

# DIRECT FROM MIDREX

1ST QUARTER 2020



## INSIDE THIS ISSUE

2

**COMMENTARY:**  
Toward a  
Carbon-Neutral  
Steel Industry

3

**ULTRA-LOW  
CO<sub>2</sub> IRONMAKING:**  
Transitioning  
to the Hydrogen  
Economy

13

**GETTING THE  
MOST FROM  
RAW MATERIALS  
VIA THE DIRECT  
REDUCTION/EAF  
ROUTE  
(Part 2)**

21

**NEWS & VIEWS:**  
Record-Setting  
Performances in 2019  
  
KC Woody Appointed  
Midrex COO

[www.midrex.com](http://www.midrex.com)

## COMMENTARY

## TOWARD A CARBON-NEUTRAL STEEL INDUSTRY

By KC Woody, Chief Operating Officer



**We announced in 3Q2019 Direct From Midrex that ArcelorMittal and Midrex are teaming up to use hydrogen on an industrial scale as the reductant for producing direct reduced iron (DRI).** The

project, which will utilize hydrogen generated by the existing MIDREX® Plant at ArcelorMittal Hamburg, will further our understanding of how DRI plants could take advantage of green hydrogen generated from renewable sources and help move closer to a carbon-neutral steel industry.

Although high percentages of hydrogen have been used in operational MIDREX Plants, there are still things to be learned about using pure hydrogen, which can be

studied only when the process configuration is run on a large scale. Some of the challenges we see are outlined in the following article, “Ultra-Low CO<sub>2</sub> Iron-making: Transitioning to the Hydrogen Economy.”

### Key Points of the ArcelorMittal-Midrex Cooperation

Midrex and ArcelorMittal have signed two agreements: a Framework Cooperation Agreement (FCA) and a Project Development Agreement (PDA). The FCA allows the companies to cooperate on the current hydrogen project and future development efforts. This agreement envisions the parties working together on projects through individual PDAs. The first PDA deals with designing and constructing a demonstration plant utilizing the hydrogen from the existing MIDREX Plant. This project will allow the companies to demonstrate the production of DRI with hydrogen, as well as to utilize carbon-free DRI in the EAF at an industrial scale. It will help us see how the DRI behaves when produced with hydrogen. The Hamburg plant will have an annual production capacity of 100,000 tons, with nearly pure hydrogen as the reducing gas.

### Technical Challenges of the Hydrogen DRI/Steel Project

This will be the first DRI plant to utilize only hydrogen for reduction, so it's understood that the thermal balance of the furnace will be slightly different. The plant design will draw on our deep understanding of the thermodynamics of direct reduction derived from 50 years of supplying MIDREX Plants around the world, some utilizing more than 80% hydrogen. We also ran a pilot plant at the Midrex R&D Technology

Center with very high levels of H<sub>2</sub> in the 1990's. ArcelorMittal has amassed extensive practical experience in the operation of direct reduction furnaces using various reducing gas sources, and their expertise in plant operation will be very valuable in successfully demonstrating direct reduction with hydrogen.

Perhaps of most interest to the project team will be how the DRI performs in the EAF. This will be an important milestone for carbon-neutral steelmaking. The ArcelorMittal Hamburg team has years of experience in EAF operations, which will be very beneficial during these trials.

### Midrex sees hydrogen as an important part of the solution for a carbon-neutral steel industry.

Midrex is very excited to work with ArcelorMittal, which has more DRI-EAF experience than any other steel company in the world. Their Hamburg plant is the only direct reduction plant in Western Europe and already has one of the lowest CO<sub>2</sub> emissions of any industrial facility in the European Union (EU). The plant, which was started up in 1971, is a testament to the reliability and longevity of MIDREX Plants and the operational know-how and expertise of ArcelorMittal. It seems only fitting that it will be on the leading edge of developing carbon-neutral steelmaking. ■



## ULTRA-LOW CO<sub>2</sub> IRONMAKING:

# Transitioning to the Hydrogen Economy

By Vincent Chevrier, PhD, *General Manager – Business Development*

### INTRODUCTION

**M**itigating carbon dioxide (CO<sub>2</sub>) emissions in the iron and steel industry will become even more critical in Western Europe as the cost of CO<sub>2</sub> emissions increases over time. While the MIDREX® Process using natural gas, paired with an electric arc furnace (EAF) has the lowest CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub>™.

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. As green hydrogen becomes available and cost effective, the MIDREX Process can be converted to MIDREX H<sub>2</sub> in stages allowing steelmakers to take advantage of CO<sub>2</sub> reduction immediately and further reduce emissions in the future without major capital expenditure.

### 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<sub>2</sub>, 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]. CO<sub>2</sub> 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<sub>2</sub>/kg steel depending on the technologies used. The MIDREX NG™ Process paired with an EAF has the lowest CO<sub>2</sub> emissions of any commercially proven steelmaking route using virgin iron ore at 1.1 – 1.2 kg CO<sub>2</sub>/kg steel. By adding a CO<sub>2</sub> removal system, the MIDREX Process can lower CO<sub>2</sub> 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 use of hydrogen as a fuel and chemical reactant in the MIDREX Process. The ultimate method for drastically reducing the steel industry's CO<sub>2</sub> 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<sub>2</sub>, 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 cost without a large CO<sub>2</sub> 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

Besides nuclear power, most energy today comes from one of three hydrocarbon sources: petroleum, coal, and natural gas. Renewable energy, such as wind, solar or hydro power have steadily increased market share, but their penetration is often limited by geography and the ability of the grid to accommodate the fluctuating generation (also known as the 'duck curve') associated with them. Electrical power is also expensive to store and distribute due to high yield losses in the transmission lines.

In the case of hydrogen, there are specific issues to overcome for it to become a major economic factor. For instance, hydrogen has a high energy density by weight, but a low energy density by volume when not compressed or liquefied. Thus, the prohibitive cost of a hydrogen fuel cell has been a major obstacle in its development. Other related issues, such as storage, distribution infrastructure and sufficient hydrogen purity, and concerns for safety will have to be overcome for the Hydrogen Economy to take off.



Also, there is the perceived “chicken and egg” syndrome, where potential producers are eagerly awaiting consumers to come forward so they can generate hydrogen at scale (and lower cost from economy of scale), while consumers claim they will be ready once sufficient amounts of hydrogen can be produced at a competitive cost. Cooperation between industry, academia, government, and the end consumers is needed to address these challenges. Many countries already have such initiatives in place and are collaborating to expedite full realization of the Hydrogen Economy.

## CURRENT HYDROGEN USAGE AND GENERATION

There are two major uses for hydrogen today. About half is used to produce ammonia (NH<sub>3</sub>) 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<sub>2</sub> 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<sub>2</sub> emissions because it is made from natural gas and still has significant CO<sub>2</sub> emissions. Capture from SMR is feasible, but the CO<sub>2</sub> needs to be sequestered, as generation of CO<sub>2</sub> 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<sub>2</sub> on-site via a reformer and the hydrogen is used for direct reduction in the adjacent shaft furnace.



## “GREEN” HYDROGEN

Another technology for H<sub>2</sub> production is electrolysis, which uses electricity to split water into hydrogen and oxygen. Water electrolysis accounts 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 two 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<sub>2</sub> footprint, and 2) the cost of hydrogen is too high for many applications at prevailing electricity prices (about twice the cost of hydrogen from steam reforming).

In 2016, the US Department of Energy (DOE) introduced the H<sub>2</sub>@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.

There are many growth areas for green hydrogen and transportation is leading the way. 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. Further, the technological challenge of providing safe, energy-dense storage of hydrogen both at distribution stations and on board the vehicle must be overcome to provide sufficient range between fill-ups.

Industrial use of hydrogen, such as for producing iron, offers the advantage of a fixed location and large demand. Hydrogen can be generated on-site or supplied over-the-fence with significant 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.

Between the challenges of transportation, storage, and use of hydrogen, at-scale hydrogen generation is of prime interest for industrial users. There are several technologies at various levels of technical readiness to produce hydrogen from water. The most mature is the alkaline electrolyzer. However, proton exchange membrane (PEM) is in the commercialization stage and solid oxide electrolysis cell (SOEC) is in demonstration stage. The cost of hydrogen from these technologies currently is not competitive to SMR, by at least a factor of 2x. *Figure 1 (next page)* 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 in *Figure 1*). Further

manufacturing and R&D advances could result in an even lower capital cost for electrolytic hydrogen.

Undoubtedly, increased production will reduce the capital cost of these electrolyzers. The total world installed capacity is growing rapidly: in 2017, DOE estimated the global electrolyzers sales to be 100MW. There are electrolyzers commercially available today in the range of 1MW, but large capacity electrolyzers are becoming reality – for example voestalpine is commissioning a 6MW PEM in Austria, and AirLiquide announced in February 2019 the construction of a 20MW PEM in Canada. In 2018, Nel (Oslo, Norway) contracted 1GW of capacity between Nikola Motor company and the largest alkaline electrolyzer plant (360MW) in Norway. The current technologies generate ~200Nm<sup>3</sup>/h of H<sub>2</sub> 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<sub>2</sub> for iron and steelmaking. While increasing plant size will decrease production cost, scaling up the electrolyzer does not lead to significant economies of scale like most industrial equipment. Scaling up is accomplished by multiplying cells and stacks, not by increasing their volume. 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.

The other aspect of cost reduction is the cost of electricity, which is the majority of the operational cost associated with electrolysis, regardless of technology. *Figure 1* shows that 1¢/kWh is needed to achieve competitiveness to SMR. The cost of electricity varies greatly between countries and even within regions, but it is generally not available at this price over long periods. It is however conceivable that – at times when supplies far exceed demand – cheap electricity can be supplied intermittently and used to produce hydrogen. This topic is outside the scope of this article, but national agencies like the DOE are looking at the overall balance of technologies (renewable, fossil, and nuclear) to provide both grid resilience (e.g. no blackouts) and electricity at competitive costs.

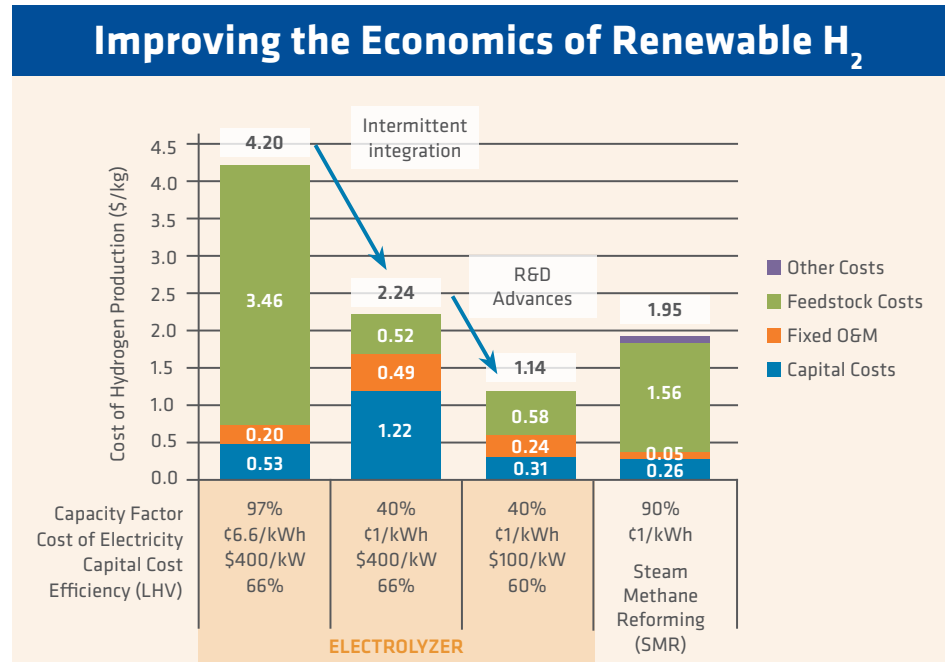


FIGURE 1. Improving the Economics of Renewable H<sub>2</sub> (Department Of Energy H<sub>2</sub> @ Scale FCTO Webinar - July 28, 2016)

### 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<sub>2</sub> 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 tons/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<sub>2</sub> 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<sub>4</sub>.

In the case of the standard MIDREX NG Process, the typical gas content is 55% H<sub>2</sub> and 36% CO. Since reduction occurs at about 900°C, temperature control is a very 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<sub>2</sub>/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<sub>2</sub>/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 plant 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<sub>2</sub>/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<sub>2</sub> (100% hydrogen as the feed gas) and a MIDREX NG flowsheet with H<sub>2</sub> substituted for part of the natural gas [4]. Together with the MIDREX NG flowsheet, they provide a staged transition to the Hydrogen Economy.

### **Reduction (removal of oxygen from iron ore)**

1.  $\text{Fe}_2\text{O}_3 + 3\text{H}_2 \longrightarrow 2\text{Fe} + 3\text{H}_2\text{O}$  (endothermic)
2.  $\text{Fe}_2\text{O}_3 + 3\text{CO} \longrightarrow 2\text{Fe} + 3\text{CO}_2$  (exothermic)

### **Carburization (addition of carbon to iron)**

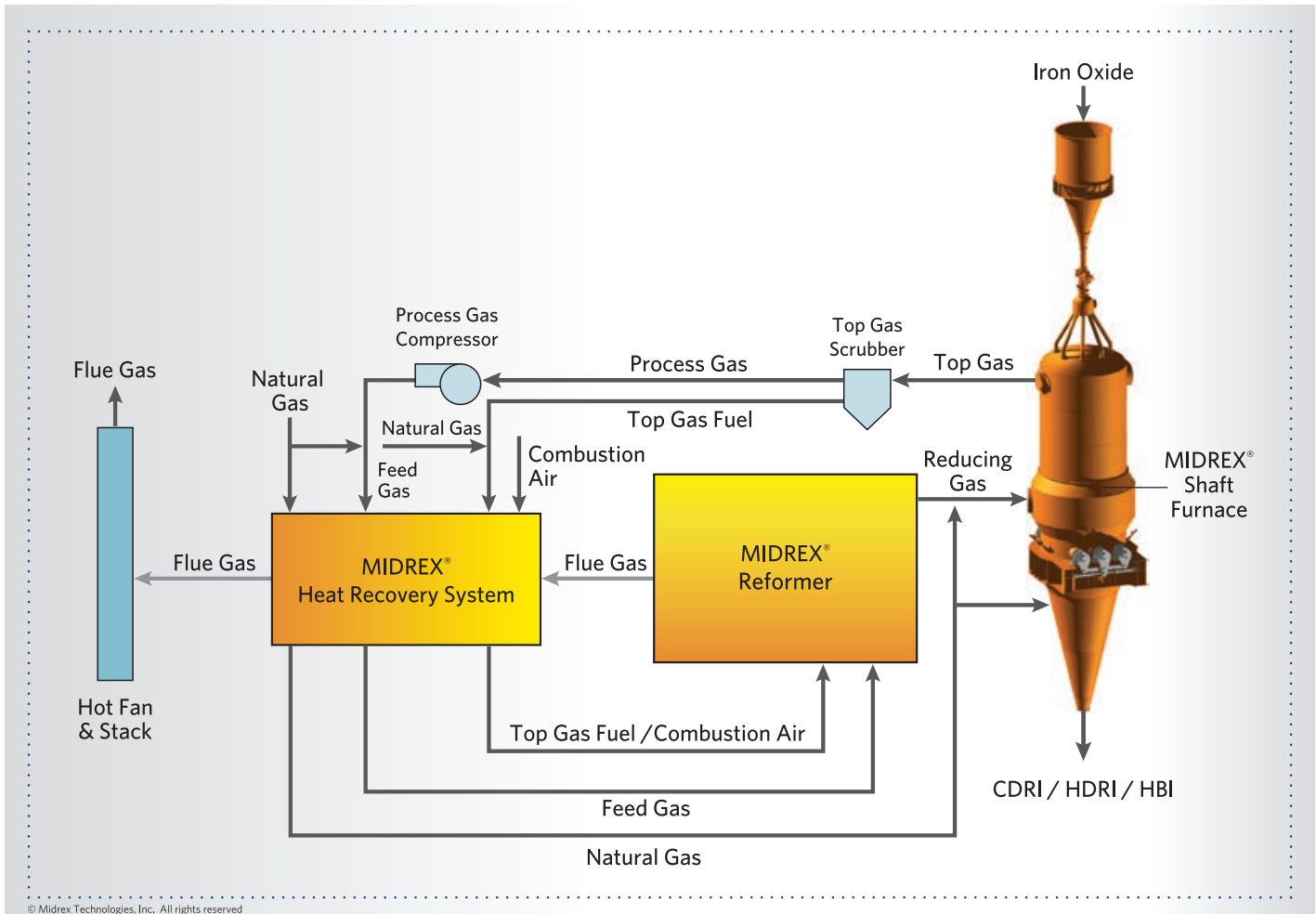
3.  $3\text{Fe} + \text{CO} + \text{H}_2 \longrightarrow \text{Fe}_3\text{C} + \text{H}_2\text{O}$
4.  $3\text{Fe} + \text{CH}_4 \longrightarrow \text{Fe}_3\text{C} + 2\text{H}_2$
5.  $3\text{Fe} + 2\text{CO} \longrightarrow \text{Fe}_3\text{C} + \text{CO}_2$

### **Reforming (conversion of CH<sub>4</sub> to CO and H<sub>2</sub>)**

6.  $\text{CH}_4 + \text{CO}_2 \longrightarrow 2\text{CO} + 2\text{H}_2$
7.  $\text{CH}_4 + \text{H}_2\text{O} \longrightarrow \text{CO} + 3\text{H}_2$

FIGURE 2. Ironmaking Reactions





**FIGURE 3.** MIDREX NG standard flowsheet

- **MIDREX NG** (Figure 3) is well-proven and can cut CO<sub>2</sub> 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.
- **MIDREX NG with hydrogen addition** (Figure 4, next page) 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<sup>3</sup>/h of natural gas can be substituted by approximately 60,000 Nm<sup>3</sup>/h of H<sub>2</sub> 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 flow-sheet 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.



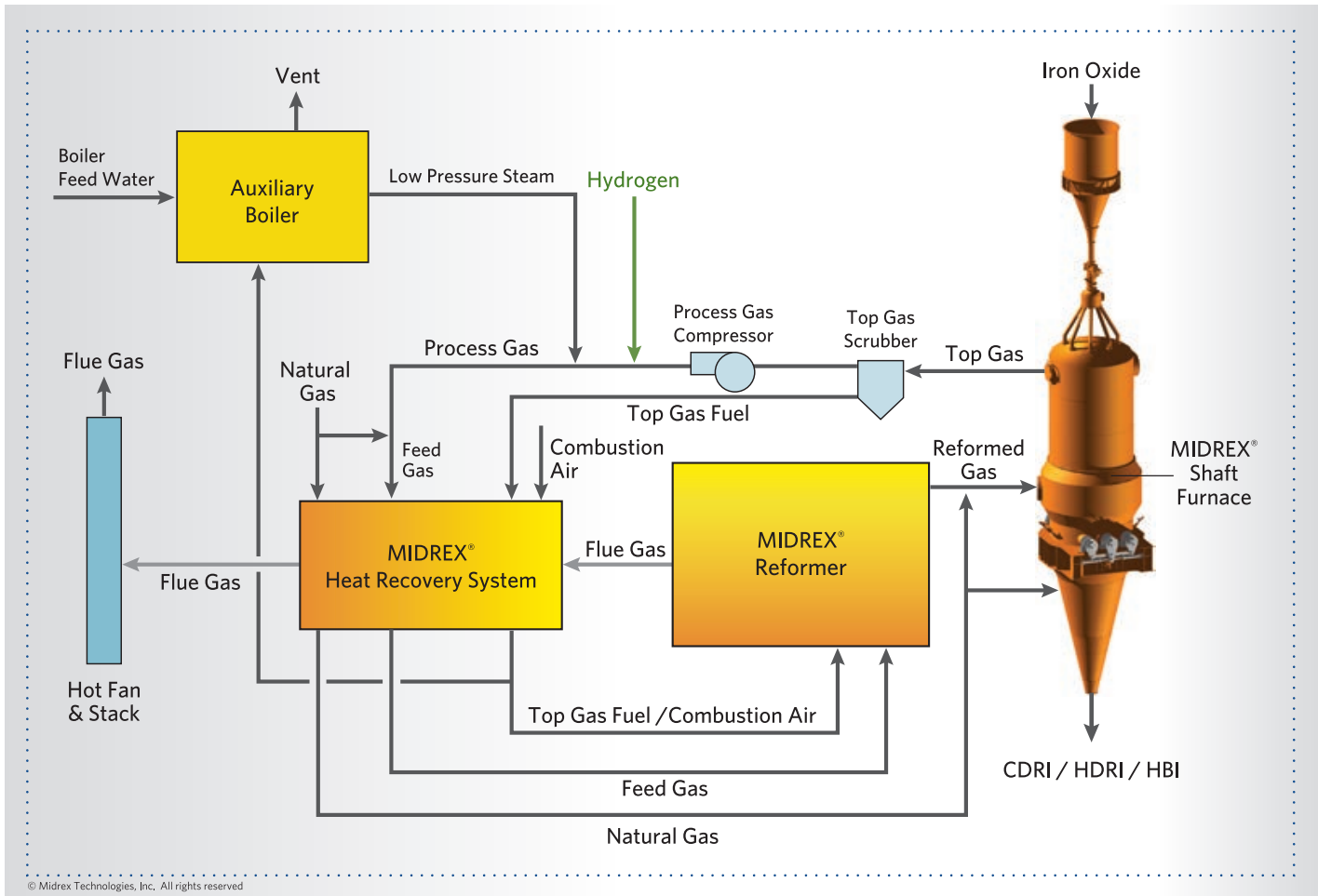


FIGURE 4. MIDREX NG Process with hydrogen addition

# MIDREX H<sub>2</sub>™

• MIDREX H<sub>2</sub> is similar to the standard MIDREX NG flowsheet except the hydrogen input gas is generated externally to the process (see Figures 5a) or integrated within the process (Figure 5b, next page). 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.

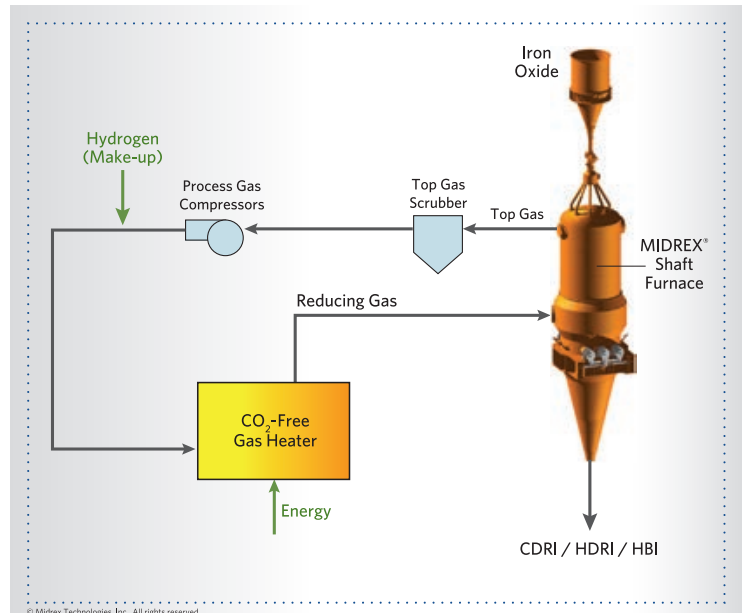
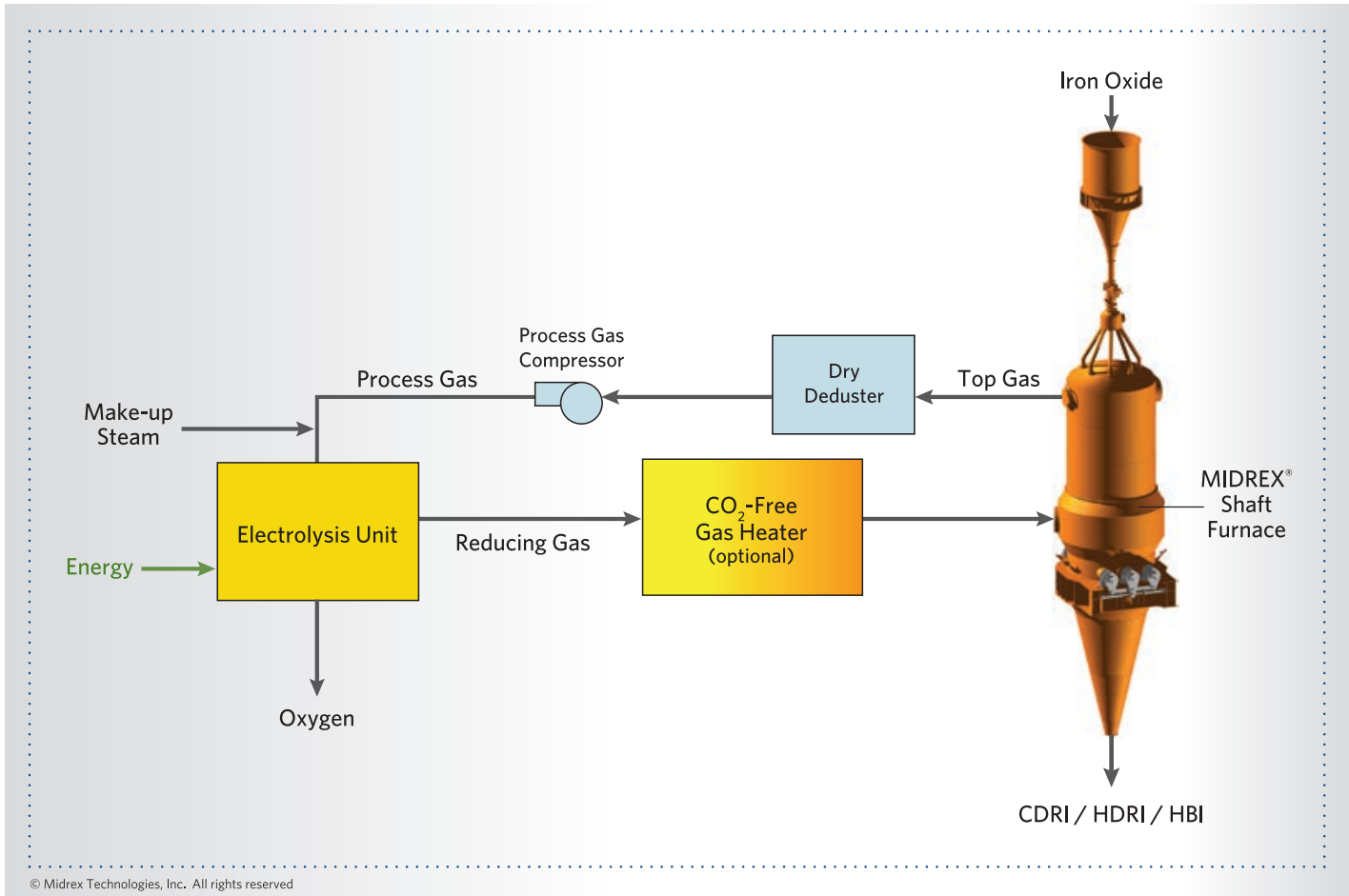


FIGURE 5a. MIDREX H<sub>2</sub> with hydrogen supplied over-the-fence



**FIGURE 5b. MIDREX H<sub>2</sub> with integrated hydrogen generation**

For this flowsheet, the hydrogen consumption is approximately 550 - 650 Nm<sup>3</sup>/t DRI. Additionally, up to 250 Nm<sup>3</sup>/t DRI of H<sub>2</sub> 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<sub>2</sub> emissions could be reduced up to 80% vs. the BF/BOF steelmaking route.

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**



### 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<sub>2</sub> 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.

### A 3-STEP TRANSITION FOR IRON & STEEL PRODUCTION

Since the BF-BOF process is unlikely to meet the target CO<sub>2</sub> 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 modifications 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<sub>2</sub> emissions. The product of this plant (CDRI, HDRI or HBI) can be used in existing BOF and EAF meltshops, 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<sub>2</sub>. 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub>. 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.

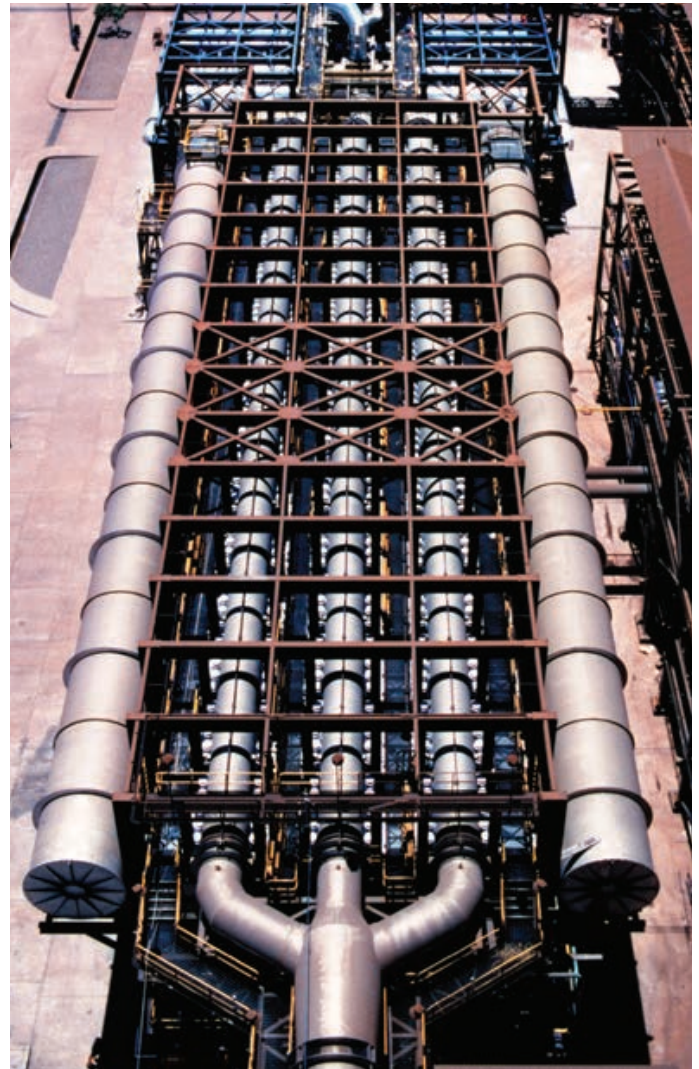
The best possibility for reducing the steel industry's CO<sub>2</sub> footprint is the use of hydrogen as an energy source and reductant for iron ore in the MIDREX Process. Today, reduction of CO<sub>2</sub> emissions by 50% (over BF/BOF) is achievable and well proven. Although the hydrogen comes from 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<sub>2</sub> emissions. Ultimately, the use of hydrogen in the MIDREX Process – known as MIDREX H<sub>2</sub> – 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.

## SUMMARY

Mitigating CO<sub>2</sub> emissions in the iron and steel industry is becoming critical worldwide, but especially in Western Europe as the cost of CO<sub>2</sub> emissions increases over time. The MIDREX NG Process paired with an electric arc furnace (EAF) has one of the lowest CO<sub>2</sub> emissions of any steelmaking route today and has been proven commercially. It is possible to further significantly reduce the CO<sub>2</sub> footprint by using green hydrogen with MIDREX H<sub>2</sub> to produce CDRI/HDRI/HBI as a feedstock for steelmaking. Unfortunately, hydrogen is not currently available at sufficient scale and low cost for rapid adoption. In the transition to a Hydrogen Economy, the MIDREX Process can be converted to MIDREX H<sub>2</sub> in stages allowing the steelmakers to take advantages of CO<sub>2</sub> reduction immediately, and further reduce them in the future without major capital expenditure. ■

## 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



## Getting the Most from Raw Materials Via the Direct Reduction/EAF Route

# Maximizing Iron Unit Yield from Ore to Liquid Steel (Part 2)

This series is based on a paper titled, “Getting the Most from Raw Materials – Iron Unit Yield from Ore to Liquid Steel via the Direct Reduction/EAF Route” by Christopher Manning, PhD, Materials Processing Solutions, Inc. and Vincent Chevrier, PhD, Midrex Technologies, Inc. and articles previously published in *Direct From Midrex*.

*This is Part 2 of a three-part series on getting the most from raw materials, which is focused on the four interrelated factors that influence iron unit yield via the DR/EAF route:*

- Ore selection (Part 1)
- DRI physical properties (Part 2)
- DRI handling and storage (Part 2)
- Melting practice (Part 3)

### INTRODUCTION

**DRI products provide value to steelmaking operations as highly metalized, low residual iron units. Product quality – and hence value to the steelmaker – can be directly impacted by what happens to the DRI prior to it being melted. The extent of its value depends on maximizing the amount of iron units reaching the melting furnace by minimizing fines and maintaining product metallization after production.**

DRI products, like other forms of iron, have the potential to degrade over time especially if not properly handled and stored. Steelmakers largely have control over maintaining this quality, if they take the right measures. Part 2 of the series, “Maximizing Iron Unit Yield from Ore to Liquid Steel”, examines the effect of the physical properties of DRI on resistance to fines generation and metallization loss and the measures that can be taken to maintain the value of DRI during handling and storage.

### PART 2 – DRI PHYSICAL PROPERTIES

All forms of DRI have similar chemical characteristics because they are derived directly from iron oxide pellets and lump iron ores. The main difference is their physical characteristics (*TABLE I*), which lead to differences in behavior in handling and storage, as well as when contacted by water.

CHARACTERISTICS	CDRI & HDRI	HBI
Bulk Density	1.6-1.9 t/m <sup>3</sup>	2.4-2.8 t/m <sup>3</sup>
Apparent Density	3.5 t/m <sup>3</sup>	5.0-5.5 t/m <sup>3</sup>
Nominal Size	4-20 mm	30x50x110 mm
Weight	3-4 g	500-700 g
Water Absorption (saturated)*	12-15%	3%
Fines (<4 mm)*	5%	1-3%

\*not applicable to HDRI

TABLE I. Typical Physical Characteristics of DRI Products

The first plants produced only a DRI product that was cooled to close to ambient temperature prior to discharge (CDRI). As demand for DRI increased in areas where the production of DRI was not feasible, a product with excellent handling and shipping characteristics was needed, which resulted in the introduction of hot briquetted iron (HBI). Over time EAF steel-makers with captive DRI plants (those adjacent to or nearby a melt shop) wanted a way to take advantage of the heat contained in DRI immediately following reduction without cooling, which resulted in the introduction of hot DRI (HDRI) and the means to transfer it to the melting furnace at near its discharge temperature.



**COLD DRI (CDRI)**

Most direct reduction plants built to date produce CDRI. After reduction, the DRI is cooled in the lower part of the reduction furnace to about 50° C. Typically, CDRI is used in a nearby EAF shop as part of the primary metallic charge either in the scrap bucket or by continuous feeding.

CDRI has a sponge-like structure (hence the term “sponge iron”) comprising a network of interconnected pores, many of microscopic size, creating a large internal surface area. Measurements show surface areas of 1 m<sup>2</sup>/g, which is about 10,000 times greater than solid iron spheres of the same size. This large surface area facilitates the reduction of iron ore to DRI; however, it is prone to generate significant fines during handling and

storage and encourages reactivity with oxygen when exposed to air and water. Therefore, CDRI must be kept dry to prevent oxidation (rusting) and loss of metallization.



**HOT DRI (HDRI)**

This form of DRI allows the steelmaker to take advantage of the sensible heat (thermal energy whose transfer to or from a substance results in a change of temperature) to increase productivity and/or reduce production costs. HDRI, which already is above the ignition temperature (>200° C/390° F), will burn if contacted by air; therefore, care must be taken when handling and transporting it from the DRI plant to the steel mill.

HDRI can be transported from a MIDREX® Shaft Furnace to a nearby steel mill at up to 650° C by one of three methods: enclosed and insulated conveyor, specially configured transport vessel or HOTLINK®, a system for direct feeding of HDRI to an EAF. Some HYL plant are equipped with a pneumatic transport system for handling hot DRI.



**HOT BRIQUETTED IRON (HBI)**

HBI is produced by compacting pellet and lump DRI under extremely high pressure at temperatures in excess of 650°C, as it exits the reduction furnace. The compaction closes the major voids, increases the density, and reduces the internal surface area of the DRI. As a result, HBI absorbs 75% less water than CDRI and produces less fines, which make it the preferred merchant DRI product.

Its enhanced physical characteristics enable HBI to be

stored and transported without special precautions under the International Maritime Organization (IMO) solid bulk cargo code. The size and density of HBI make it a desirable feed material for the EAF, blast furnace (BF), and basic oxygen furnace (BOF).

Each DRI product, no matter how it is made, requires special considerations to maintain its value. Therefore, the yield and the degree of metallization (the percentage of metallic iron by weight exclusive of the iron bound up with oxygen as iron oxide, FeO) are key factors in determining DRI value. In addition, there are safety concerns that if not addressed could negatively impact a user's bottom line. These are factors that apply to all three DRI products during handling and storage; however, the ways to address these issues vary to a degree for each particular DRI product.

## DRI HANDLING

Material handling equipment selection and system design have a huge impact on how much fines will be generated during handling. The cost of fines generation should be considered when evaluating equipment options. The annual cost of operating a poorly designed system with high handling losses warrants the investment of capital to reduce yield loss, and payback/ROI can be very fast. As an example, consider a DRI handling system moving 1.6 million tons of product per year. Every 1% of material loss to spills or breakage will result in a loss of \$5,600,000 per year at \$350/ DRI ton. Fines generation on the ore handling side of a typical DR plant can be anywhere from 2% to over 5%. Fines generation and spillage on the DRI handling side can be 3% to 7%. These losses add up to large costs and represent a significant opportunity to invest in technologies that prevent loss or recover this material.

To preserve product quality, care must be taken to varying degrees with each product. As a general rule, users should try to minimize any unnecessary handling of the product. A material handling system should be designed for the minimum number of transfer points required to move material from point A to point B and with the shortest drops. The easiest way to minimize the number of transfer points is to take material along the straightest path possible. However, care should be taken not to compromise metering and feed control in an attempt to eliminate all transfer points. Spillage from overloaded belts may lose more material than breakage through the extra transfer point of a feeder.

A typical DRI handling system for a captive DRI plant may include the operations listed below.

### CDRI and HBI

- Conveying/transporting CDRI to storage silos
- Discharging/reclaiming CDRI from storage silos
- Conveying/transporting CDRI or HBI to short-term storage at EAF melt shop
- Reclaiming CDRI or HBI from short-term storage
- Conveying/transporting CDRI or HBI to EAF
- Charging CDRI or HBI to EAF

### HDRI

- Discharging HDRI from reduction furnace to pneumatic transport system, insulated hot transport conveyor or insulated hot transport vessels
- Transporting/conveying HDRI from reduction furnace to EAF melt shop
- Charging HDRI to EAF from pneumatic system, insulated conveyor or transport vessels
- Direct gravity feeding HDRI from reduction furnace to EAF melt shop (if equipped)

Yield losses during handling and storage arise from the following areas:

- Material spillage from conveyor belts and mobile equipment handling
- Material breakage and degradation at transfer points and through mobile equipment handling
- Material storage and reclaim
- Dust collection losses, including fires
- Degradation during storage

### Breakage and Spills

During the handling of DRI products, breakage and spillage can account for significant losses of product. Handling losses can exceed the impact of total iron content or gangue content on the total yield from iron ore to liquid steel. However, handling losses often are absorbed by different operating areas and are not accounted for in total.

CDRI pellets are susceptible to breaking into chips and producing iron-laden dust during handling and between various types of storage (covered outdoor piles, silos, and warehouses). A frequently quoted estimate for CDRI breakage due

to handling is 0.25% loss per 2-meter drop. This number can be much larger for weaker material, longer drops or poorly designed transitions. Fines and chips generated during handling will oxidize much faster than whole DRI products. A conservative number is 15% loss for 6.35 mm fraction material after exposed (outdoor) storage for a month.

The definition of what constitutes chips, fines, and dust is often a subject of debate. Many end users will call coarse fines (~3mm) dust or non-prime material. Depending on the user's material handling system and the exhaust system on the melting furnace, there may be very little or zero recovery of this material. Material that leaves the DR plant as "chips and fines" is likely to continue to break down to dust through subsequent handling, stacking, and reclaiming steps. Effective screening of chips and fines at a size that complements the end steelmaking operation is a critical element of producing "high quality" DRI products. Once this undersized material is separated through screening, an economic recovery method must be identified and implemented.

Although HBI is a much more durable material than CDRI, HBI is also subject to breakage when quality is poor and/or if the material is handled very roughly. Customers paying for merchant HBI expect mostly whole briquettes and limited amounts of chips and broken briquettes. HBI should be more stable, more easily handled than DRI, and much less dusty than DRI. Up to a limit, HBI also presents an opportunity to recycle metallic chips, fines, and dust back into the hot briquetting machines. Small amounts of metallic fines are beneficial, but larger amounts can complicate the briquetting operation and can reduce the strength of the resulting HBI if the fines recycling is poorly managed.

HDRI can be transferred from the DRI plant to the melt shop by hot transport vessels, hot transport conveyors or pneumatic transport, depending on the distance between the DRI plant and the melt shop or by direct gravity feeding in the case of a close-coupled reduction furnace (MIDREX HOTLINK<sup>®</sup>) and EAF. Hot transport vessel systems employ ladle-type insulated vessels that are transported on flat-bed trucks and can be maintained at temperature if the melt shop is delayed in accepting the HDRI. Pneumatic transport systems use gas to blow DRI at high velocity through pipes to the EAF or a product cooler. The high velocity and resultant turbulence can cause significant breakage and erosion of the HDRI, especially at bends in the pneumatic line. This method can result in fines generation of as

much as 8-10%. Hot conveyor systems using enclosed conveyor buckets are less jarring and greatly reduce HDRI fines generation.

Most of the breakage will occur at transfer points and stacking and reclaiming steps. A frequently quoted estimate for DRI handling breakage is 0.25% loss for each 2 meter drop the material experiences. This number can be much larger for weaker material, longer drops or poorly designed transitions. In fact, it is possible to have as much as 2.5% breakage through a single transfer point if no attention is paid to these issues. The amount of breakage also can be much lower for well-designed transitions, almost regardless of drop height.

For an existing oxide pellet or DRI material handling system, it is important to:

- (1) quantify the material breakage at each stage or transition in the system,
- (2) perform a screen analysis of samples throughout the material handling system, and
- (3) use this data to prioritize problem transitions and correct them.

For a new material handling system, the design should aim for the minimum number of transfer points required to move the material from point A to point B. Where transfer points are necessary, carefully engineered chutes or material transitions can minimize breakage, dusting, and spillage.

The easiest way to minimize the number of transfer points is to take the material along the straightest path, but this is not always possible. Accurate metering and feed control are important to avoid spillage from overloaded belts, even if an extra transfer point is required to achieve that control. Equipment selection can impact the number of transfer points required. A good example is the selection of a pipe belt conveyor (*Figure 1*) over a series of conventional troughed belts. A pipe belt starts as a conventional troughed belt in the material loading zone, then wraps the conveyor belt into a tube completely surround-

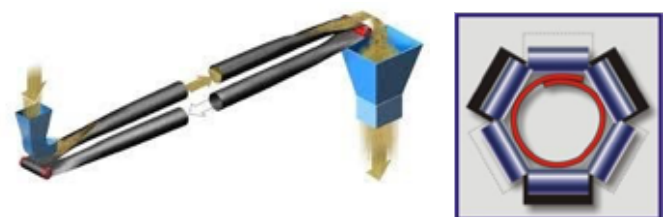


FIGURE 1. Pipe belt conveyor [1], [2]



ing the material. The belt unwraps at the discharge end, then wraps back up for the return path. By wrapping the belt into a tube, it is possible for a pipe belt to make both vertical and horizontal turns, whereas a conventional troughed belt can only make vertical plane bends. Pipe belt conveyors are not a new technology, but they are very effective for moving dusty, granular or pelletized material like both DRI and oxide pellets.

Because pipe belt conveyors make horizontal turns, they can eliminate transfer points. In addition, pipe belts have much less spillage as compared with conventional belts. Dribble from carry back material on the return side is contained to just the head and tail. Because the material being carried is wrapped up in the conveyor belt, even in a belt over-fill condition material spillage is limited to head and tail.

Because both cold DRI and oxide pellets are spherical, they can experience “roll back” on inclined conveyor sections as the material feed tails out. Under normal full belt conditions, material on an inclined section of belt is held in place by the material behind it. When material feed stops, the last bit of material on the conveyor is no longer held in place and will tend to roll back down the inclined belt. Eventually, this rolling material tends to jump over the side of a conventional troughed belt. For a high capacity conveyor where the material feed is starting and stopping many times a day, the result can be tens or even hundreds of tons of spillage in a matter of days. For the case of a pipe belt, material “roll back” is contained when the material feed stops, all but eliminating this spillage issue. *Figure 2* shows CDRI on a pipe belt conveyor.



**FIGURE 2.** Pipe Belt Conveyor Carrying CDRI [3]

## TRANSFER CHUTES

Transfer chutes are a necessary component of a material handling system because material must be loaded onto and

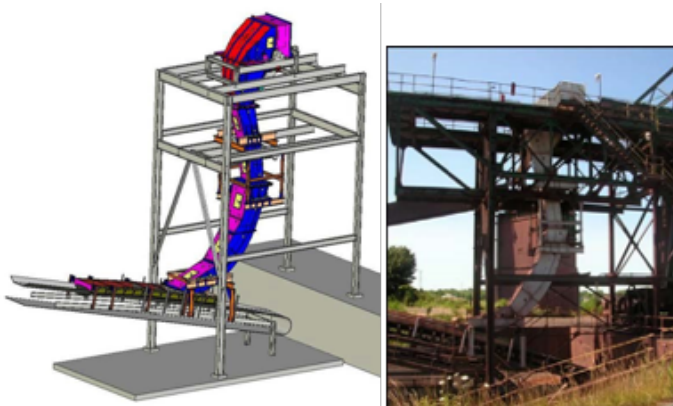
discharged from conveyors at some point. Transfer chutes often are poorly engineered with harsh direction changes and high energy impacts. This is not a major issue for many bulk materials, and functional transitions that connect one conveyor to the next are perfectly acceptable. However, rough transfer points lead to DRI breakage, rapid chute wear, and excessive dust generation.

Conventional wisdom about transfer chutes has dictated “low and slow,” meaning slow moving conveyors with minimum drop heights at conveyor-to-conveyor transfers. Unfortunately, this can cause some problems, as very low transfer heights leave little room for belt cleaning (scraper or brush) systems. Low transfer points also leave little room to collect the material leaving the conveyor head pulley and redirect it in the direction of travel of the receiving belt. The result is a transfer point where material “flops” onto the receiving belt in a very disorganized fashion. This can put a large amount of lateral pressure on the loading zone skirting system. Even when aiming for the lowest possible drop height through a transition, there is a minimum which is set by the size of the head pulley, the height of the receiving conveyor skirt board system, and other considerations.

Material will accelerate to 1000 ft/min vertical velocity through a drop of only 4.5 feet. With only 4.5 feet of height to work with, there is no chance of collecting the material in a chute and organizing its speed and direction. In most instances, it is better to use a slightly longer drop that leaves room for a belt cleaning system and a well-engineered transfer chute to the receiving belt.

Engineered or “inertial flow” chutes aim to control the speed and direction of the material stream through the transfer point (*Figure 3, next page*). All material “impacts” with the chute lining are very low angle, and thus low energy. This minimizes both material breakage and chute wear. Inertial flow chutes aim to load the material on the receiving belt, at close to the same speed as the receiving belt and in the same direction of travel of the belt. This practically eliminates spillage, and greatly reduces dust generation in the load zone, as well as reduces wear and tear on the conveyor belt itself.

A major contributor to dusting at transfer points is “induced air flow.” When material particles are in free-fall, the particles separate from one another, drawing air into the space between the particles. When the material experiences a collision



**FIGURE 3.** Inertial flow chute handling pelletized iron ore [4]

inside a receiving silo, onto a receiving conveyor or onto a stock pile, the space between the particles collapses and ejects the air that was entrained during free-fall. This can generate more than 10 times the air volume of the displaced volume of the material itself. This is frequently a major source of error in sizing dust collection equipment. Controlling the velocity and shape of the material stream through a well-engineered transfer chute can dramatically reduce the amount of induced air flow generated by the transfer point.

## MATERIAL STORAGE AND RECLAIM

DRI products are somewhat like fresh fruit. Although they don't have an expiration date they are best consumed when "fresh." As with fruit, this may not always be possible, so the products may need to be placed in storage to preserve their quality and value.

HDRI is not intended for long-term storage but can retain much of its heat when needed to wait for a charging cycle or to be transported to a different nearby melting vessel. This is a temporary option when using hot transport vessels and not really an option when using pneumatic or conveyor bucket systems.

### Outdoor Storage

HBI is normally stored outdoors in exposed piles built on a firm, well drained surface. Bulk piles of HBI tend to dissipate heat rapidly due to its good thermal conductivity characteristics and its shape and form that create voids in the pile. HBI, like scrap, can rust. Rusting has been observed to reduce its metallization by less than one percent per month even in salt-laden, humid

air and frequent, heavy rainfall conditions.

CDRI can be stored safely in open, well drained piles if it will not be moved until it is used in the melt shop. Rain can only penetrate the stack to a certain depth, typically less than a meter. Although the resulting corrosion will reduce the metallization, as described earlier in this article, the stack should not overheat unless additional material covers the wet area. This will insulate the wet iron and prevent the dissipation of the associated heat, which can cause the pile to overheat and can lead to ignition.

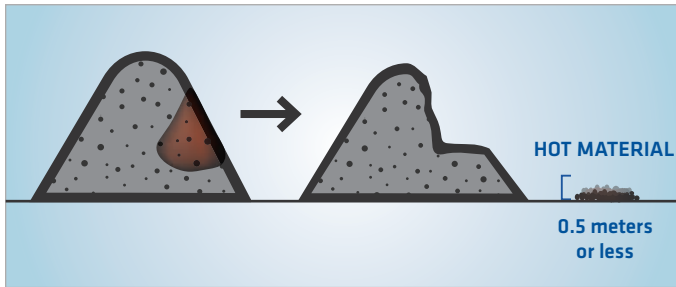
The following precautions should be followed when storing DRI products outdoors:

- Build pile on a firm base, such as concrete, and insure proper drainage to prevent the intrusion of water under the pile. The base should provide protection from moisture in the ground. A sealant layout of tar, bitumen or some other material impervious to water should be laid down before the concrete is poured.
- Avoid excessive fines content in the pile.
- In the case of cold DRI (CDRI), cover the pile to keep DRI dry and to prevent air stacking in the pile.
- Separate any DRI that has been wetted or has a temperature in excess of 65° C and follow the same precaution as for bins and silos.

A DRI pile will warm up to about 60°C/140° C as steaming occurs but will cool down again to ambient temperature when the water is evaporated. Normally it is not necessary to take additional action if the pile is steaming as long as the temperature does not exceed 100°C/212° F.

In case of a pile of DRI overheating to temperatures in excess of 100°C/212° F, the material should be removed from the pile and spread out on dry ground in a layer of about 0.5 meters using a track-equipped bulldozer or front-end loader, as shown in *Figure 4, next page*. Another method is to bury the pile under sand or other suitable material to cut off the oxygen supply.

**Important note:** water should not be sprayed on an overheated DRI pile under normal conditions. However, as a last resort in case of a runaway fire, the pile should be inundated with a strong water stream. Firefighters should be prepared for violent steaming and hydrogen flashing resulting from such action.



**FIGURE 4.** Method for controlling hot material in a storage pile

### Storage Bins and Silos

Storage bins and silos are used to protect DRI products when there is a time delay between arrival and when they can be used or shipped. Badly designed silos can create operational problems and a decrease of product quality. The design of silos should be determined always on the basis of the material flow properties of the bulk solid(s) to be stored. The expenses for testing and silo design are small compared to the costs of lost production, quality problems, and retrofits that may be needed because of irregular flow patterns.

The following precautions are recommended when storing DRI products in bins and silos:

- Any DRI at a temperature in excess of 65° C should not be sent to a storage bin or silo. It should be separated from all other material and piled no more than one meter high.
- Bins and silos should be purged with an inert gas from the bottom.
- Top slide gates should be closed except when DRI is being delivered.
- Bottom slide gates should be closed except when DRI is being discharged.
- Inert gas should be introduced into the top of the bin or silo during extended storage periods to insure a slight positive pressure while the top and bottom slide gates are closed.
- Periodic gas analyses should be performed to insure the oxygen level is below 3% and hydrogen is not being generated.
- Temperature within the bin or silo should be monitored. If high temperature (65-75° C) is observed, the bin or silo should be sealed and purged from the top until it cools. If the temperature rises to above 90° C, the DRI should be removed from the bin or silo.

### DUST CONTROL AND DUST FIRE PREVENTION

Dust collection is necessary for the safe and reliable operation of both ore and DRI material handling systems. In some areas, it may also be a regulatory requirement. Fugitive DRI dust represents a flash fire hazard and can lead to equipment fires, damage to bearings, damaged electrical equipment, etc. DRI dust is combustible and a careful dust hazard analysis should be performed to ensure hazards associated with fugitive dust and dust collection equipment are properly addressed. US consensus codes developed by NFPA [5], [6], [7] provide a good overview of how to assess and manage combustible dusts.

Once dust is collected in a dust collection system, that system may become the most likely place to have a flash fire or dust explosion. Depending on the system layout, materials being handled and aggressiveness of the dust collection system, the system may collect several percent of plant throughput as dust. The dust collected can be converted to valuable product, if it can be captured dry and cold or hot briquetted. Recovery of oxide dust and fines is more challenging and requires innovative thinking.

There are several different types of dust collection equipment that can be used for DRI/HBI and oxide handling systems. Wet collection systems, such as a venturi scrubbers, are generally regarded as intrinsically safe for handling DRI dust, since an explosion should not be possible in the system. On the flip side, the captured material is heavily degraded, since it becomes a slurry or sludge. Dry cyclone separators have a relatively low capture efficiency for very fine (<20 micron) particulate, however they can be used in conjunction with a wet scrubber to pre-filter a large percentage of the particulate as a dry dust. Conventional dry (filter media-based) collection has the highest filter efficiency and allows for nearly 100% capture of dust as a dry, recoverable material. Media-based dry dust collection has a higher potential for fires and explosion if improperly applied to DRI systems. One variation of media-based dry dust collection is “insertable” dust collection. In this case, each transfer point is equipped with a small built-in, powered bin vent and the captured dust is discharged back into the main material stream. Because this approach eliminates the ductwork, the enclosure of the dust collector itself, and the accumulation of a separate dust stream, the risk of explosion is greatly reduced. Because the dust is not captured as a separate material stream, this approach qualifies as dust containment more than as dust collection. It should be noted that if all the dust is simply

pushed to the melting furnace, recovery of that dust may be very poor. A dust hazard analysis may indicate that different solutions are appropriate for different locations. As examples: furnace discharge and dust control prior to passivation may require a wet scrubber. Dry media-based collection may be appropriate for CDRI product handling after passivation or for HBI handling. Insertable collection may be appropriate in remote transfer points and handling steps to push dust to a location where dust can be collected and handled more safely.

Ultimately, if the dust amounts to several percent of the total material throughput, a plan should be developed and implemented to recover or recycle that material. Metallic DRI or HBI fines can be a valuable material if they can be effectively recovered. The payback time for capital equipment investment to recycle fines is typically very fast. For an HBI plant, it is possible to recycle chips and fines (up to a limit) into the hot briquetting process. For a facility producing CDRI, DRI fines can be mechanically or pneumatically injected into a melting furnace if it is on-site but can be a challenging process and may not result in great recovery of the fines as liquid steel if done incorrectly.

Cold briquetting is a proven and effective method of recycling DRI dust and fines to a useful form, cold briquetted iron (CBI). Cold briquetting involves capital investment and comes with operating cost. There are technical challenges to consistently producing strong, high quality cold briquettes, including binder selection. Because cold briquettes typically have a lower total iron content than the parent cold DRI or HBI produced from the same ore, CBI typically has a slightly lower value in use to the steelmaker as compared with prime DRI or HBI.

Oxide fines recycling at a DR plant is more challenging than recovery/recycling of the metallic fines. There are not many cost-effective options for on-site recycling of oxide fines. In many cases, oxide fines are sold to a 3rd party at a fraction of the original purchase price. Some efforts have been made to compact oxide fines (e.g. briquettes) and run them through the direct reduction shaft furnace, but detailed reporting on the effectiveness of this technique is not widely available.

## YIELD LOSSES DURING STORAGE & RECLAIM

Static piles of HBI and DRI experience degradation or weathering when exposed to outside elements; metallic iron tends to revert to oxide and flake off. The losses to rust are mostly confined to the edges of the pile: studies have shown that the

center of an HBI pile does not experience much degradation even after 6 months.

Water in the form of rain or ocean spray will have the strongest impact. It is recommended to store DRI in silos or covered buildings whenever possible. Even in a covered building, ground moisture can cause the DRI to oxidize.

Material storage and reclaim of both ore and DRI can be a major source of breakage and material loss. Front end loaders tend to grind up ore and DRI. Bucket wheel or drag chain reclaimers for ore yards are a much better option. Gravity reclaim of DRI is the best option, with the least amount of handling. DRI silo or stock house filling operations often can involve very large free-fall drops. Special care should be taken to minimize damage during filling and discharging operations.

## CONCLUSION

The value of DRI is best determined by how it contributes to meeting the operational and productivity goals of those who use it. DRI must be highly metalized and of consistent quality. Therefore, it is essential that DRI products arrive at the melting furnace in as close as possible to their physical and chemical condition as when they were made.

All iron is reactive and will rust when in contact with air (oxidize) and when in contact with water (corrode). Rust robs DRI of metallization and can lead to dangerous and unsafe situations during storage if proper procedures are not followed.

The good news is that by taking some well documented precautions and following procedures developed from decades of industry experiences, these materials can be handled and stored to preserve their quality – and thus their value. ■

## References

- [1] [www.overlandconveyor.com/consulting/conveyor-consulting-services/pipe-conveyor.aspx](http://www.overlandconveyor.com/consulting/conveyor-consulting-services/pipe-conveyor.aspx)
- [2] [www.pipeconveyor.com/Papers/History/History.htm](http://www.pipeconveyor.com/Papers/History/History.htm)
- [3] [www.dimisa.com/dm/Projects.html](http://www.dimisa.com/dm/Projects.html)
- [4] [documentlibrary.flexco.com/W011\\_enUS\\_011\\_TWT\\_0114.pdf](http://documentlibrary.flexco.com/W011_enUS_011_TWT_0114.pdf)
- [5] NFPA 652: Standard on the Fundamentals of Combustible Dust - 2019
- [6] NFPA 654: Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids - 2017
- [7] NFPA 484: Standard for Combustible Metals- 2019

## MIDREX News & Views

# Record-Setting Performances in 2019

### JINDAL SHADEED – Sohar, Oman

The world's first DRI plant designed to operate with the HOTLINK® system established new daily and monthly production records in 2019. HOTLINK allows hot DRI (HDRI) to be gravity-charged into an EAF via a direct connection between the MIDREX® Plant and the melting furnace. Jindal Shadeed produced 1.75 million tons of HDRI and hot briquetted iron (HBI), 89% of which was HDRI that was charged to the EAF melt shop by HOTLINK. En route to the annual production milestone, the plant had record-setting months in March and May, producing more than 160,000 tons each month, operating in excess of 8200 hours, and using more than 25% blast furnace-grade pellets in the feed mix.



*Jindal Shadeed*

### NU-IRON UNLIMITED – Point Lisas, Trinidad and Tobago

The Nu-Iron MIDREX Plant exceeded its previous annual production record by more than 100,000 tons in 2019, producing over 1.7 million tons of highly metallized (>96%), high carbon (2.7%) cold DRI (CDRI). The plant was operated in excess of 8,000 hours, a noteworthy achievement and a highly valued goal of the plant. Nu-Iron ships all of its product to Nucor's steelmaking plants in the US.



*Nu-Iron Trinidad and Tobago*

### QATAR STEEL – Mesaieed, Qatar

The DR-2 combination HDRI/CDRI MIDREX Plant operated continuously for 6,024 hours (251 days), which likely is a record if this statistic were tracked for MIDREX Plants. Interestingly, operation was tripped due to reasons external to the plant. Qatar Steel's DR-1 plant achieved 186 days (4,464 hours) of continuous operation in 2018.



*Qatar Steel*

### TOSYALI ALGERIÉ – Bethioua (Oran), Algeria

A new DR industry record for daily production (7,700 tons) was achieved by Tosyali Algerié's MIDREX Plant in July 2019. The world's largest DRI plant, capable of producing 2.5 million t/y of HDRI and CDRI, was commissioned in July 2018, commenced CDRI operations in November 2018, and began transferring HDRI to the nearby EAF melt shop in February 2019.



*Tosyali Algerié*



## MIDREX News & Views

# KC Woody Appointed Midrex COO



**M**idrex has announced the promotion of KC Woody to Chief Operating Officer (COO). Signaling a more focused commitment to customer service

and support, Woody will be actively involved in the integration of the Midrex Operations and Sales & Marketing teams and the activities of the Midrex offices in India and the United Kingdom.

In making the announcement, Stephen Montague, President & CEO of Midrex Technologies, Inc., said, "The Midrex Board of Directors wants us to continue focusing on growth initiatives within our core business while seeking out and developing new business opportunities. To be successful in an ever-evolving marketplace, we must be able to anticipate and respond to change. The creation of the COO position will allow us to better coordinate our sales & marketing, global services, and plant operations support teams

under the leadership of KC Woody."

Woody, a graduate of the US Military Academy at West Point, served on active duty as an officer in the U.S. Army for more than eight years prior to Midrex. He joined Midrex in 2010, as Plant Sales Manager responsible for commercial activities in Australia and Southeast Asia. Woody served as the first Managing Director of Midrex India Private Limited from 2011-2013, and became Director-Plant Sales in 2014, with responsibility for Midrex India and Midrex China (Shanghai). He was promoted to Vice President-Sales & Marketing in 2016, to lead all commercial activities of Midrex including the offices in China, India, and the United Kingdom.

# Mark Boedecker Named Director-Sales & Marketing



**C**oncurrently, Mark Boedecker was promoted to Director-Sales & Marketing, with day-to-day responsibility for Midrex Sales and Marketing activities, as well as the operation of the United Arab Emirates (Dubai) and China offices.

Boedecker has more than 15 years of technology-related experience and was instrumental in bringing Industry 4.0 concepts to Midrex. He has worked on developing several Midrex projects around the world and was the Plant Sales

Manager for the voestalpine Texas, LLC HBI plant. Boedecker earned a Bachelor of Science Degree in Computer Engineering from the Milwaukee School of Engineering and an MBA from Duke University.

The MIDREX® Process is the world's most reliable and productive direct reduction technology.



Lauren Lorraine: Editor

Vincent Chevrier, PhD: Technical Advisor

**DIRECT FROM MIDREX** is published quarterly by Midrex Technologies, Inc., 3735 Glen Lake Drive, Suite 400, Charlotte, North Carolina 28208 U.S.A. Phone: (704) 373-1600 Fax: (704) 373-1611, Web Site: [www.midrex.com](http://www.midrex.com) under agreement with Midrex Technologies, Inc.

The publication is distributed worldwide by email to persons interested in the direct reduced iron (DRI) market and its growing impact on the iron and steel industry.

©2020 by Midrex Technologies, Inc.

The processes and equipment depicted in this material are subject to multiple patents and patents pending in the U.S. and internationally.



Midrex Technologies, Inc.

*MIDREX*®, *MEGAMOD*®, *SUPER MEGAMOD*®, *ITmk3*®, *MxCōl*®, *DRIpax*® and *HOTLINK*® are registered trademarks of Kobe Steel, Ltd.

*MidrexConnect*™, *Thermal Reactor System*™, *MIDREX H<sub>2</sub>*™, and *MIDREX ACT*™ are trademarks of Midrex Technologies, Inc.

*Corex*® and *Finex*® are trademarks of Primetals Technologies.

## CONTACTING MIDREX

**General E-mail:**  
[info@midrex.com](mailto:info@midrex.com)

**Phone: (704) 373-1600**  
3735 Glen Lake Drive, Suite 400  
Charlotte, NC 28208

**General Press/Media Inquiries**  
Lauren Lorraine  
[LLorraine@midrex.com](mailto:LLorraine@midrex.com)  
Phone: (704) 378-3308

To subscribe please register at [www.midrex.com](http://www.midrex.com) to receive our email service.