in FY23. Steel production and consumption remain crucial indicators of industrial strength, given the material's centrality as both a key raw material and an intermediate industrial product. According to ICRA, India's domestic steel demand is projected to grow by 9–10% in FY25, driven by infrastructure projects, construction growth, capital goods expansion, and a steady automotive market. As of Q1 FY25, the nation recorded 36.61 MT crude steel production and 35.42 MT finished steel consumption—reflecting its ever-growing importance in the global industrial ecosystem. [1]

Decoding Steel Production Pathways and Carbon Challenges

Steel manufacturing employs primarily four technological routes:

1. Blast Furnace-Basic Oxygen Furnace (BF-BOF)

2. Smelting Reduction Iron with BOF (SRI-BOF)

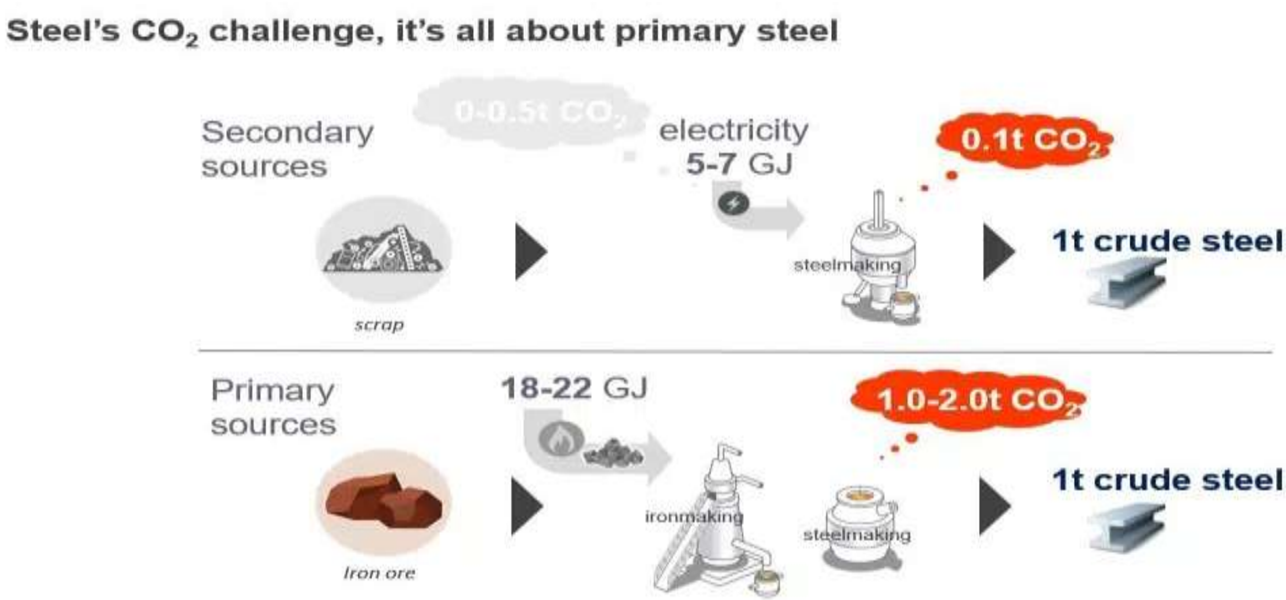
3. Direct Reduced Iron in Electric Arc Furnace (DRI-EAF)

4. Direct Smelting of Scrap in EAF (Mini Mill)

In all these pathways, carbon acts as a fundamental reducing agent and energy source. Specifically, the BF-BOF process, the dominant route, uses coke derived from high-grade coal to reduce iron ore, also imparting carbon to the molten iron. EAF routes rely more on scrap and electricity but still utilize carbonaceous materials for slag foaming and maintaining process conditions. [2]

The global steel industry continues to release a staggering 3.7 billion tonnes of CO_2 every year, with no clear indication that these emissions have reached their peak. Iron and steel production alone is on track to consume nearly one-fourth of the world's remaining carbon budget by 2050. Yet, even in this critical period, new coal-based blast furnaces are being commissioned and existing ones refurbished—decisions that will lock high carbon emissions into the future for decades. Meanwhile, the effects of climate change are no longer distant warnings; the year 2024 has already seen unprecedented wildfires, destructive floods, and intense heatwaves across the globe, impacting millions of lives and serving as a stark reminder of the urgent need for change. [3]

However, this heavy reliance on fossil carbon sources—primarily coal—has made steel production one of the most carbon-intensive industries globally, responsible for nearly 8% of total greenhouse gas emissions. The iron and steel sector's direct CO_2 emissions have risen steadily due to surging steel demand worldwide, even though the CO_2 intensity per tonne of crude steel has seen modest reductions. Conventional steelmaking processes, particularly blast furnaces, released an average of 2.33 tonnes of CO_2 for every tonne of crude steel produced in 2022. In contrast, newer technologies such as electric arc furnaces have drastically lower emissions, averaging just 0.68 tonnes of CO_2 per tonne of steel. This sharp gap underscores the significant opportunity to cut the industry's carbon footprint by shifting towards cleaner, more efficient production methods. [4]



Decarbonizing steel production is no longer a distant goal; it is a pressing necessity. Yet, challenges remain: existing facilities are relatively young (especially in developing economies like India), the capital cost for technological transition is steep, and proven large-scale, low-carbon alternatives are not yet widely commercialized.

Emerging Decarbonization Strategies:

- Increased energy efficiency
- Greater scrap utilization
- Renewable power integration
- Hydrogen-based reduction (H-DRI)
- Carbon capture, utilization, and storage (CCUS)
- **Biomass-derived carbon utilization**: a near-term,

  practical solution

Biomass as a Viable Low-Carbon Substitute in Steelmaking

Biomass and its derivative products, such as **biochar and bio-oil** (via pyrolysis), have garnered significant attention as potential sustainable carbon sources for the steel industry. Unlike coal, biomass is renewable, carbon-neutral, and widely available. India produces approximately **750 million metric tonnes (MMT)** of biomass annually, contributing about **32% of its primary energy mix**. [5]

Application Points in Steel Production:

- **Coke-making**: Biochar can replace a portion of coke in the sintering and iron-making stages.
- **Blast Furnace Injection**: Pulverized biochar can be partially injected in place of coal fines.
- **Electric Arc Furnaces**: Biochar enhances slag foaming, improving thermal efficiency and reducing electrode wear.
- **Sintering and Pelleting**: Biomass-derived carbon fines can substitute for fossil fuel-derived binders or reductants.
- Notably, **partial replacement of fossil carbon by biochar up to 20%** in various steel processes has been documented as technically feasible without compromising output quality.

Why Biochar? Why Now?

- **High Reactivity**: Accelerates reduction reactions, although controlling reactivity is essential for furnace stability.
- **Foamy Slag Enhancement**: Especially beneficial in EAF operations, improving energy efficiency and protecting furnace linings.
- **Circular Economy Potential**: By transforming agricultural residues, energy plantations (like bamboo), and organic wastes into value-added steelmaking inputs.

Bamboo: India's Strategic Biomass Resource

Among various biomass feedstocks, **bamboo stands out** due to India's vast 14 million hectares of bamboo coverage and 136 indigenous species. Bamboo offers:

- **Rapid growth and high yield** (compared to woody biomass)
- Low cultivation cost
- Coal-like properties ideal for biochar production
- Local availability, reducing transport emissions and costs
- However, biochar for steelmaking demands stringent physicochemical properties (density, ash content, volatile matter), necessitating **tailored pyrolysis processes** to meet these criteria consistently.

Challenges and the Road Ahead

For biomass-based decarbonization to scale meaningfully in steel production, several hurdles must be addressed:

- **Standardization** of biochar quality for blast furnace and EAF applications
- Sustainable, large-scale **biomass sourcing frameworks**
- Development of **rural-level decentralized pre-processing units** for pyrolysis, reducing feedstock logistics costs
- Integration with India's **existing biomass policies**, such as SATAT and GOBAR-Dhan, which are already building a biomass utilization ecosystem

The Indian government's policy thrust—including 500 planned "Waste-to-Wealth" plants and mandatory biomass co-firing in thermal plants—provides a supportive backdrop for similar adoption in the steel sector.

Future Outlook: Biomass for a Greener Steel Industry

As India marches towards its **net-zero emissions target**, the steel sector's decarbonization roadmap cannot ignore biomass. A future steel industry may well feature:

As India marches towards its **net-zero emissions target**, the steel sector's decarbonization roadmap cannot ignore biomass. A future steel industry may well feature:

- **20–30% fossil carbon substitution** by bio-based carbon
- Dedicated bamboo plantations, energizing rural economies
- Integration of pyrolysis-derived **bio-oil as auxiliary furnace fuel**
- Widespread **biochar use in EAF mini-mills** and blast furnaces
- Co-development with CCUS and hydrogen technologies for a holistic decarbonization strategy

In conclusion, biomass offers a **cost-effective, scalable, and immediately deployable pathway** for reducing the steel industry's carbon footprint—an opportunity India is well-positioned to harness.

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At the initiative of Hon'ble Tajikistan Ambassador in India, several rounds of discussions were held to guide their potential investors to set up a DRI and steel plant. Accordingly SIMA provided all necessary support which was highly appreciated. Subsequently, proposed plant authorities joined SIMA as a Overseas Member .

Tajikistan has got 3.6 billion tonnes of anthracite and low ash coal. They are looking for collaboration to gainfully utilize this high quality coal . Members /readers who are interested in this venture may kindly approach SIMA.

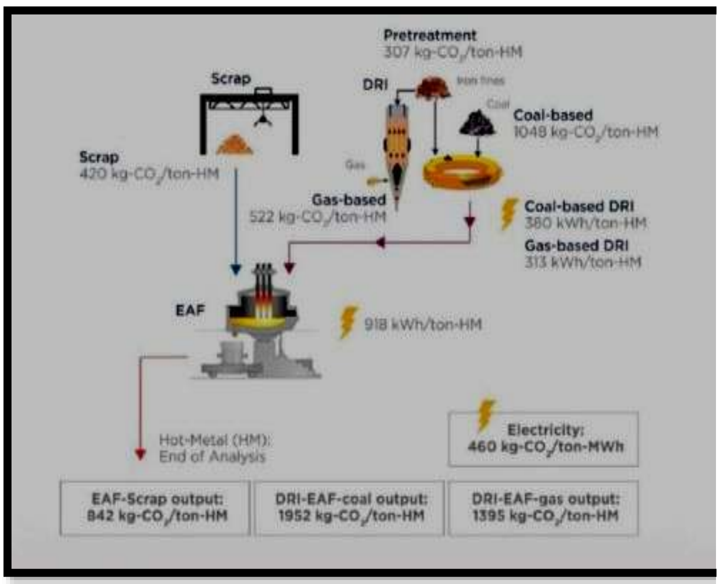
DG,SIMA & Director, SIMA with Hon'ble Ambassador of Tajikistan in India Mr. Lukmon Bobokalonzoda

Challenges and Solutions for Cost-Effective Use and Handling of Next-Generation Non-Fossil Fuel: Hydrogen

Atul Bhatnagar
Director,SIMA

1. Introduction

Eliminating carbon dioxide (CO_2) emissions from iron making is a significant and pressing global challenge. Steel, an alloy of iron, is a critical material with widespread use across industries. With global steel demand expected to rise by 30% by 2050, addressing emissions from iron production becomes crucial. Currently, iron making contributes approximately 4% of total global CO_2 emissions. These emissions primarily result from the use of carbon monoxide (CO) derived from fossil fuels as a reducing agent for converting iron ore into metallic iron. Transitioning to cleaner alternatives, such as hydrogen, is essential for green steel production.



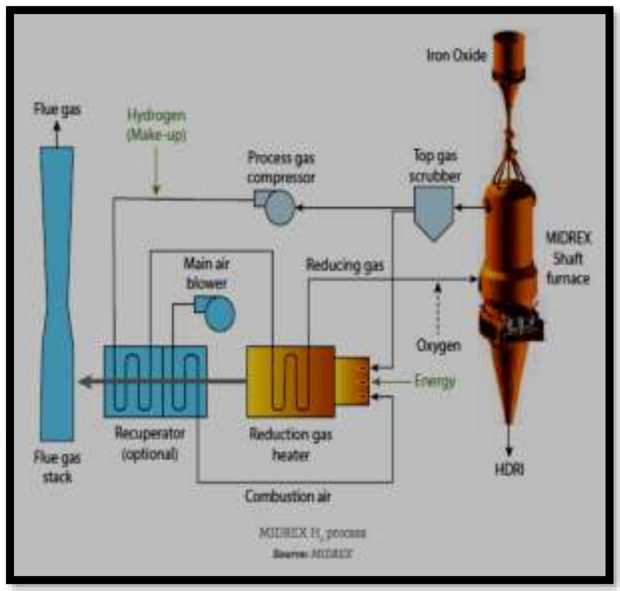
2. Hydrogen as a Decarbonization Enabler

Hydrogen (H_2) is increasingly being recognized as a pivotal element in replacing fossil fuels like coal, petroleum, and natural gas. Unlike these traditional fuels, hydrogen combustion does not produce CO_2—only water vapor—making it an environmentally friendly alternative.

In direct reduction of iron (DRI) processes, iron ore in the form of pellets or lumps is reduced in a reactor using a gas mixture containing CO and H_2. The two key reactions are:

- $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
- $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$

These reactions convert iron oxide into metallic iron while emitting either CO_2 or H_2O. To eliminate CO_2 emissions entirely, the goal is to use nearly 100% hydrogen as the reducing agent.



3. Decarbonization Challenges in India

India faces unique challenges in adopting hydrogen-based steel production. The country lacks significant natural gas reserves, and international gas price volatility adds further uncertainty for domestic iron producers. Consequently, the development of cost-effective, smaller-scale DRI models using alternative reducing agents becomes vital.

3.1. Cost Factor

The primary obstacle in decarbonizing the Indian steel industry lies in the high cost of green hydrogen. A breakdown of hydrogen production costs is as follows:

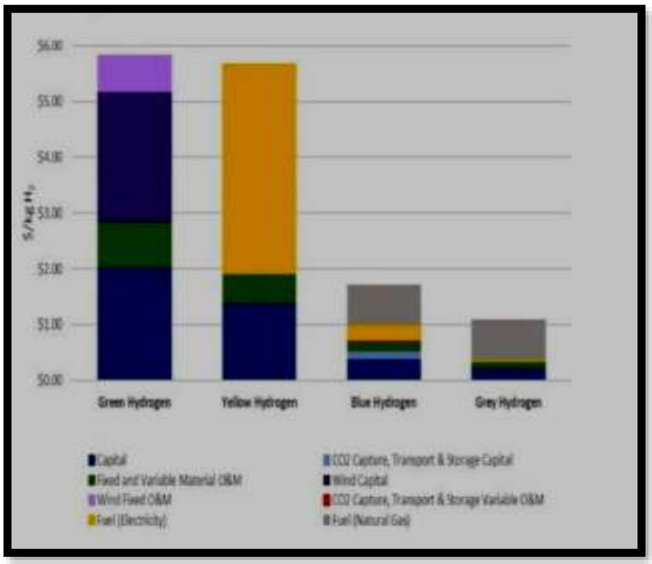
•**Grey Hydrogen** (~$1.00/kg): Capital $0.2, fixed & variable (O&M) $0.1, Natural Gas $0.7

•**Blue Hydrogen** (~$1.80/kg): Capital $0.4, fixed & Variable (O&M) $0.1, Electricity $0.4,

•**Yellow Hydrogen** (~$5.80/kg): Capital $1.5, fixed & variable (O&M) $0.4, Electricity $3.9

•**Green Hydrogen** (~$5.90/kg): Capital $2.0, fixed & variable (O&M) $0.9, Wind O&M $0.8, Wind Capital $2.2

H2 DRI-EAF PRODUCTION COST



Source: GRETECHECN Research Group

Green hydrogen is approximately six times more expensive than grey hydrogen and three times more costly than blue hydrogen, making it financially unviable for most large-scale applications without subsidies or major technological breakthroughs.

3.2. Hydrogen Handling Complexities

In addition to cost, hydrogen poses significant storage and safety challenges:

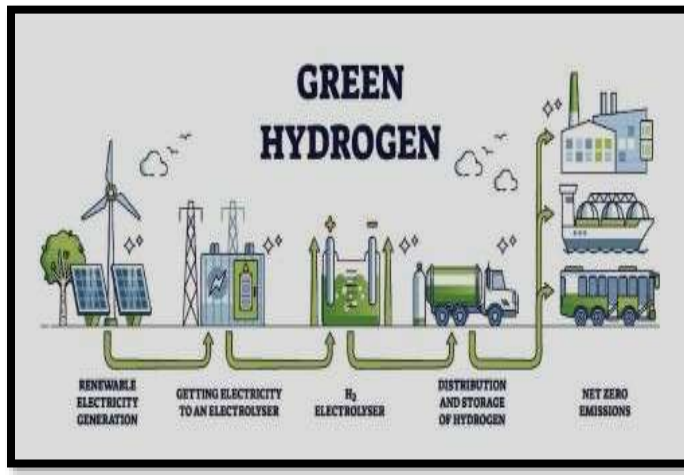
•It is **colorless, odorless, and tasteless**, making detection of leaks or fires difficult without specialized equipment.

•Being the **smallest molecule**, hydrogen easily leaks through materials considered to be airtight.

•Hydrogen can cause **metal embrittlement**, leading to structural degradation in pipelines and tanks.

•Its **low density** causes it to rise quickly and accumulate in ceiling spaces, creating a risk of explosion in confined environments.

These properties make handling and transporting hydrogen a technically demanding and costly endeavor.



4. To resolve above issues Ammonia offers a promising alternative

Ammonia (NH_3) has emerged as a promising hydrogen carrier that can circumvent many of the difficulties associated with hydrogen storage and transport. Ammonia offers several distinct advantages:

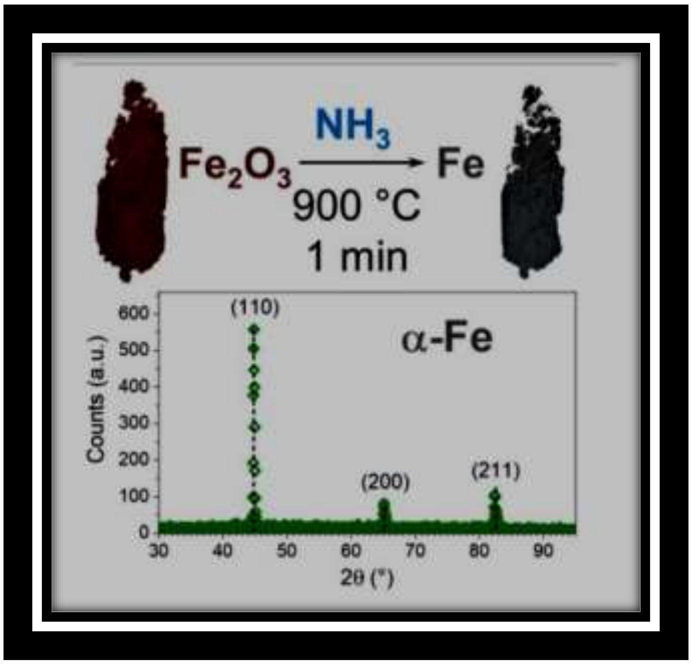
• It is easily **liquefied at room temperature** and transported via existing infrastructure—ships, pipelines, trucks, and rail.

•Ammonia is not a **greenhouse gas** and has a **narrow flammability range**, making it relatively safer than hydrogen.

•Most importantly, ammonia can act as a **direct reducing agent** in iron making, eliminating the need to reconvert it back into hydrogen, which otherwise incurs a 10–30% energy loss.

The direct reduction reaction using ammonia is:

- $Fe_2O_3 + 2NH_3 \rightarrow 2Fe + N_2 + 3H_2O$



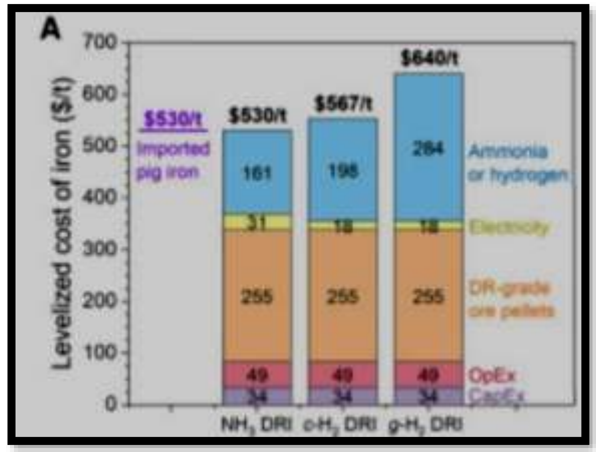
This reaction results in the formation of nitrogen and water as byproducts, both of which are environmentally benign.

4.1. Let us now discuss comparative reduction pathways

Three potential routes for iron ore reduction using hydrogen are currently being explored:

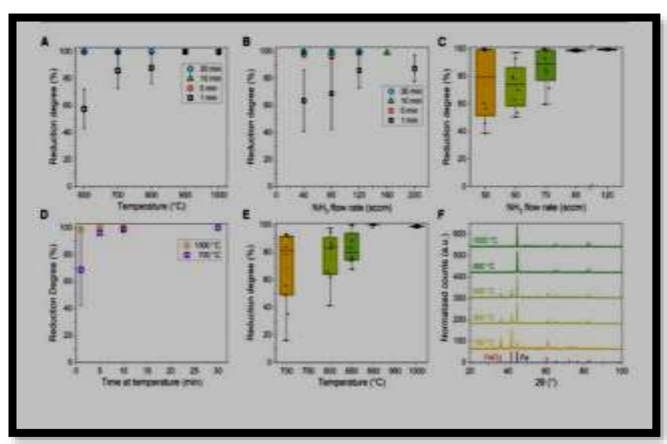
- **NH_3-DRI**: Direct reduction using ammonia
- **c-H_2-DRI:** Hydrogen derived from ammonia via thermal cracking
- **g-H_2-DRI**: Hydrogen produced on-site using renewable energy (green hydrogen)

Of these, the NH_3-DRI process offers significant advantages by bypassing the conversion loss and simplifying logistics.



4.2. Thermochemical Insights and Process Optimization

Thermochemical assessments reveal that high temperatures and increased ammonia flow rates significantly enhance the efficiency of the NH_3-DRI process. Experimental studies on a small scale have demonstrated up to **64% ammonia utilization within one minute** under optimal conditions. From a kinetic perspective, these parameters contribute to faster and more effective reduction reactions, paving the way for industrial scalability.



4.3. Process Integration and Byproduct Utilization

A notable advantage of the NH_3-DRI route is the useful byproduct—**nitrogen gas**. This can be efficiently repurposed for:

- **Sealing reactor inlets and outlets**
- **Purging systems to prevent contamination**

For reference, a pilot DRI plant requires approximately 25 normal cubic meters (NCM) of nitrogen per ton of DRI produced. This integration of byproducts enhances process efficiency and sustainability.

5. Conclusion

Green hydrogen offers a viable path for decarbonizing iron and steel production, but current limitations—particularly high production cost and complex handling requirements—pose substantial barriers. Ammonia presents a highly promising alternative, serving both as a hydrogen carrier and a direct reducing agent. Its easier transport, storage, and favorable reduction chemistry position it as a cornerstone in the transition to low-carbon iron making.

Moving forward, efforts must focus on:

- **Scaling up NH_3-based DRI technologies**
- **Optimizing reaction conditions**
- **Establishing pilot plants for validation**
- **Leveraging low-cost renewable electricity for ammonia synthesis**

By harnessing the potential of ammonia, the steel industry can make significant strides toward sustainable, low-carbon DRI and steel production.

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Adani New Industries Ltd (ANIL) has announced on 23.6.2025 the successful commissioning of India's first off-grid 5 MW green hydrogen pilot plant in Kuchh. This state -of- the- art plant is 100% green powered by solar energy and integrated with the Battery Energy Storage System.

Continuous Charging of DRI in Electric Arc Furnace

Deependra Kashiva, Director General ,SIMA

Steel production through the EAF route has been contributing about 30% of a total crude steel production in the country . Status and production of this important segment of Indian steel industry during the last five years is as under;

Year	Units	Capacity(MT)	Production(MT)
2020-21	38	40.35	29.41
2021-22	36	36.73	30.50
2022-23	34	36.61	28.20
2023-24	39	39.52	31.61
2024-25	41	42.44	31.61*

Crude steel production (*) Provisional

From the below table it may be seen that electric steel making route is playing a dominant role in Indian steel production.

Year	BOF Route	EAF Route	IF Route
2023-24	42.7%	21.9%	35.4%
2024-25	41%	21%	38%

In view of global focus of green steel , EAF route in combination of gas based DRI is increasingly getting focused . In fact existing blast furnace route is being replaced by DRI +EAF route .

Optimizing the operating para meters is highly desirable in order to have competitive edge over other routes . Continuous feeding of Direct Reduced Iron (DRI) during Electric Arc Furnace (EAF) steelmaking offers distinct operational advantages over traditional bucket feeding methods. By enabling simultaneous charging and melting, continuous feeding significantly enhances thermal efficiency, reduces overall energy consumption, and shortens tap-to-tap times. Additionally, it promotes more stable arc behavior, improves control over the melting process, and enhances slag foaming. All these factors contribute to increase in productivity and refractories life.

To achieve optimal performance, the DRI feed rate must be carefully managed to maintain a balanced energy input. The efficiency of DRI melting is strongly influenced by several key characteristics of the DRI material:

- **DRI Temperature**: Higher feed temperatures reduce the energy required for melting.
- **Gangue Content**: Non-metallic impurities increase slag volume and energy demand.
- **Degree of Metallization**: Higher metallization improves melting efficiency and reduces slag formation.
- **Carbon Content**: Carbon presence can enhance melting through exothermic oxidation reactions.

Proper alignment between the DRI feed rate and the furnace’s energy input is critical to avoid thermal imbalances.

Apart from the above, an improperly balanced process can lead to **ferroberg formation**—a condition where unmelted DRI accumulates due to insufficient or uneven heating. This issue is basically due to following factors :

- The furnace lacks adequate energy input or suffers from poor heat distribution.
- Low slag fluidity or suboptimal slag chemistry inhibits effective melting.
- Cold spots, particularly near furnace walls, prevent complete melting of the DRI.

It is highly desirable to avoid formation of solidified clusters of metal and slag due to the fact that these clusters obstruct the melting process, decrease EAF productivity, and increase maintenance challenges.

Conclusion

Continuous DRI feeding in EAF operations offers a pathway to greater process efficiency, energy savings, and improved furnace performance. However, success depends on careful control of feed rate, energy input, and material properties to maintain a stable, efficient melting environment and prevent operational disruptions such as ferroberg formation.

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Forth Coming SIMA Event

NEWS ITEM

Primetals Technologies with Strategic Partner Mitsubishi Corporation, voestalpine, and Rio Tinto to Implement Hydrogen-Based Ironmaking Plant

- **Industrial-scale prototype plant to be implemented in Linz, Austria**
- **Production of hot briquetted iron, hot metal, and pig iron via Hydrogen-based Fine-Ore Reduction (HYFOR) and Smelter solutions**
- **First time a hydrogen-based direct reduction plant for iron ore fines is linked to a Smelter**

On April 1, 2025, Primetals Technologies, together with its strategic partner Mitsubishi Corporation, Rio Tinto, a leading mining and materials company, and globally leading steel and technology group voestalpine, signed a cooperation agreement to fast-track the development of fluidized bed and smelter technologies. The participants will implement and operate an industrial-scale prototype plant featuring a new process for potential net-zero-emissions ironmaking at the voestalpine site in Linz, Austria. Startup of the plant is scheduled for mid-2027.

Hydrogen-Based Direct Reduction and Smelting

The new ironmaking process with a projected capacity of three tons of hot metal per hour is based on the HYFOR and Smelter solutions from Primetals Technologies. HYFOR is the world's first direct reduction technology for iron ore fines that does not require any agglomeration steps. Since 2021, Primetals Technologies has operated a pilot plant on voestalpine's premises in Donawitz, Austria, and has run numerous successful test campaigns. The Smelter is a furnace powered by renewable energy used for melting and final reduction of direct reduced iron (DRI). It produces potential net-zero hot metal for the steelmaking plant.

"This project represents a significant advancement in future-proof ironmaking – for the first time, we will implement a continuous production process with hydrogen-based direct reduction," said Alexander Fleischanderl, Chief Technology Officer and Head of Green Steel at Primetals Technologies. "The combination of HYFOR and Smelter is a highly innovative development with the potential to transform the industry, similar to the impact the LD converter (BOF) had on steel production. We are extremely proud to have the support of strong partners in voestalpine, Rio Tinto and Mitsubishi Corporation, and together, we are poised to make a big difference to the future of net-zero ironmaking."

"Mining and trading of ferrous raw materials has been one of our core businesses for many decades and we envision to develop a new supply of low emission metallics to support steel decarbonization. HYFOR and Smelter are new promising technologies to accelerate the decarbonization of the steel industry and Mitsubishi Corporation, as a strategic partner of Primetals Technologies, is excited to participate in the development of these groundbreaking technologies together with leading partners in the steel supply chain," said Kenichiro Tauchi, COO, Ferrous Raw Materials Division of Mitsubishi Corporation.

"With greentec steel, voestalpine has a clear phased plan for steel production with net zero CO2 emissions. In a first step, one green-powered electric arc furnace will be put into operation at each of our sites in Linz and Donawitz starting in 2027. By 2029, we will have reduced our CO2 emissions by up to 30 percent compared to 2019. That is equivalent to almost 5 percent of Austria's entire annual CO2 emissions, making greentec steel the largest climate protection program in Austria. Our long-term strategy is to use green hydrogen to achieve carbon-neutral steel production. Together with Primetals Technologies and Rio Tinto, we are taking an entirely new and promising approach to research into hydrogen-based pig iron production," said Herbert Eibensteiner, CEO of voestalpine AG.

Rio Tinto, one of the world's largest iron ore producers, will draw on its extensive expertise in iron ore quality and preparation to provide technical input to the project. Additionally, Rio Tinto will supply 70 percent of the iron ore for the new plant from across its global operations. It will also support Primetals Technologies to accelerate the commercialization of the technology.

Rio Tinto General Manager, Steel Decarbonization Thomas Apffel said, "We are delighted to join a consortium that encompasses the entire iron and steelmaking value chain. By contributing our ironmaking expertise and iron ores from our Pilbara, Iron Ore Company of Canada, and future Simandou operations, we aim to advance the development and adoption of fluidised bed technology. This fines-based ironmaking solution presents a compelling alternative to shaft furnace technology by eliminating the need for pelletization, potentially offering substantial benefits to both steelmakers and miners. Rio Tinto welcomes additional participants to the consortium and looks forward to supporting the widespread implementation of this innovative technology."

EU and Austrian Government Funding

Funding for the investment and operation of this prototype plant has been provided by the Austrian federal government through its "Transformation of Industry" program managed by Kommunalkredit Public Consulting (KPC) and the "Twin Transition" initiative managed by Austria Wirtschaftsservice (aws). In addition, the European Union supports the venture through the European Union Research Fund for Coal and Steel within the Clean Steel Partnership (CSP) and the European Union Clean Hydrogen Partnership within the Hydrogen Valleys, i.e. areas where hydrogen serves more than one end sector or application in the mobility, industry, and energy sectors.

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A delegation of National Solar Energy Federation of India led by its CEO (second from the right) visited SIMA and it has been decided to build a cooperative platform to promote RE in sponge iron industry.

STATISTICS

Top 5 DRI Producing Countries - 2024

(Quantity in million tons)

Country	2020	2021	2022	2023	2024
India	33.6	39.0	42.3	49.6	54.82
Iran	30.8	30.4	32.9	33.4	34.15
Russia	7.8	7.8	7.7	7.8	8.0
Egypt	4.8	5.4	6.0	7.2	7.1
Saudi Arabia	5.2	6.1	6.7	6.8	6.9
World Total	**106.3**	**117.9**	**127**	**138.7**	**144.1**
India (%age)	**31.60**	**33.07**	**33.30**	**35.76**	**38.04**

Source: WSA

Indian Steel Industry at a Glance in 2024-25

Item	Performance of Indian steel industry		
	April-March 2024-25*(MnT)	April-March 2023-24(MnT)	% change*
Crude Steel Production	151.967	144.299	5.3
Hot Metal Production	91.339	87.045	4.9
Pig Iron Production	8.334	7.364	13.2
Sponge Iron Production	55.654	51.560	7.9
Finished Steel (alloy/stainless + non-alloy)			
Production	146.560	139.151	5.3
Import	9.551	8.320	14.8
Export	4.858	7.487	-35.1
Consumption	152.001	136.290	11.5
Source: JPC; *provisional; MnT=million tonnes			

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