DRI UPDATE

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

September, 2020

SIMA

Sponge Iron Manufacturers Association

Indian voice for the ore based metallic & steel industry

Editorial

Dear readers,

It is a matter of great satisfaction that India continues to be the world's largest sponge iron producer for last 18 consecutive years. Our congratulations to the DRI fraternity who have contributed to achieve this milestone in spite of facing many challenges. At the time of issuing our last Edition of July, 2020, the industry was mainly facing demand and migrated labour problems. Today, to some extent these problems have normalized. But now a new problem being faced by the industry i.e. severe shortage of iron ore and it's rising prices. I think the situation has been created due to several factors. If you recall iron ore production in FY 2020 was 245 Million Tonnes. With 145 Million Tonnes, Odisha continued to be the largest iron ore producer and their production was increased by 30% in FY 2020 compared to 110 Million Tonnes in FY 2019. As you all know, iron ore mines were cancelled on 31st March, 2020. State Government of Odisha took prompt action to auction 19 mines under the new Mining Policy of having iron ore mining capacity of 86 Million Tonnes. These 19 mines produced 71 Million Tonnes in FY 2020. The current severe demand – availability gap is due to the fact that these mines are not able to produce as per the provision of MDPA for various reasons. I am sure that current situation of shortage of iron ore would considerably eased in coming months when these mines start mining and despatching to their potential and improvement in supplies from NMDC and OMC sources.

In this issue, there is an article from Midrex Technologies Inc, USA focusing on 'Ultra-Low Co_2 Iron Making: Transitioning to the Hydrogen Economy'. There is a growing discussion on the hydrogen based DRI / steelmaking to be carbon neutral. Recycled steel is another concept which is gaining momentum in India. Availability of domestic steel scrap is expected to considerably increase due to the Vehicle Scrapping Policy which is expected to be announced shortly. As such, we have included an article from Tata Steel, India. In addition to these, there is an article from RECYRON Engg. & Consulting, Austria highlighting how plant wastage can be converted into wealth.

Deependra Kashiva

Executive Director

Ultra-Low CO_2 Ironmaking: Transitioning to the Hydrogen Economy

Dr. Vincent Chevrier, Midrex Technologies inc. USA

"Mitigating CO2 emissions in the iron and steel industry is becoming critical as it represents one of the largest industrial emitter of greenhouse gases worldwide. As the Indian steel industry is growing, the domestic generation of CO2 will drastically increase due to its overwhelming reliance on coal in both blast furnaces and rotary kilns. Growing the steel industry with coal will make difficult for India – currently representing approximately 7% of the world CO2 emissions – to meet the terms of the Paris Agreement on climate change. A report released in early 2020 by The Energy Resources Institute (TERI) "Towards a Low Carbon Steel Sector" forecasted that India's steel demand will grow five-fold, reaching 500 million tons, with a 35% rise in the sector's CO2 emissions. In absolute figures, emissions would rise from 242 million tons today to 843 million tons by 2050, which is equivalent to 35% of India's total current emissions of CO2 from fossil fuel combustion and industrial activities. The Indian government is not expected to enact more stringent emissions requirements for the iron and steel sector for several years, based on claims that the nation's per capita CO2 emissions are very low compared to any developed country. Coal is and will remain a central part of the energy landscape in India; coal gasification and coal liquefication will continue to be incentivized. However, India voluntarily committed to reducing greenhouse gases by signing the Paris Agreement, so the government is expected to enforce more stringent measures in the future. TERI's report highlighted how India's steel sector could lower its emissions by up to 55% by 2050, while at the same time meeting the needs of a rapidly growing economy.

This article was previously published in Direct from Midrex in the first quarter of 2020. It presents a proven alternative to coal-based ironmaking with immediate reduction of CO2 emissions by half or more: the MIDREX NG™ Process to produce DRI/HBI as a feedstock for steelmaking in electric arc furnace (EAF), blast furnaces or induction furnaces. The long-term availability and pricing of Natural Gas in India has recently decreased to a level where natural gas-based direct reduction is attractive; alternatively, syngas from coal-gasification can be used in the MIDREX process variant known as MXCoL™. As the Hydrogen economy is implemented, this investment can be modified to a net-zero CO2 emission by using green hydrogen. This approach was highlighted in the TERI report as one of the leading solutions to drastically reduce the emission intensity of the Indian steel industry. Although green Hydrogen is not currently available at sufficient scale and low cost, this gradual switch from coal to natural gas to hydrogen an important consideration for steelmakers. Policies promoting the development of natural gas infrastructure and distribution in India are beneficial to the transition. Further policies to deploy nuclear and renewable power as well as hydrogen generation will make the concept of zero-carbon steelmaking a reality."

Indian Iron & Steel and Carbon Emissions

A report titled, "Towards a Low Carbon Steel Sector", released in early 2020 by The Energy Resources Institute (TERI) forecasted that India's steel demand will grow five-fold, reaching 500 million tons. The industry's currently overwhelming reliance on coal in both blast furnaces and rotary kilns will make it difficult for India to meet the terms of the Paris Agreement on climate change. In absolute figures, emissions would rise from 242 million tons today to 843 million tons by 2050, which is equivalent to 35% of India's total current emissions of CO_2 from fossil fuel combustion and industrial activities.

The Indian government is not expected to enact more stringent emissions requirements for the iron and steel industry for several years, based on claims that the nation's per capita CO_2 emissions are very low compared to any developed country. Coal is and will remain a central part of the energy landscape in India; coal gasification and coal liquefication will continue to be incentivized. However, India voluntarily committed to reducing greenhouse gases by signing the Paris Agreement, so the government is expected to enforce more stringent measures in the future.

The long-term availability and pricing of natural gas in India has recently decreased to a level where natural gas-based direct reduction, such as the MIDREX® NG Process, is more attractive; alternatively, syngas from coal-gasification can be used in a variant of the MIDREX Process variant known as MXCoL™. As the Hydrogen Economy is implemented, this investment can be modified to a net-zero CO_2 emission by using green hydrogen. This approach was highlighted in the TERI report as one of the leading solutions to drastically reduce the emission intensity of the Indian steel industry.

Although green hydrogen is not currently available at sufficient scale and low cost, the gradual switch from coal to natural gas to hydrogen is an important consideration for steelmakers. Policies promoting the development of natural gas infrastructure and distribution in India are beneficial to this transition. Further policies to deploy nuclear and renewable power, as well as hydrogen generation will make the concept of zero-carbon steelmaking a reality.

Introduction

In order to meet the targets of the Paris Agreement on climate change, reducing CO_2 emissions in the iron and steel industry will become even more critical as it represents one of the largest industrial emitter of greenhouse gases worldwide. While the MIDREX® Process using natural gas (MIDREX NG™) paired with an electric arc furnace (EAF) has the lowest CO_2 emissions of any steelmaking route using iron ore, there is room to further decrease emissions using hydrogen as a fuel and chemical reactant in the direct reduction process. The best possibility for significantly reducing the CO_2 footprint now and in the future is to use green hydrogen to produce DRI/HBI, which then can be used as feedstock for steelmaking. This concept is known as MIDREX H_2™.

Unfortunately, hydrogen is not currently available at sufficient scale and low enough cost for rapid adoption. This article discusses the status of the transition from a Carbon Economy to a Hydrogen Economy, its challenges, and various on-going activities.

Moving Toward a Hydrogen Economy

The Hydrogen Economy is a proposed system of delivering energy using hydrogen. It has been put forth to solve some of the negative effects of using hydrocarbon fuels, which release carbon to the atmosphere as CO_2, CO, unburnt hydrocarbons, etc. Proponents of a world-scale Hydrogen Economy argue that hydrogen can be an environmentally cleaner source of energy to end-users without the release of pollutants, such as particulate matter or carbon dioxide at the point of end use. The only emission from using hydrogen as fuel or in fuel cells is water.

The Paris Agreement opened for signature on Earth Day 2016 and entered into force on 4 November 2016. The goal of this agreement is to increase the global response to the "threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels" [1]. Carbon dioxide (CO_2) reduction from the industrial sector is widely recognized as a key to achieving these targets. The steel industry, especially traditional ironmaking, is among the largest contributors of greenhouse gases emissions – in the range of 7-9% of total emissions – because of its significant reliance on coal.

About 75% of the world's iron is made using blast furnaces (BF), which is refined in a basic oxygen furnace (BOF). The BF uses coke (refined coal) as the energy source and as the reductant to make iron with ~4.5% carbon, which is burned in the BOF to produce energy. As a result, BF/BOF emissions can be 1.6-2.0 kg CO_2/kg steel depending on the technologies used. The MIDREX NG™ Process paired with an

EAF has the lowest CO_2 emissions of any commercially proven steelmaking route using virgin iron ore at 1.1 – 1.2 kg CO_2/kg steel. By adding a CO_2 removal system, the MIDREX Process can lower CO_2 emissions even further to around 1/3 of the emissions from the BF/BOF route.

Yet, there is even more room for lower emissions through the use of hydrogen as a fuel and chemical reactant in the MIDREX Process. The ultimate method for drastically reducing the steel industry's CO_2 footprint is the use of green hydrogen (produced from renewable energy) for DRI production in a MIDREX Shaft Furnace. This concept, known as MIDREX H_2, holds great promise in either new or existing MIDREX Plants. A major obstacle to implementing hydrogen direct reduction ironmaking is the difficulty of producing enough hydrogen at a low enough low cost without a large CO_2 footprint, as it is done currently in steam-methane reformers. Still, this idea may be closer than many realize as the idea of the Hydrogen Economy gains traction and support.

Issues to Overcome

The biggest obstacle towards a rapid shift to hydrogen relates to GHG emissions from power generation since hydrogen generation requires a lot of electric power. Renewable energy, such as wind, solar, geothermal or hydro have steadily increased market share worldwide, but most of the energy todays still comes from hydrocarbon sources (petroleum, coal, and natural gas) - and nuclear power plants in some countries. Renewable energy penetration is often limited by geography and the ability of the grid to accommodate the fluctuating generation associated with them, while still providing a base load. Electrical power is also expensive to store and distribute due to high yield losses in the transmission lines. To reduce CO_2 in steelmaking with hydrogen, it is critical that the electricity needed to electrolyze water is from non-CO_2 emitting sources. Therefore, a transformation of the steel industry starts with a transformation of the power industry: less GHG and more tolerance to supply-demand fluctuations.

There are also specific issues about hydrogen that need to be resolved for it to become a major energy carrier. For instance, hydrogen has a high energy density by weight, but a low energy density by volume when not compressed or liquefied. Thus, the cost of infrastructure for storing and transporting hydrogen can be a major obstacle in its development. Other related issues, such hydrogen purity, material compatibility, and concerns for safety will have to be overcome for the Hydrogen Economy to take off.

Finally, cost and availability of green hydrogen are currently one of the main limitations for widespread use.

Current Hydrogen Usage and Generation

There are two major uses for hydrogen today. About half is used to produce ammonia (NH_3) for use in fertilizer. The other half is used to convert heavy petroleum sources into lighter fractions suitable for use as fuels, which is known as hydrocracking. Hydrocracking can effectively enhance poorer source materials, such as tar sands and oil shale. In 2016, 96% of the global hydrogen production was from fossil fuels; 48% from natural gas, 30% from oil, and 18% from coal. Most of this 'blue' hydrogen is generated and consumed on the same site; it is not traded or transported. The vast majority of this hydrogen is produced in a steam methane reformer (SMR) using natural gas as the feedstock. The reformer produces a gas containing H_2 and CO, then the CO is removed.

While large-scale hydrogen production utilizing steam reformers is a reality today, it does not provide a solution for greatly reducing CO_2 emissions because it relies on natural gas and still has significant CO_2 emissions. Capture from SMR is feasible, but the CO_2 needs to be sequestered, as generation of CO_2 far exceeds consumption. Gas-based direct reduction of iron ore falls into that category, whether from the MIDREX Process or from HYL / ENERGIRON. Both technologies generate H_2 on-site via a reformer and the hydrogen is used for direct reduction in the adjacent shaft furnace.

Green Hydrogen

Another technology for H_2 production is electrolysis, which uses electricity to split water into hydrogen and oxygen. Water electrolysis accounted for 4% of the global hydrogen production. Since the hydrogen molecules come from water and not hydrocarbons, it may be considered "green." However, there are three problems for its use in the Hydrogen Economy: 1) in most countries, electricity is generated primarily with fossil fuels so there remains a large overall CO_2 footprint, 2) technologies for hydrogen generation from water are not at sufficient scale, and 3) the cost of hydrogen is too high for many applications at prevailing electricity prices (about twice the cost of hydrogen from steam reforming). Scale and cost will improve over time as demand for green hydrogen grows.

In 2016, the US Department of Energy (DOE) introduced the H2@Scale initiative to "advance affordable hydrogen production, transport, storage and utilization to increase revenue opportunities in multiple energy sectors." [2] The DOE consortium includes universities, national labs, and industry and focuses on R&D projects and providing funding opportunities. The overall approach is not solely to produce hydrogen from renewable energy sources, such as solar and wind, but rather to use hydrogen as a response to fluctuating power generation vs. demand and to increase utilization of all sources of power including coal, natural gas, nuclear, and renewables. For example, hydrogen can be produced and stored during times of excess power generation (e.g. when the sun is shining or the wind is blowing), then converted back to power for times of high power demand. Hydrogen can also be transported to industrial users, such as a steel producer. This scheme is more realistic than generating hydrogen solely from renewable energy sources.

The transportation sector is leading the way in hydrogen technology development. Use of hydrogen in commercial vehicles, such as buses, drayage trucks or forklifts is rapidly increasing. Hydrogen-fueled cars are being demonstrated in select locations like California. However, linking the centralized production of hydrogen to a fleet of light-duty fuel cell vehicles would require the construction of a costly distribution infrastructure for further expansion. And conversely, distributed hydrogen generation (such as at the fueling station) does not benefit from scaling effects. Further, the technological challenge of providing safe, energy-dense & economical storage of hydrogen both at distribution stations and inside the vehicle must be overcome to provide sufficient range between fill-ups. All of these topics are being investigated in the transportation sector but will be universally applied.

Industrial use of hydrogen, such as for producing iron, offers the advantage of a fixed location and very large demand. Hydrogen can be generated on-site or supplied over-the-fence with significantly lower infrastructure cost per volume of gas. Steel mills also have the ability to integrate hydrogen generation with other utilities available on site, such as steam and other gases like oxygen.

There are several technologies at various levels of technical readiness to produce hydrogen from water. The most mature is alkaline electrolysis; proton exchange membrane (PEM) is in the commercialization stage and solid oxide electrolysis cell (SOEC) in demonstration stage. Large scale hydrogen generation is of prime interest for industrial users, but the size is still a fraction of what is needed. However, there are larger capacity electrolyzers in development: Air Liquide announced in February 2019 the construction of a 20MW PEM in Canada from hydropower; Air Products is investing in ammonia production via alkaline electrolysis in Saudi Arabia, powered by 4GW of wind and solar. The current technologies generate ~200Nm^3/h of H_2 per MW, although the figures vary based on the technology, so the volumes that can now be produced lead us to the very real possibility of using H_2 for iron and steelmaking.

The majority of the operational cost associated with electrolysis is the cost of electricity. Figure 1 shows the vision of the economics: using \$0.01/kWh electricity, the cost of hydrogen is about the same as from a steam reformer (see second bar from left), even though the capacity factor is only 40% (from intermittent renewable power source). Renewable electricity is not currently available at this price over long periods, but may be in the future with technology advancement, large installations and reduction in fabrication costs. At times when supplies far exceed demand, cheap electricity can be supplied intermittently and used to produce hydrogen.

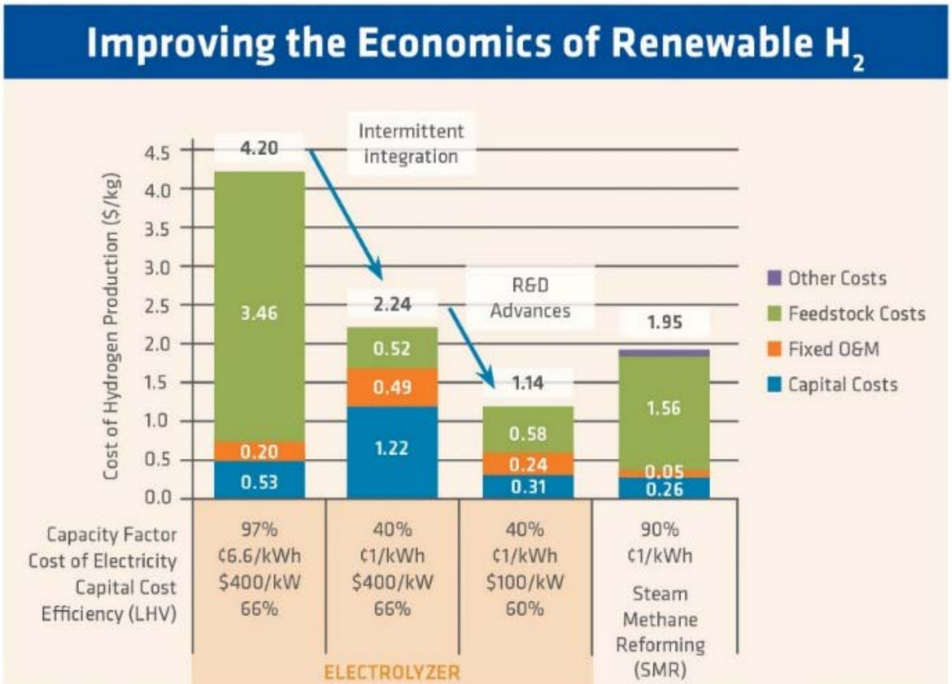

Figure 1 – Improving economics of Renewable H_2 (Department of Energy H_2 @ Scale FCTO Webinar- July 28, 2016)

Reduction of the capital cost of hydrogen generation (from \$400/kW to \$100/kW as in Figure 1) is another requirement to achieve parity with fossil-made hydrogen. While increasing plant size will decrease production cost, scaling up electrolyzers does not lead to significant economies of scale like most industrial equipment. Reduction in capital costs must come from efficiencies in manufacturing and raw material selection. On the other hand, this linear scale up involves significantly less technical risks.

Ironmaking Using Hydrogen

Using hydrogen to make iron is not a new concept. Over the last 50 years, direct reduction technologies like the MIDREX Process and ENERGIRON use a majority of hydrogen in the reducing gas (balance is mostly CO), and already offer a significant reduction in CO_2 emissions. Other technologies have been tried and others are underway, driven in part by the desire to reduce emissions (raw materials and cost reductions are also important). For example, Cleveland-Cliffs, Lurgi, and LTV Steel built a 400,000 ton/year Circored direct reduction plant in Trinidad that used hydrogen from a steam reformer as its reductant and energy source. The plant was started up in 1999, but the fluidized bed reactor had numerous problems and it produced only about 150,000 tons by the time it was shut down in 2001. More recently, the Flash Ironmaking technology - developed by the University of Utah with support from AISI and DOE – is looking at building a demonstration plant.

Perhaps more of an evolution than a breakthrough technology, the MIDREX Process already uses large amounts of hydrogen to produce DRI. The process can be adapted to accommodate more hydrogen as it becomes economical to do so. The process uses CO and H_2 to accomplish reduction, which is the removal of oxygen from ore (opposite of oxidation). There are many reactions occurring in the direct reduction reactors, but the primary ones are shown in Figure 2. Iron is represented by Fe and methane (primary component of natural gas) is represented by CH_4.

Reduction (removal of oxygen from iron ore)

1. $Fe_2O_3 + 3H_2 \longrightarrow 2Fe + 3H_2O$ (endothermic)
2. $Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$ (exothermic)

Carburization (addition of carbon to iron)

3. $3Fe + CO + H_2 \longrightarrow Fe_3C + H_2O$
4. $3Fe + CH_4 \longrightarrow Fe_3C + 2H_2$
5. $3Fe + 2CO \longrightarrow Fe_3C + CO_2$

Reforming (conversion of CH_4 to CO and H_2)

6. $CH_4 + CO_2 \longrightarrow 2CO + 2H_2$
7. $CH_4 + H_2O \longrightarrow CO + 3H_2$

Figure 2 – Ironmaking Reactions

In the case of the standard MIDREX NG Process, the typical gas content is 55% H_2 and 36% CO. Since reduction occurs at about 900°C, temperature control is a particularly important consideration. Reaction 1 is endothermic (requires heat) while reaction 2 is exothermic (gives off heat). Reforming reactions are highly endothermic and mostly done in the reformer, although some in-situ reforming takes place in the shaft furnace. Careful consideration and design of the process temperatures makes the MIDREX Process easy to control. Since 1969, MIDREX Plants have produced more than 1 billion tons of DRI made with over 50% hydrogen.

Direct reduction with higher levels of hydrogen has been proven in a MIDREX Shaft Furnace. The FMO MIDREX Plant in Venezuela uses a steam reformer, and the H_2/CO ratio has varied from 3.3 to 3.8. There are six MIDREX Modules that utilize gas made from coal, and these have hydrogen-to-CO ratios from 0.37 to 0.56. Thus, the MIDREX Process has successfully produced DRI at H_2/CO ratios from 0.37 to 3.8.

On a smaller scale, Midrex has vast experience with hydrogen reduction. In the late-1970s to mid-1980s, Midrex operated a pilot plant at its R&D Technology Center. The pilot was built to test and demonstrate the Electrothermal Direct Reduction Process (EDR). While the purpose of this pilot plant was not to test hydrogen reduction, several campaigns utilized a very high hydrogen content – as high as 4.2 H_2/CO in 1986.

More recently, all tests designed to evaluate carburization kinetics, which are the basis for the MIDREX Adjustable Carbon Technology (ACT™), were performed under pure hydrogen in the experimental furnace at the Midrex R&D Technology Center [3].

In 2017, Midrex introduced two concepts: MIDREX H_2 (100% hydrogen as the feed gas) and a MIDREX NG flowsheet with H_2 substituted for part of the natural gas [4]. Together with the MIDREX NG flowsheet, they provide a staged transition to the Hydrogen Economy.

- **MIDREX NG** (Figure 3) is well-proven and can cut CO_2 emissions by half or more immediately and without technology risks. The product of this plant (CDRI, HDRI or HBI) can be used in the EAF or BF/BOF in existing melt shops with limited or no modifications.

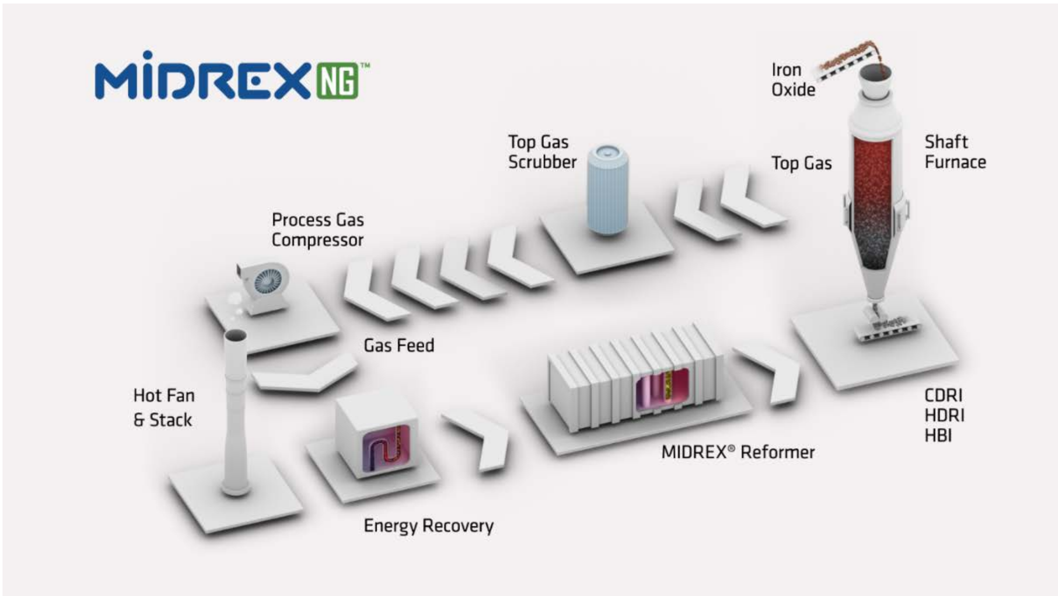

Figure 3. MIDREX NG standard flowsheet

- **MIDREX NG with hydrogen addition** (Figure 4) can displace some natural gas in an existing MIDREX NG plant as green hydrogen becomes available, the MIDREX NG flowsheet can accommodate up to 30% substitution by hydrogen without modification of equipment. For example, 20,000 Nm^3/h of natural gas can be substituted by approximately 60,000 Nm^3/h of H_2 in a 2.0 million t/y plant, which represents approximately 30% of the total natural gas consumption. For substitution up to 100%, an external steam supply, which can be supplied by a boiler or from other sources of steam at an integrated steel plant, is required to protect the reformer. The maximum hydrogen addition without modification of the flowsheet depends on a number of factors including the desired carbon level in the DRI.

  This modification can be done to an existing plant or designed as an option in a new plant to provide future flexibility. The heater design would depend on energy sources available economically including a hydrogen-fired heater.

  The MIDREX Plant is flexible enough to allow changes in energy source over time to accommodate the likely fluctuations (daily or seasonal) in hydrogen availability when the infrastructure transitions from a Carbon to a Hydrogen Economy. The hydrogen can be generated on-site or provided over-the-fence.

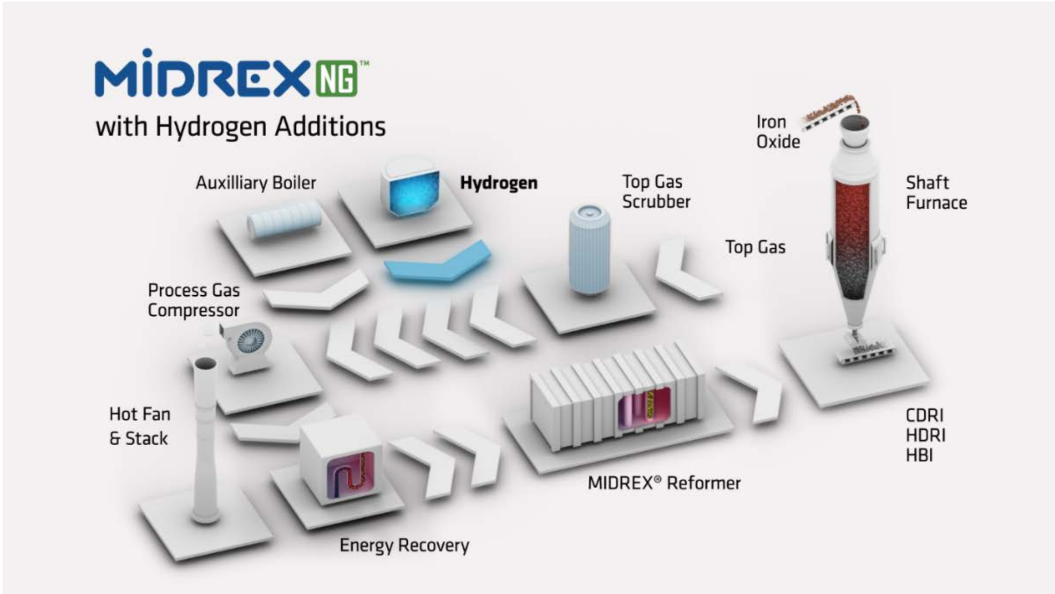

Figure 4. MIDREX NG Process with hydrogen addition: more than 30% natural gas displacement

- **MIDREX H_2** is similar to MIDREX NG except the hydrogen input gas is generated externally to the process (see Figures 5a) or integrated within the process (Figure 5b). Thus, there is no need for the reformer; only a gas heater is needed to heat the gas to the required temperature. For an existing plant, the reformer can easily be converted to a heater since the heat duties are lower due to the absence of endothermic reforming reactions. For a new plant, the duties of each major piece of equipment will be defined specifically for hydrogen. Process modeling and laboratory experiments conducted at the Midrex R&D Technology Center have proven that almost pure hydrogen can be used to make DRI in a MIDREX Shaft Furnace, as currently designed.

  For this flowsheet, the hydrogen consumption is approximately 550 - 650 Nm^3/t DRI. Additionally, up to 250 Nm^3/t DRI of H_2 or another environmentally friendly heat source, such as waste heat, electricity, and natural gas is required as fuel for the reduction gas heater. With this process, CO_2 emissions could be reduced up to 80% vs. the BF/BOF steelmaking route.

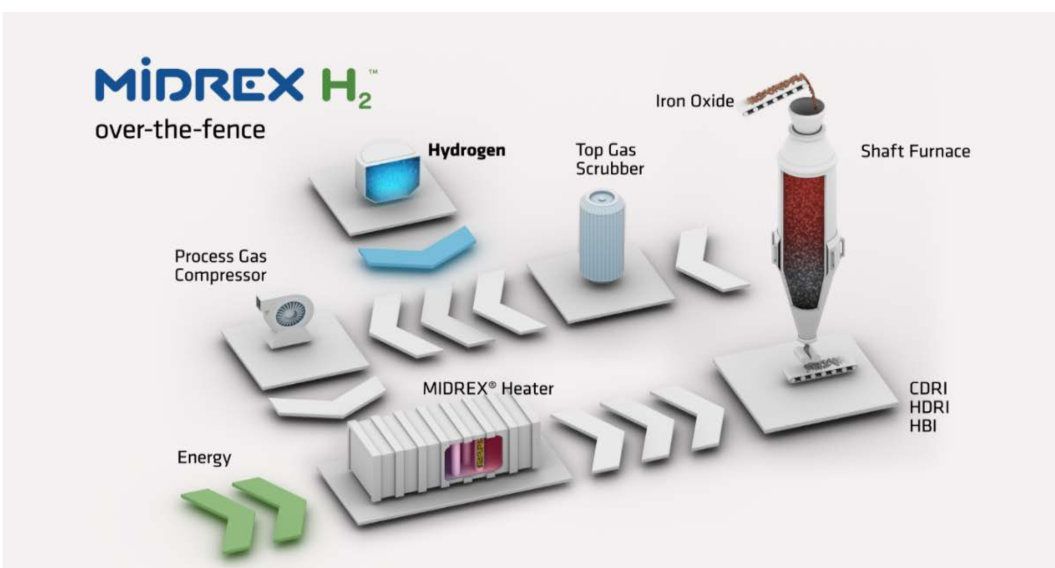

Figure 5a. MIDREX H_2 with hydrogen supplied over-the-fence

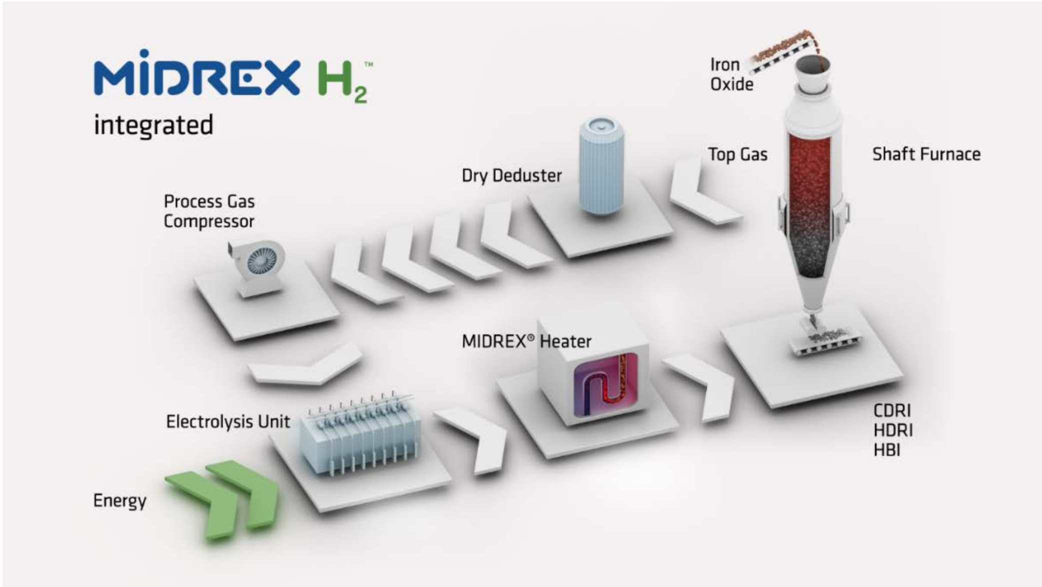

Figure 5b. MIDREX H_2 with integrated hydrogen generation

In September 2019, ArcelorMittal announced an agreement with Midrex to design a demonstration plant at its Hamburg site to produce steel with hydrogen (Figure 6). The project will demonstrate the large-scale production and use of DRI made with 100% hydrogen as the reductant. In the coming years, the demonstration plant will produce about 100,000 tons of DRI per year, initially with "blue" hydrogen sourced from natural gas. Conversion to green hydrogen derived from renewable energy sources will likely take place once available in sufficient quantities and at an economical cost. The plant will be the world's first direct reduction plant on an industrial scale powered by hydrogen.

Figure 6. MIDREX Plant Owned and Operated by ArcelorMittal in Hamburg, Germany

Issues Facing Hydrogen Ironmaking

There are a few issues to consider for making DRI with hydrogen; the first of which is temperature. With such a large amount of hydrogen, the energy balance of the shaft furnace is affected by the absence of the exothermic carbon monoxide reduction (reaction 2 in Figure 2) to balance the endothermic reduction (reaction 1). Thus, it is necessary to add energy to the shaft furnace to carry heat in the burden. Midrex has several options available to control the shaft furnace heat balance.

The second issue is the resulting DRI carbon content; the DRI will have 0% carbon with pure hydrogen. The majority of DRI is used in EAFs, and EAF steelmaking practice generally employs carbon addition either in metallic charge materials, such as DRI, HBI and pig iron, or even pure carbon. Part of the carbon is needed to complete the metallization of the DRI, and the majority is burned with injected oxygen to create a significant amount of heat, thus reducing electricity consumption and enabling faster melting. DRI can have 1-4.5% carbon depending on the process, the type of reducing gas, and the way the DR plant is operated. Most EAF steelmakers prefer to use DRI with 1.5-3% carbon, but the optimum carbon level varies based on metallic charge mix and the steel grade produced. Under current melting practices, it will be necessary to add hydrocarbons at some place in the process to achieve the desired carbon level, including addition of hydrocarbon to the cooling zone or in the furnace lower cone. However, this added carbon will then be converted to CO_2 in the EAF. The next evolution in steelmaking will be to melt iron without using carbon, but this will be very energy intensive since the melting point of steel increases as carbon content decreases. Alternatively, carbon from a renewable source (like biomass) could be used in the MIDREX Process to make the process carbon neutral.

3-Step Transition for Iron & Steel Production

Since the BF/BOF process is unlikely to meet the target CO_2 reductions, steelmakers – especially European steelmakers – face a daunting challenge in transitioning to (near) carbon-neutral ironmaking. Blast furnaces are generally old and need expensive relines and EAFs cannot meet the target residual levels without significant amounts of ore-based metallics (like pig iron or HBI). Hydrogen is not available in quantities and cost needed to be competitive; and no one can predict when it will be.

As a possible answer, Midrex introduced two modification of the MIDREX NG process that use some or all hydrogen as the reducing gas (see Figures 4 and 5), which will allow a 3-stage transition to the Hydrogen Economy:

> **Step 1:** build a MIDREX NG Plant and take immediate advantage of the reductions in CO_2 emissions. The product of this plant (CDRI, HDRI or HBI) can be used in existing BOF and EAF melt shops, as well as BFs (in the case of HBI).
> **Step 2**: add up to 30% hydrogen as it becomes available, but not in quantity or cost suitable for full transition to MIDREX H_2. The MIDREX Plant is flexible enough to allow changes in energy source over time to accommodate the likely fluctuations in hydrogen availability when the infrastructure transitions from a carbon to a hydrogen economy.
> **Step 3**: Modify the MIDREX NG Plant to the MIDREX H_2 flowsheet and take full advantage of the available hydrogen when it becomes widely available and cost effective to do so.

This approach offers the ability to 'buy time' while minimizing technology risks. The MIDREX Process is a proven and reliable technology with immediate environmental benefits. The intermediate step of hydrogen addition does not require many modifications to an existing plant and can be pre-engineered on a new plant. Converting to MIDREX H_2 will require modifications of some of the process equipment, as the process duties (flows, temperature, gas composition etc.) will change. These modifications will be necessary regardless of the direct reduction technology selected.

Conclusion

Iron and steelmaking are a large contributor to the emission of greenhouse gases, notably CO_2. The industry is facing increasing pressure to de-carbonize, but there are many challenges to overcome. Hydrogen ironmaking is a real possibility for future (near) carbon-free steelmaking, but there are significant uncertainties around the availability of hydrogen in volumes needed for ironmaking and at a competitive cost.

The best possibility for reducing the steel industry's CO_2 footprint is the use of hydrogen as an energy source and reductant for iron ore in the MIDREX Process. Today, reduction of CO_2 emissions by 50% (over BF/BOF) is achievable and well proven. Although the hydrogen comes from natural gas ('blue hydrogen'), the process is flexible to accept 'green' hydrogen produced from water electrolysis as it becomes available and economical, which will further reduce CO_2 emissions. Ultimately, the use of hydrogen in the MIDREX Process – known as MIDREX H_2 – holds great promise to be developed and realized in either new or existing DRI plants. Investments for the future can be made today with a MIDREX Plant, knowing that it is adaptable to the hydrogen economy.

References

1) United Nations Climate Change website (https://unfccc.int/)
2) H2@scale website (https://www.energy.gov/eere/fuelcells/h2scale)
3) Arandas, M. et al. "New Technologies for Maximizing Operational Flexibility of MIDREX® DRI Plants: Adjusting Product Carbon in MIDREX® DRI Products". AISTech 2017 conference, Nashville, TN.
4) Millner, R. et al. "Future of Direct Reduction in Europe – Medium and Long-Term Perspectives". ESTAD conference, June 2017, Vienna, Austria

***Author's Note**: This is an updated and revised version of an article by the same title, which was published in the first quarter 2020 issue of Direct from Midrex.*

---------------X---------------X---------------

IIMA 2021 biannual members' meeting

to be held in

Warsaw, Poland, 22-24 March 2021

Steel Recycling in India: Evolving Landscape

Yogesh Bedi , Chief of Steel Recycling Business, Tata Steel, India

There is a lot of discussion in India and in the world about recycled steel basically utilizing steel melting scrap. This concept is gaining the momentum as the world is gradually moving away from conventional BF-BOF route. Govt. of India is expected to announced shortly Vehicle Scraping Policy which will further give momentum to this concept.

Editor

Steel is a 100 percent recyclable material. It can be recycled over and over again without losing its properties. It has to be seen a as a Resource rather than Waste. This makes it a perfect candidate for a circular economy.

Globally, there are two main steelmaking routes:

- The blast furnace route which uses iron ore and coal as the raw materials.
- The electric arc furnace route (EAF) which predominantly uses scrap as the input.

The EAF route is asset light, modular & scores high on sustainability. In countries like India , Bangladesh & Pakistan a third route is prevalent viz the Induction Arc Furnace(IF) route.

Historically, as economies mature, production shifts towards the EAF route due to sustainability and environmental concerns. With economic development, the availability of scrap also increases, providing a sustained raw material for recycling. China is a recent example of this shift and it is significantly enhancing the EAF capacity and related scrap-processing facilities. India is expected to follow a similar trend.

The Indian Scenario:

The Indian market for scrap is worth almost $ 10 Billion. The demand for scrap is ~30 MnTPA. Domestic generation is ~25 MnTPA and the balance of ~5 MnTPA is imported. The supply is likely to increase due to some impending Government policies, rapid urbanisation and economic activity.

The Indian scrap industry, however, is highly fragmented and unorganised. There is hardly any processing or value-addition of scrap. There is limited attention to safety and environmental concerns. In more developed countries, scrap is a well-established industry with a robust ecosystem. There are well-laid out regulations, supporting infrastructure and formalised channel networks.

The Indian government has recognised this challenge and is actively considering putting in place a regulatory and supporting framework to address the same.

The Challenges:

Given the current state of the scrap industry in India, there are a number of challenges that it faces. The industry is highly fragmented and unorganised with long and complex supply chains. There are tens of thousands of small aggregators who collect scrap from various sources. They are not a part of the formal economy, and hence lack social security. The operations are manual and there is little concern towards safety and environmental issues.

Indian scrap is largely sold unprocessed and is of inconsistent quality. Processing of scrap can offer significant value to customers, through enhanced quality and productivity. Scrap processing includes steps like shredding, baling and shearing, amongst others.

There is a lack of requisite policy framework for the industry. For example, there are no guidelines related to scrapping of a vehicle and the dismantling procedure. This is under active consideration of the Government now and policies related to steel scrap collection & processing, end-of-life vehicle dismantling and resource efficiency are under formulation.
The specifications and standards for scrap are inadequate and need to be revised in line with global standards. Currently, the industry uses local nomenclature which varies by region.

The Potential:

Having discussed the challenges, I must also highlight the potential of organised steel recycling in India. Firstly, there is a significant potential for job creation and social upliftment. The steel recycling industry employs about one million people who are mostly in the informal segment. So, formalising the sector would impact the lives of this large pool. Then, there are significant benefits owing to sustainability. For example, there is a 50-60 per cent reduction in energy consumption, carbon emissions and resource utilisation. Steel recycling will be a critical lever in achieving the National Steel Vision of 300 million tonnes of steel production by 2030.

There are multiple enablers for establishing organised scrap processing capabilities in India in the face of the outlined challenges.

First and foremost, there is a need to have a good policy framework in the country which incentivises and nurtures organised steel recycling. A good first step might be according the industry status to scrap recycling.

Secondly, there needs to be a good ecosystem and support system comprising various stakeholders such as peddlers, aggregators, processors, dismantlers, logistics partners as well as the downstream end-consumers.

Land acquisition is currently a big hurdle in India. There is the need to simplify the process of acquiring land with adequate utilities. Steel recycling and steelmaking are power-intensive industries and, hence, the power costs need to be looked into. Also, there is the need to look at the policy of taxing obsolete scrap, given that it is already providing so many benefits. There would be a significant need for capability and skill development as well.

Lastly, we need to do this quickly. So, to hasten the learning curve, one would need to leverage the knowledge and experience available globally and have collaborations in various fields.

---------------X---------------X---------------

Mr. Yogesh Bedi may be contacted at **yogeshbedi@tatasteel.com**

RECYRON®: The Ultimate Road to Zero-Waste Ironmaking!

Dr. Anrin Bhattacharyya, Founder & CEO, RECYRON Engg. & Consulting, Leoben, Austria

Abstract: Waste products are actually raw materials in disguise, waiting for a smart person to identify them and put them back into use by an appropriate process. RECYRON® is a novel technology for a zero-waste ironmaking process. This process is designed to recycle all possible raw material wastes (RMWs) from an integrated steel plant to produce direct reduced iron (DRI). RECYRON® takes care all RMWs of steel plants and iron ore mines, starting from superfine ores, coke breeze, sinter dust and BF dust and sludge, mill scale, just to name a few. RECYRON® uses a simple technology like briquetting to its utmost potential to agglomerate all the wastes, and thereafter reduces it using a rotary kiln. The reduced briquettes with high metallic iron could be used in mini-mills having electric arc furnaces (EAF), or to charge in the blast furnace to lower the coke rate as much as possible. The process is also able to generate power as the by-product. RECYRON® offers several advantages in parallel, such as reduction of landfill, complete utilization of raw materials, low CO_2 footprint and last but not the least – a highly profitable process. The financial aspects such as estimated CAPEX and OPEX along with the NPV (Net Project Value) and IRR (Internal Rate of Return) for plants are also discussed.

1. Introduction

An integrated steel plant generates a huge amount of solid wastes every day, mostly in the fine form (excluding slags, which are derived products and not raw materials for ironmaking and therefore not considered in this context). For example, an average the blast furnace (BF) alone generates around 20.3 kg dust and sludge per ton of crude steel produced. It could be calculated from actual plant data, that an integrated steel plant which produces around 6 Million tons of crude steel per year, generates around 580.000 tons of raw material wastes (RMWs) containing iron and carbon in average per year. The enormous amount of RMWs generated in a steel plant are not only hazardous to the environment or sheer wastage, they also cost a lot of money.

Till date, partial recycling of RMWs have been achieved, but not to its fullest extent, the biggest challenge being the BF sludge (because of its high zinc content). A standard practice in integrated steel plants is to recycle some of the RMWs in the sinter plant. But, this practice often gives rise to poorer sinter quality and decreases the efficiency of the process. Also, there are significant differences on the extent of RMW utilization among different companies situated in different countries. However, a complete solution does not exist. The precious RMWs often end up in dumping or landfill, which is a massive wastage of their value and recycling potential. To solve these problems, RECYRON was developed.

2. Technological Background

The basic idea of the RECYRON technology is quite simple. It consists of two major steps – 1) Briquetting or agglomeration of all RMWs and 2) High temperature reductions of the briquettes to generate direct reduced iron (DRI). But the technical know-how behind these easy steps are quite challenging and therefore, will not be explained here in detail for IP protection.

The heart of RECYRON process is the briquetting technology. The briquetting technique involved here consist of an array of diverse materials. The briquettes must have sufficient strength to undergo the high temperature solid-state reduction process without disintegrating and therefore, the selection of binders and additives is crucial for the operation of the process. A list of possible RMWs for RECYRON is shown in Table 1.

Table 1: List of possible RMWs

Waste Type	Source	Major Recyclable Constituents
Superfine Iron Ore	Hematite Mine	Iron
Mine Tailings	Hematite Mine	Iron
Coke Breeze	Coke Oven	Carbon
ESP Dust	Sinter Plant	Iron and Fluxes
BF Dust and Sludge	Blast Furnace	Iron and Carbon
Mill Scale	Rolling Mill	Iron

Another focal point is the calculation of the stoichiometry of the charge mix, which has to be carefully optimized to achieve good metallization of the briquettes. The reduction is performed using a rotary kiln, which adds more flexibility to process operations. The process can separate the zinc content and the zinc content ca be recovered after post combustion of the flue gas in oxide form.

The metallic iron content of the product varies strongly on the availability and composition of input raw materials. So far, metallic iron content in the range between 73,5% to 80% has been attained in various laboratory and pilot scale trials.

The briquettes hence produced could be used in two possible ways - 1) Either charging back into the blast furnace, which will save around 400 kg of coke per tons of briquettes charged or 2) by providing these briquettes to mini-mills which operate EAFs as alternative charge materials.

3. Investment Analysis

An exemplary financial calculation related to a RECYRON® plant is shown in the Table 2, where the produced DRI is sold to external buyers. The interest rate for the NPV (net project value) and IRR (internal rate of return) calculations is chosen to be 12 %.

Other assumptions –

The plant capacity is set to 500 tons per day

Complete Plant CAPEX – 35 million Euros in 1.5 years

OPEX per ton of DR briquettes - 150 Euros

Sales price per ton of DRI – 280 Euros

OPEX includes all other costs from Year 3.

330 production days has been considered per year.

Year	Cash Inflow (million EUR)	Cash Outflow (million EUR)	Net Cashflow (million EUR)
0	0	3	-3
1	0	17	-17
2	0	15	-15
3	47	20	27
4	47	20	27
		NPV (@12%)	**6,24**
		IRR	**22%**

4. Conclusion

Implementation of RECYRON® in any steel plant steel plant will not only ensure the complete usage of the wasted raw materials, but will also enable the company to save significantly by reducing landfills and saving coke by charging DRI back into the BF or by selling the it to mini-mills. This process has huge potentials of success in the global context.

---------------X---------------X---------------

Dr. Anrin Bhattacharyya may be contacted at **ceo@recyron.com**

Press Release

Since the 1950's, the **TENOVA HYL/ENERGIRON** technology using Reformed gas as source of reducing gas, includes a conventional steam/NG reformer.

In 1990's Tenova HYL has carried out extensive tests at pilot plant with up to **90% H_2**,

Tenova HYL carried out production campaigns with different types of gases, ranging from 100% NG, to simulated COG, up to 90+% Hydrogen, producing Cold DRI, Hot DRI or HBI in all cases. In our pilot module we also tested different kinds of pellets and lump ores and developed the CO2 absorption unit that allows us to be the benchmark technology in terms of GHG emissions.

Completion of pilot plant tests with ~90% H_2 since 1990's

For any reformer, H_2 is produced in different. You can observe the H2/CO ratio is higher in our case. Needless to mention, Tenova HYL has the long lasting industrial experience with intensive use of H_2 for DRI production.

Parameter relatad to H_2	ENERGIRON
H_2O/C ratio in Reformer	2.0 – 2.5
H_2/CO ratio in reducing gas	4 - 5
%H_2 to reactor (% vol.)	~70%

The above reflects the long lasting industrial experience with intensive use of H2 for DRI production.

New technologies are now being developed to produce H2 from renewable energy sources.

tenova
HYL

Tenova: Innovative Solutions for Metals and Mining
Visit our website at: www.tenova.com

Statistics

Top 5 DRI Producing Nations in 2019

Source: World Steel Association, Sponge Iron Manufacturers Association (SIMA) & Midrex Technologies Inc.

Important Statistics during 2020-21

Item	Performance of Indian Steel Industry		
	April-August 2020-21*(mt)	April-August 2019-20(mt)	%age Change*
Crude Steel Production	34.272	46.228	-25.9%
Hot Metal Production	24.240	30.935	-21.6%
Pig Iron Production	1.608	2.548	-36.9%
Sponge Iron Production	11.654	15.463	-24.6%

Total finished steel (alloy/stainless – non alloy)

Production	30.080	43.515	-30.9%
Import	1.667	3.453	-51.7 %
Export	5.680	2.917	94.8%
Consumption	27.435	42.539	-35.5%

Source: JPC, *Provisional, mt-million tonnes