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DIRECT FROM MIDREX

4TH QUARTER 2021

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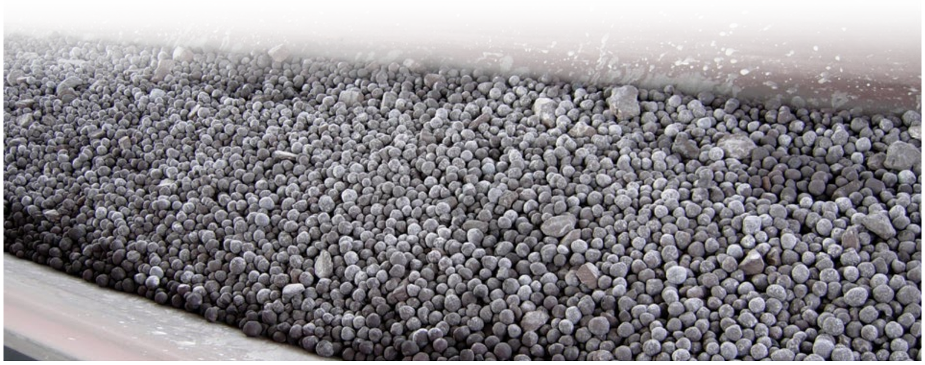
COMMENTARY

STARTING A NEW CHAPTER

By Will Dempsey
Vice President – Commercial
Midrex Technologies, Inc.

It's an exhilarating time to be in the iron and steel industry. Steel is vital to global industrial progress and for creating opportunities to improve economic conditions throughout the world. However, finding a way to make iron and steel that protects the environment is key to improving the overall quality of life.

My years of experience as a Midrex process engineer and most recently as engineering director have prepared me well to continue the strong technical focus of our commercial activities as we help decarbonize iron and steelmaking through the implementation of innovative direct reduction technology.



Some form of direct reduction has been around for thousands of years but it only became a modern ironmaking method in the second half of the 20th century. Initially, direct reduced iron (DRI) was seen as an alternative metallic for making basic steel grades in electric arc furnace (EAF)-based mini-mills. However, the flexibility and economies-of-scale of the EAF led to its expansion into the realm of flat-rolled steel, once the private domain of traditional integrated steelmaking. Today, EAFs make up close to 30% of global steel production and are producing the highest grades of steel.

Along the way, it became clear that the EAF produced "cleaner" steel relative to CO_2 emissions due to its use of scrap and DRI in place of coal and coke. Most steel industry experts point to the scrap/DRI-based EAF route as the key to achieving greenhouse gas (GHG) emissions goals by 2050.

Midrex can provide solutions for reducing CO_2 emissions for EAF operators, as well as blast furnace/basic oxygen furnaces (BF/BOF). In my engineering role, I was closely involved in development of the technology for transitioning the natural gas-based MIDREX® Process (MIDREX NG™), which has demonstrated the reduction of iron oxide with up to 70% hydrogen, to MIDREX H2™ that can be operated on 100% hydrogen. Likewise, we have worked with our Construction Partners and Kobe Steel, Ltd., our parent company, to advance the use of hot briquetted iron (HBI) in the BF/BOF, as a means to extend their operational life and to help improve their environmental sustainability.

So, I want to introduce myself to those of you who may not have known me in my previous engineering roles at Midrex, and say that I look forward to working with many of you in exploring the ways that MIDREX Direct Reduction Technology can be instrumental in decarbonize the global iron and steel industry.

→

This issue of *Direct From Midrex* includes Part 2 of the two-part series on raw materials challenges by John Linklater, General Manager of Midrex Gulf Services FZCO (Dubai) and a guest article by Midrex partner, Primetals, with a perspective on the road to zero-carbon ironmaking, plus a description of the various colors assigned to hydrogen gas.
In addition, the News & Views section contains noteworthy Midrex-related events occurring during 4Q2021.

ADAPTING TO RAW MATERIALS CHALLENGES

PART 2

OPERATING MIDREX PLANTS WITH LOWER GRADE PELLETS & LUMP ORES

By JOHN LINKLATER
*General Manager –
Midrex Technologies
Gulf Services FZCO*

INTRODUCTION

This is the second article in a two-part series exploring the options for using lower grade oxide pellets or lump ores to operate a MIDREX® Plant. Part 2 presents a strategy for increasing the percentage of lump ore in the feed mix of a MIDREX Plant, which involves MIDREX Remote Professional Services (RPS). A step-by-step case study documents the method that was used to adapt to an alternative raw materials strategy and the results that were achieved. Part 2 concludes with a series summary.

PART 2

IMPLEMENTATION STRATEGY

MIDREX Remote Professional Services (RPS) has collaborated with clients in successfully increasing the lump ore in a MIDREX Shaft Furnace. Prior to introduction/procurement of lump ore, it is critical that the ore is tested in the laboratory or with a basket test in the MIDREX Shaft Furnace. RPS is involved with and the following evaluations are recommended:

- Evaluate the type of lump – some lump ores rupture during the transition from Fe_2O_3 to Fe_3O_4, generating excessive fines and chips.
- Evaluate size distribution – simulate the furnace conditions with Midrex proprietary software to determine the maximum reformed gas flow attainable with the different blends. The following will be evaluated:
  - Maximum flow to cause fluidization with different feed mixes – this requires the feed mix size distribution.
  - Furnace delta P with increased flow/various feed mixes – increased fines generation assumed from results of standard and non-standard tests. The following equipment sizing needs to be evaluated to evaluate the effects on the process:
    - System pressure – furnace dynamic seals to be checked with increased system pressure.
    - PG compressor sizing – if the process is PG compressor limited, what production can be achieved or what can be done to increase compressor output.
    - Seal gas system sizing – includes compressors, seal gas dryer, BSG compressor etc. If the system pressure is increased, flow to the seal legs requires an increase.

– Super data runs to predict process changes will maintain product quality.

– Evaluate the burden feeder speed adjustments required with the various blends due to density changes – these will be altered as the % lump ore is increased and the % DR-grade pellets is reduced.

– Process changes required prior to introduction of ore i.e. bed temperatures, etc.

– Reducibility testing of the lump ore.

Once the implementation of lump ore has been evaluated, it is critical to ensure the current plant operation is stable with a low standard deviation of product quality prior to introducing the lump. Introducing a different feed mix into an unstable plant will result in further instability and wider swings in product quality.

CASE STUDY

In the case study below, the steps after the evaluation have been outlined. This is plant-specific and each plant will differ.

STEP 1 - STABILIZING THE OPERATION

As stated previously, before introducing lump ore into a feed mix, it is essential that plant operation is stable. Changing feed mix always carries the risk of introducing instability. In this case study, there were several areas that needed to be addressed prior to introducing the lump ore. These have been listed to highlight the importance of preparing the plant to be successful in the introduction of the new feed mix.

Bed Temperature

A stable plant would typically have a maximum bed temperature variation of approximately 10°C. The study plant had furnace bed temperatures, with a variance of 85°C. With the MIDREX Shaft Furnace separated into segments, it can be seen how the temperatures in each segment differed, showing hot and cold zones ***(Figure 1)***. This can be an indication that there are bustle ports blocked farthest from the inlet, where the bustle gas velocities are the lowest. This was resolved by inspecting and clearing all the bustle ports during the following turn around. In addition, the velocities at the nozzles were analyzed prior to the turnaround and recommended - 25% of the nozzles be blanked off to increase gas velocities into the bed.

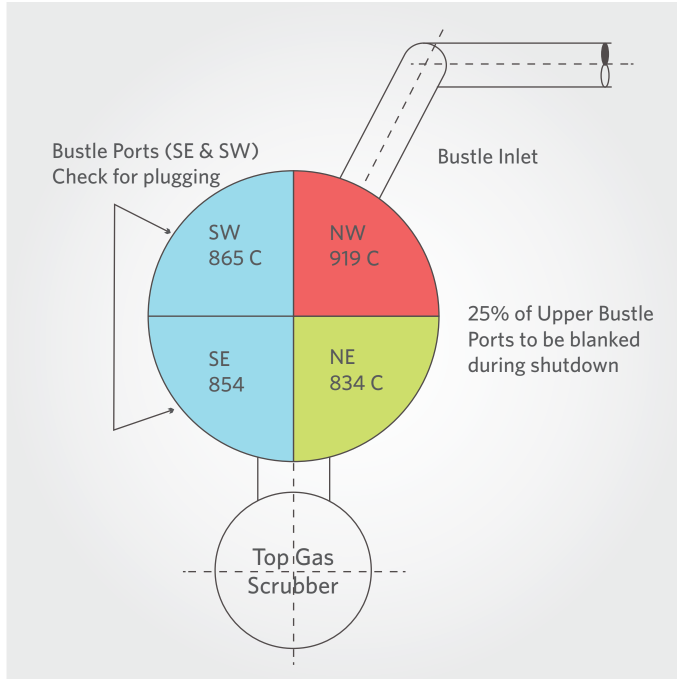


FIGURE 1. *Furnace Bed Temperatures*

Bustle Temperature

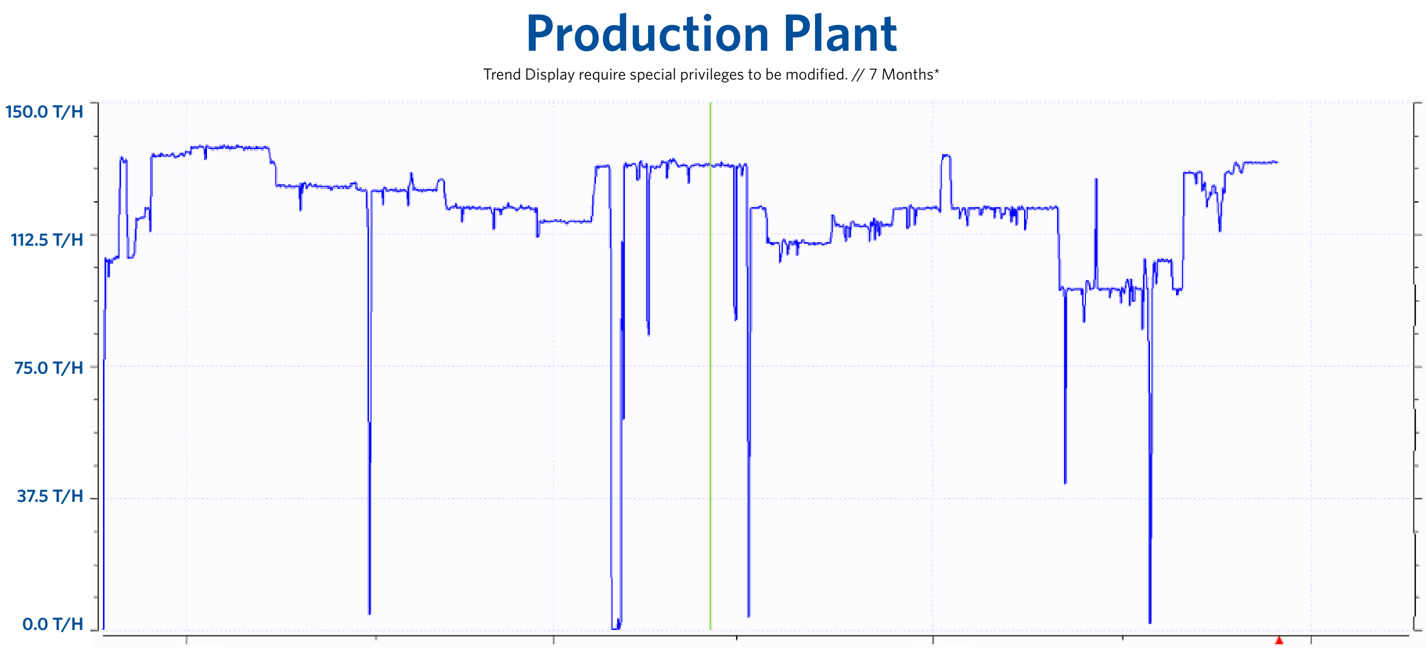
In a MIDREX Plant, it is preferable that the control of the bustle temperature is operated in automatic mode. The operating criteria of the bed temperature in combination with the process gas flow/ton ratio is used to maintain the bed temperature at an optimum and stable value (+/- 10°C) to ensure product quality and process stability. Automatic bed temperature control was not possible in the study plant due to failed thermocouples not providing the bed temperature feedback that was required to run in automatic. It was recommended these be repaired during a turnaround.

Discharge

The discharge rate for the product was erratic and showed significant fluctuations. The following process parameters in the furnace were being affected due to the swings in the discharge:

- Bustle temperature
- Top gas temperature
- System pressure
- Top gas fuel
- Roof temperature

Discharge variations shown in ***Figure 2 (next page)*** resulted in an unstable process, and therefore unstable quality. An investigation showed the furnace product discharge feeder capacity to be undersized due to production increases over time. This



Inconsistent furnace discharge had to be stabilized.

FIGURE 2. *Product Discharge*[1]

resulted in a lack of control in the feeder that produced an unstable discharge. It was recommended to replace the discharge feeder with one having a larger capacity, which would guarantee operating fluctuations of less than +/-2 TPH for discharges up to 40% above the current average production rate.

Feed Mix

Changing the feed mix can introduce some process instability. The study plant was currently blending its feed mix from three feed bins. Each bin was charged with a different raw material supplier. Feed bin discharge rates were examined to ensure there was a consistent feed from each bin. It was found that the feed mix was constantly changing. Midrex worked with the client in assessing the optimal feed mix blend using fluidization software to ensure the optimal mix for the available material was selected. Once this was determined and the feed mix more consistent, introducing the lump ore in stages could be planned.

The trend in ***Figure 3 (next page)*** shows the inconsistent feed mix. You can see significant fluctuations in the discharge from each bin. Each feed bin discharge rate should be in a steady state. A fluctuating discharge rate results in constant production changes making it difficult to maintain a consistent product and process, such as the NG/ton product ratio, etc.

Burden Feeders

In a MIDREX Plant, the burden feeders are designed to promote uniform movement of the bed and to reduce the size of clusters formed during process upsets. Experience shows that ensuring the burden settings, such as the angular speeds relative to the material density are critical in ensuring a stable furnace operation. The burden feeder speeds were evaluated and then adjusted. It is important to note that excessive burden feeder speeds can result in higher fines generation as a result of material being crushed.

Reformer Temperature Control

Reformer temperature control is fundamental to ensure the process is stable. The reformed gas quality, gas volume, product quality, and NG consumption are all affected when the reformer temperature control is not precise. It was recommended the reformer temperature be stabilized by adding natural gas to the main burners. This would allow fine roof temperature adjustments are made with natural gas to main burners, which is according to Midrex design. The natural gas has a stable heating value relative to the top gas fuel, where the heating value can fluctuate. This allows the necessary adjustments to be made to the temperature with minimal natural gas flow adjustments. This would stabilize the process and quality.

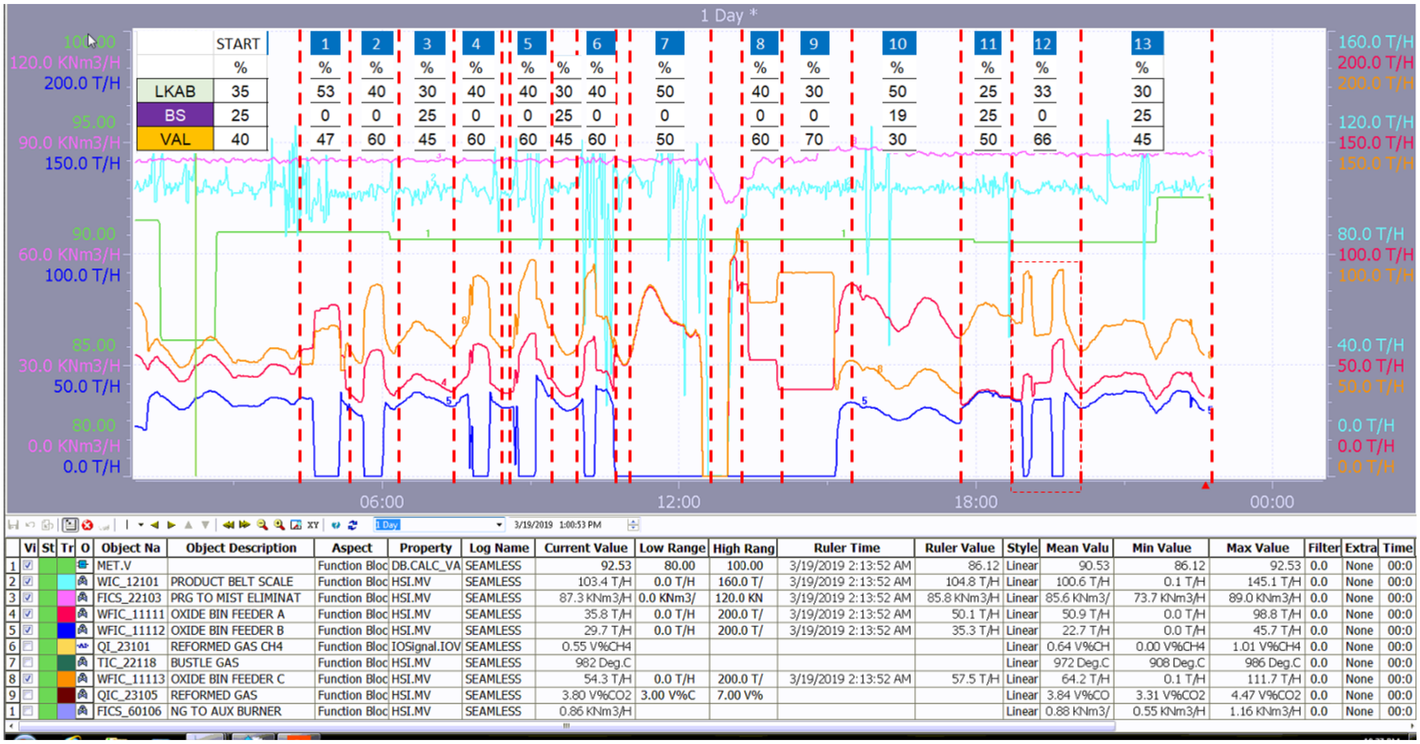
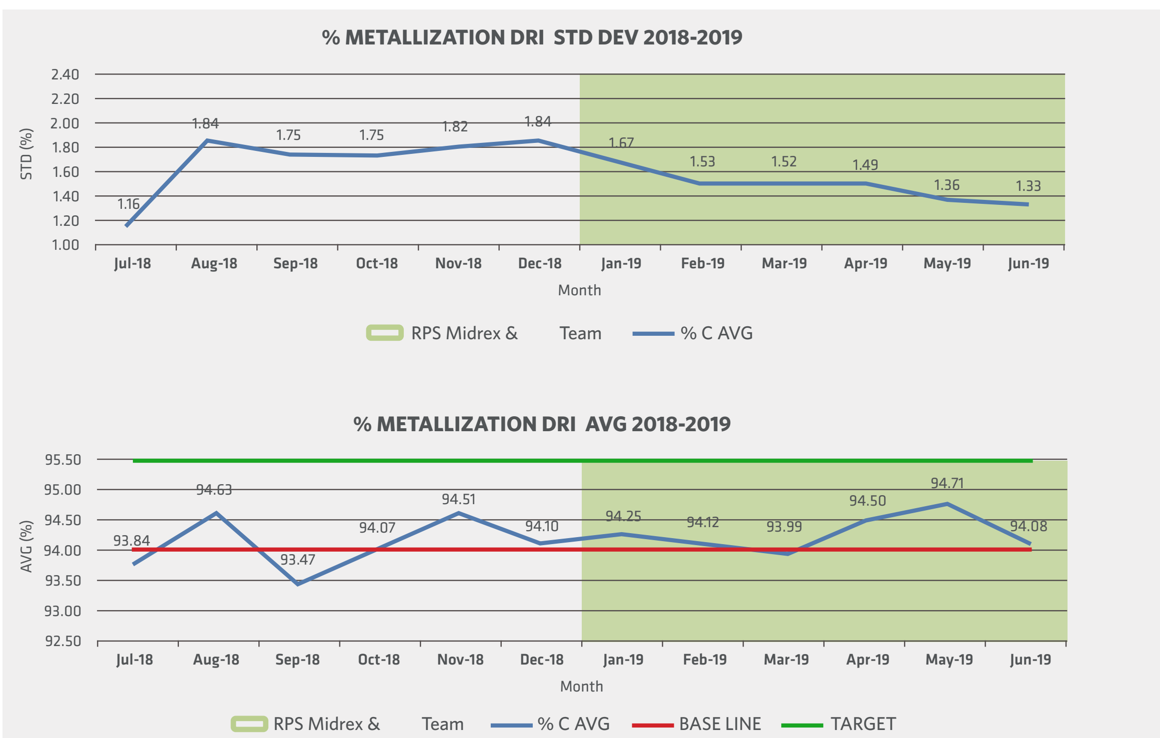


FIGURE 3. *Inconsistent Feed Mix Trends.*[1]

Step 2 - Control Product Quality

Once many of the steps covered were implemented, the results were seen in the product quality ***(Figures 4 and 5)***. Ultimately, the process stability is measured by the product quality standard deviations. Once at a satisfactory level, lump can be introduced.



Standard deviation for metallization improved from 1.8 to 1.33

FIGURE 4. *Standard Deviation for Metallization.*[1]

Step 3 - Maximizing the Metallization

In an attempt to reduce electrical consumption in the EAF, the metallization in the DRI was not only stabilized but increased. There was an increase in NG consumption in the DR plant to achieve this, but it should be noted that part of this increased consumption really was necessary to achieve the required operational stability in the reformer and furnace to achieve a more consistent product quality. Higher and more consistent metallization would likely reduce the melt shop's electrical consumption, tap to tap times, and EAF refractory consumption.

For the case study, the EAF was already charging DRI, so there was no significant increase in slag.

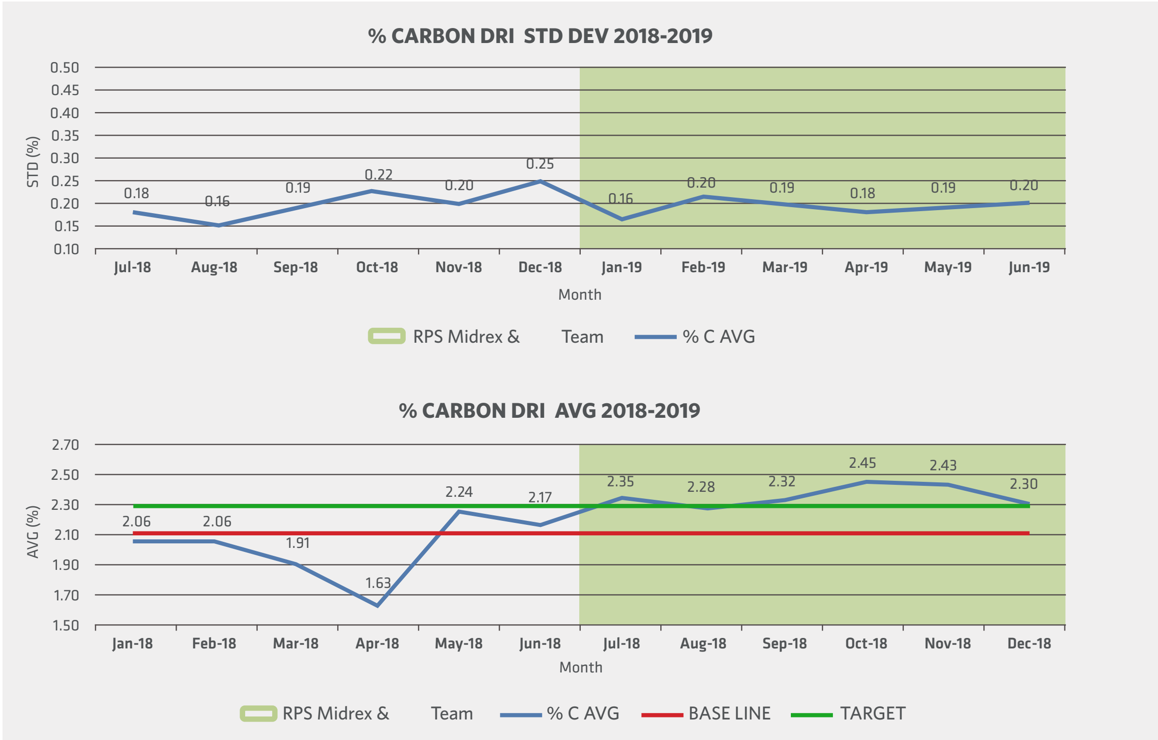


FIGURE 5. *Standard Deviation for Carbon.* [1]

Step 4 - Introducing Lump Ore

Once the plant was stable, lump ore addition was increased gradually in 5% increments every 72 hours, adjusting the process as required. The following parameters were monitored by the Midrex RPS team with each increase:

- Bed temperatures – check that there are no symptoms of gas channeling in the furnace.
- Top gas CO_2 to be held between 18-20% – indicates the reduction is as expected.
- Top gas temperature – same as above.
- Adjusting burden feeder speeds as the feed mix density changes.
- Observe burden feeder behavior – burden feeder pressures.
- Upper and lower seals – additional fines can cause lost seals.
- Quality.
- Fines in water system – from top gas duct.

Financial Impact – Introducing Lump Ore

There are several factors to consider when deciding on the feed mix for an EAF. Some examples are.

- The quality of steel to be produced. This play a role in determining the amount of virgin iron if any to be added vs available scrap.
- How much copper and other impurities are in the scrap available.
- Use of DRI or pig iron, etc.
- Using/increasing the use of DRI - a DRI with an increase in gangue would require the EAF slag practice to be adjusted. This can result in significant losses in yield.
- Increased fines generation in the DR plant will reduce yield in the DR plant and in the EAF (fines may not be able to penetrate the slag, resulting in yield loss in the feed material).

SERIES SUMMARY

In summary, substituting the feed material in a DR Plant is a lot more complicated that just calculating the price difference between the raw material available to that plant. It should encompass the operation from receiving the raw material to the final liquid steel.

In this study, the EAF was already being charged with a set percentage of DRI. The objective here was to increase the high-grade lump ore portion in the DRI makeup. This would help counter the iron oxide pellet shortage and reduce material cost in the DR plant feed material by eliminating the premium. It was assumed that replacing the DR-grade pellets with a high-grade lump ore with similar chemical properties would not have a significant effect on the slag practices or losses in the EAF.

In this example:

- Lump ore feed increased from 3% to 25% - an increase of 22% in lump ore translates to a substantial material savings
- There was a NG/t increase. This was to:
  - Stabilize the plant quality – reduce standard deviation (part of this increased consumption was required regardless of the lump addition to achieve stable operation prior to increasing lump in the feed mix).
  - Increase metallization – to reduce EAF electrics/tap to tap times/reduce refractory
- Increased metallization and more consistent quality translated to a saving in the steel mill by:
  - Electrical saving in the arc furnace
  - Electrode saving – by reduced tap-to-tap and reduced power consumption.
  - Shorter tap-to-tap times result in higher productivity

Reference:

[1] Midrex RPS

THE WINDING ROAD TOWARD ZERO-CARBON IRON

The steel industry's biggest product today isn't steel – it's carbon

By Johannes Rothberger, *Head of Sales Direct Reduction*;
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INTRODUCTION

Iron and steel production is responsible for about 9% of global CO_2 emissions. A decisive shift away from carbon-based reductants to alternatives like hydrogen is all but inevitable – but it will have to come in stages.

Roughly 1.8 tons of CO_2 are released into the atmosphere for every ton of liquid steel produced by the still predominant Blast Furnace/Basic Oxygen Furnace (BF/BOF) route – a number based on calculations that assume an average modern BF operated in OECD Europe. However, there are many plants around the world that emit two or more tons of CO_2 per ton of steel. These facts are hardly good news to decision makers inside the industry. But they are only beginning to dawn on governments around the world that are now weighing their options for achieving the massive reductions in greenhouse gas emissions (GHG) mandated by the Paris Climate Agreement. As some of these governments strive toward the even more ambitious goal of net-zero carbon emissions by 2050, scrutiny is inevitably going to increase, and pressure is going to build on steel producers to bring down emissions in drastic ways. Emissions trading schemes are going to be implemented and widened in scope, carbon taxes are looming, and consumers will ultimately show concern for the carbon footprint of steel products.

Producers in some parts of the world are already feeling the painful pinch of carbon pricing. The development of prices for European CO_2 Emissions Allowances, as illustrated in ***Figure 1***, is a prime example. At their peak in mid-2021, prices had seen close to an eight to tenfold increase over a four-year period. And they remain near record highs, as the EU emissions trading scheme entered its next phase in 2021, when several measures kicked in that will progressively tighten the supply of allowances.

In anticipation of such regulatory measures and market pressures, steel producers around the world are racing to deploy new technologies aimed at reducing carbon intensity in iron and steelmaking. Merely shifting iron production from coal and coke-based blast furnaces to natural gas-based direct reduction plants will not be sufficient. The industry will need to develop other energy sources without a direct carbon footprint, such as hydrogen based on renewable energy to commercial scale and in a manner that is economically feasible.

FIGURE 1. *Price-Tag Increases for Carbon in the EU (EUA) (www.eex.de)*
After hovering at low levels for years, the price of European CO_2 Emissions Allowances has recently skyrocketed. As emissions-trading schemes are set to spread, allowances will inevitably become a significant driver of cost.

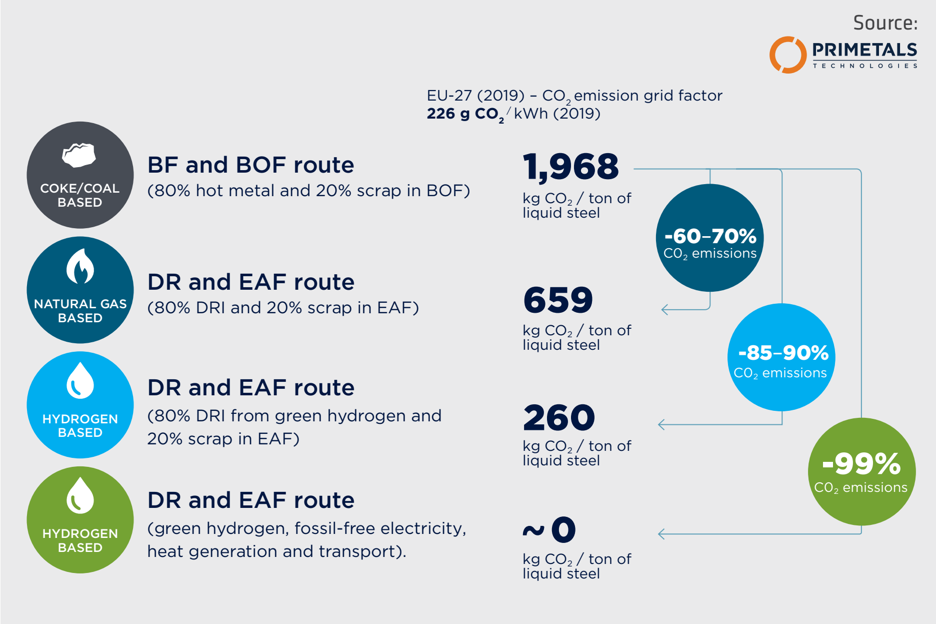


FIGURE 2. *CO_2 emissions of different process routes to liquid steel (CO_2 emission grid factor 0.226 kg/kWh – EU27 2019)*

COMPARING THE PRODUCTION ROUTES

As ***Figure 2*** shows, the Direct Reduction/Electric Arc Furnace (DR-EAF) route, using natural gas in the DR process, cuts carbon intensity for liquid steel by more than 50% in comparison with the conventional BF/BOF route. By using "green" hydrogen instead, emissions can be reduced by 85-90%.

Most emissions at this point are actually attributable to electricity production for the EAF process. The calculations for ***Figure 2*** are based on a CO_2 emission grid factor of 0.226 kg of CO_2 per kWh, which is the average value for EU-27 from 2019. Applying the CO_2 emission grid factor of Sweden (currently at 0.023 kg of CO_2 per kWh) would bring emissions down to only 181 kg CO_2 per ton — a whopping 90% reduction compared to the BF/BOF route. From there, all that stands in the way of true zero-carbon iron would be the provision of fossil-free energy for electricity, heat, and transport.

PRODUCING HYDROGEN AT SCALE

Needless to say, establishing a ready supply of hydrogen that can make iron and steelmaking truly carbon-free will be a major challenge. One of the key barriers is the sheer hydrogen volume needed to support a massive upscaling in use by the industry. The amount that will be consumed is tremendous. Converting a typical integrated plant with a production of 5 million tons per year from coal and coke to hydrogen will require a supply of at least 480,000 Nm³ (equaling 44 tons) of hydrogen per hour. To put this into perspective, the largest proton exchange membrane (PEM) electrolyzer currently in operation generates only about 3,000 Nm³ (i.e., 0.25 ton) of hydrogen per hour.

Not only will vast quantities of additional hydrogen be needed to support the steel industry, but it will also have to be produced using alternative processes. Currently, around 95% of hydrogen is "gray" – meaning it is produced by extracting gas from fossil fuels. It is possible to use carbon capture, utilization, and storage (CCUS) technology to prevent emissions from being released into the atmosphere, resulting in "blue" hydrogen. But this only makes economic sense where a high volume of CO_2 can be captured at a single site. And it is only feasible in areas where there are geologically safe places to store captured carbon, such as beneath the sea or deep underground.

HYDROGEN ELECTROLYSIS WITH "GREEN" ENERGY

As of today, most of the hydrogen for industrial use is produced by steam methane reformers (SMRs). Since the natural gas that feeds these reformers (methane – CH_4) contains carbon, the resulting "gray" hydrogen causes a sizable amount of CO_2 emissions. To fully decarbonize the process, hydrogen for ironmaking will have to be produced by electrolysis from water, using fossil-free energy.

Since the year 2000, more than 230 hydrogen-electrolysis projects (counting both those based on renewable, as well as conventional sources of energy) have entered into operation around the world. Most of them, like the H2Future project are based in Europe. But several have been started or announced also in Australia, China, and the Americas. Almost all have been at a scale of less than 10 MW, but a 20 MW plant is now operating in Canada and lately there have been several proposals for plants exceeding 100 MW.

There are three main electrolysis processes that make all of this possible: alkaline, proton-exchange membrane (PEM), and high-temperature steam electrolysis. The most advanced technology at this point—and the one that most recent hydrogen-generation projects have favored, is Proton-Exchange Membrane or PEM ***(Figure 3)***. It attaches electrodes on two sides of a solid polymer membrane, which act as the electrolyte and as a separator to prevent the produced gases from mixing. Hydrogen ions form at the anode, pass through the membrane, and combine with electrons from the cathode to form hydrogen gas.

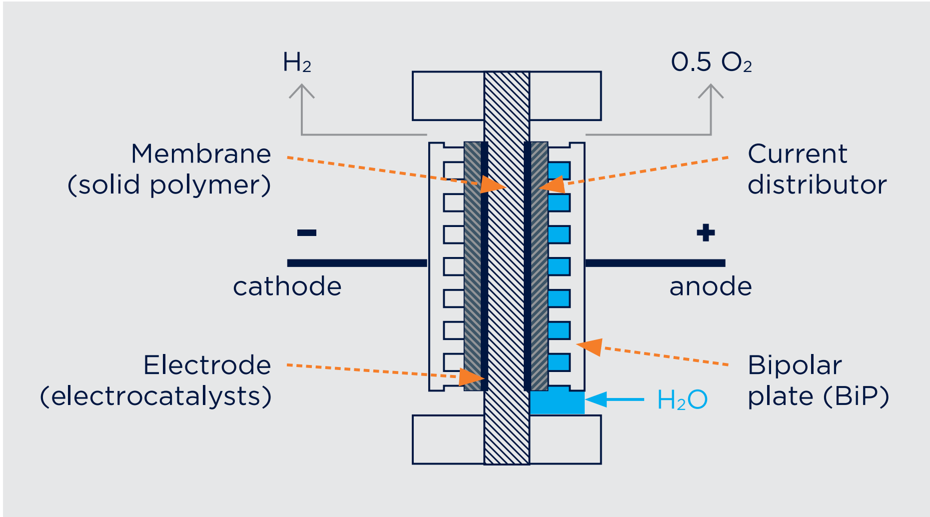


FIGURE 3. *Working principle of a proton-exchange membrane (PEM) electrolysis cell.*

The PEM-type electrolyzer has several advantages: It is highly efficient, features high power density, and has an extended dynamic operating range, allowing it to be directly coupled to renewable sources—because it can quickly react to changes in the electricity supply. Modules are available in the range of 3 to 100 MW, producing up to 20,000 Nm³ (or roughly 2 tons) of hydrogen per hour.

APPLYING HYDROGEN IN COMMERCIALLY PROVEN DIRECT REDUCTION SOLUTIONS

Hydrogen (H_2) is already part of the reduction gas mix in mainstream direct reduction processes—alongside carbon monoxide (CO), of course. This flexibility of direct reduction processes provides an enticing way for plant owners to switch to hydrogen in a gradual fashion, increasing the addition of hydrogen over time as prices come down and supplies increase. It also

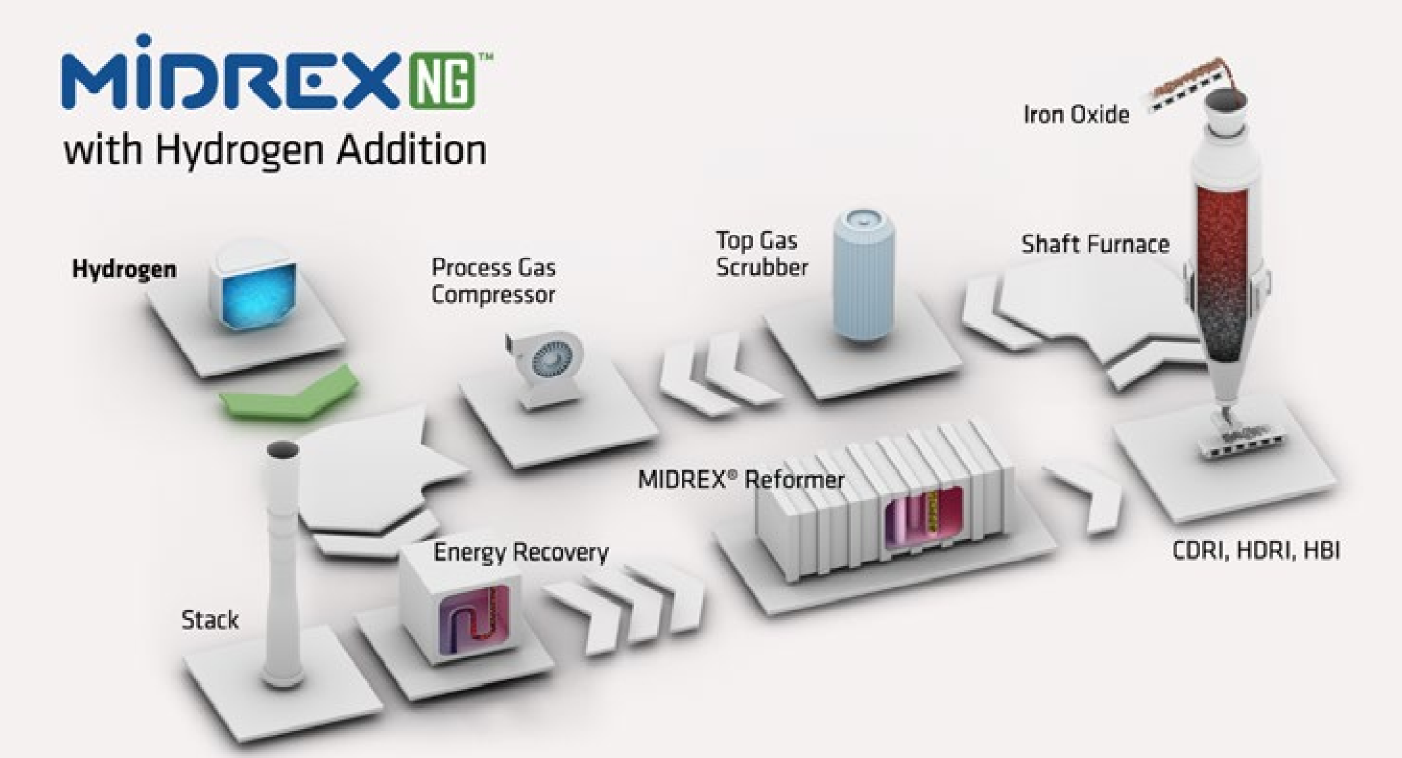


FIGURE 4. *MIDREX NG with Hydrogen Addition*

underlines the value of new investment in direct reduction plants: Whatever the future might hold in terms of emissions regulations or prices for raw materials, direct reduction technology allows for maximum adaptability.

HYDROGEN AND THE MIDREX PROCESS

MIDREX® Direct Reduction Plants produce roughly 60% of the world's DRI and have been available from Primetals Technologies for more than 30 years. The reducing gas – mainly a mixture of H_2 and CO – is produced from natural gas in a special CO_2 reformer. Without any modifications to the equipment, the process allows up to 30% of the natural gas to be replaced by hydrogen ***(Figure 4)***. For example, 60,000 Nm³/h of hydrogen could be brought in to substitute 20,000 Nm³/h of natural gas. With minimal modifications to the plant, the rate can reach as high as 100% - the limit determined by the required carbon content in the final product. The process can easily accommodate fluctuations in the hydrogen addition rate, allowing the plant to react to changing hydrogen supplies that are to be expected when sourcing the gas from water electrolysis with renewables like wind or solar.

MIDREX ON 100% HYDROGEN

If hydrogen is to be used as the sole reductant (MIDREX H_2™ configuration), the natural gas reformer can be replaced by a reduction gas heater ***(Figure 5, next page)***. Hydrogen will be converted to H_2O during reduction and condensed in the top gas scrubber. Since there is no source of CO in the process loop, there is no need for a CO_2 removal system. The process uses approximately 650 Nm³ of hydrogen per ton of DRI for reduction. Additionally, it requires about 250 Nm³ of H_2 per ton of DRI for heat, which can be accommodated also by other energy sources (e.g., electrical energy). Of course, in case a flexible utilization with hydrogen (0 – 100% hydrogen) and natural gas is required from the beginning, the plant can also be designed in such way to meet this demand as well.

CONCLUSION – A "GREEN" HYDROGEN REVOLUTION

To be a true game changer, the hydrogen used in the ironmaking process must be "green" hydrogen, generated by electrolysis from water, using fossil-free power only. To date, producing hydrogen in this way has proven too costly to be competitive. But this is changing, as the boom in renewable energy sources, such as wind and solar power, brings down global electricity prices and carbon capture, utilization, and storage (CCUS) technology offers a way to store energy in times of excess electricity production, i.e., when the wind

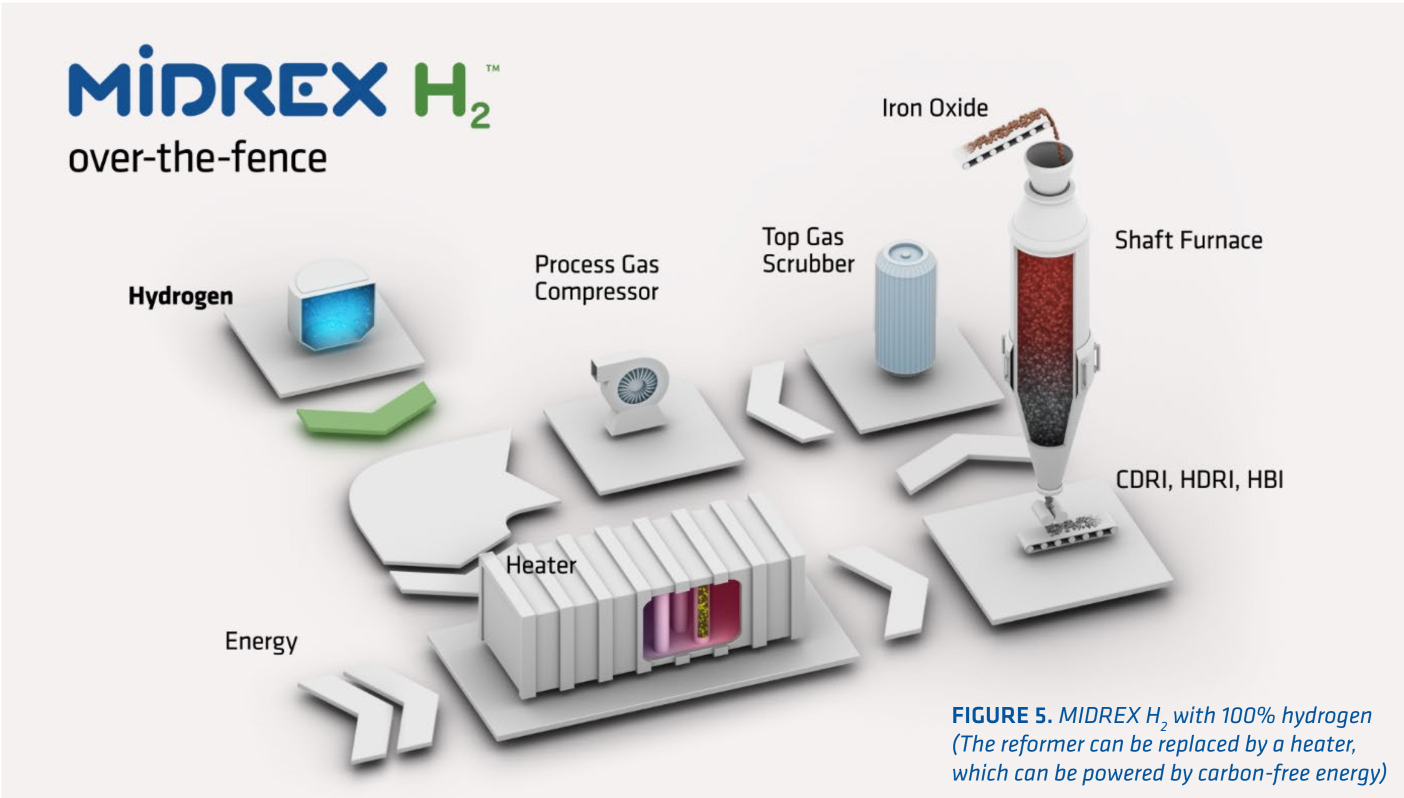
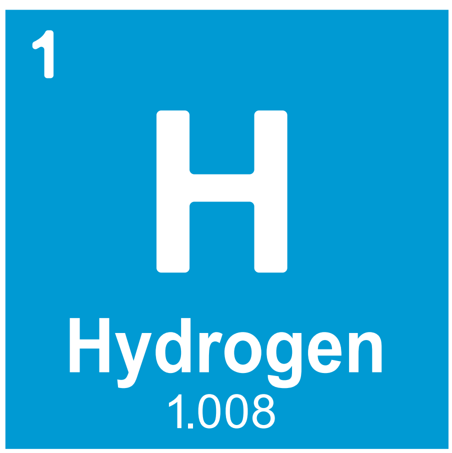


FIGURE 5. *MIDREX H_2 with 100% hydrogen (The reformer can be replaced by a heater, which can be powered by carbon-free energy)*

is blowing, or the sun is shining during times of low demand. Establishing a policy and financial incentive framework for adopting hydrogen is an essential part of this shift toward a more sustainable future – one which gives industry leaders the confidence to invest in long-term hydrogen projects.

Hydrogen is already part of the reduction gas mix in mainstream direct reduction processes. The flexibility of direct reduction processes provides an enticing way for plant owners to switch to hydrogen in a gradual fashion, increasing the addition of hydrogen over time as prices come down and supplies increase. It also underlines the value of new investment in direct reduction plants: Whatever the future might hold in terms of emissions regulations or prices for raw materials, direct reduction technology allows for maximum adaptability.



Using hydrogen to decarbonize ironmaking and other industrial processes is a powerful idea but not actually a new one. Leaders in the industry who are now nearing retirement may remember it vividly from their student days. There were peaks of interest in the 1970s during the oil price shocks, the 1990s with incipient concerns about climate change, and in the early 2000s on the same note. None of these developments resulted in a breakthrough moment for hydrogen. However, this time around may well be different, as the International Energy Agency (IEA) noted in a recent report, "last year marked a period of unprecedented momentum for hydrogen, combining a new depth of political enthusiasm with a breadth of new possibilities around the world."

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Article was adapted from articles originally published in Primetals Metals Magazine, January 2020, with supplemental figures supplied by Midrex Technologies.

The Colorful World of Hydrogen

(As defined by National Grid Group, London, UK)

HYDROGEN IS AN INVISIBLE GAS. HOWEVER, THE VARIOUS TYPES OF HYDROGEN HAVE BEEN GIVEN COLORFUL NICKNAMES WITHIN THE ENERGY INDUSTRY TO DIFFERENTIATE BETWEEN THEM:

GREEN HYDROGEN

Green hydrogen is the one produced with no harmful greenhouse gas (GHG) emissions. Green hydrogen is made by using clean electricity from surplus renewable energy sources, such as solar or wind power, to electrolyze water. Electrolyzers use an electrochemical reaction to split water into its components of hydrogen and oxygen, emitting zero-carbon dioxide in the process.

Green hydrogen currently makes up a small percentage of overall hydrogen because production is expensive. However, green hydrogen will come down in price as it becomes more common, as has energy from wind power.

BLUE HYDROGEN

Blue hydrogen is produced mainly from natural gas, using a process called steam reforming, which brings together natural gas and heated water in the form of steam. The output is hydrogen and carbon dioxide, as a by-product. That means carbon capture and storage (CCS) is essential to trap and store this carbon.

Blue hydrogen is sometimes described as "low-carbon hydrogen," as the steam reforming process doesn't actually avoid the creation of GHG.

GREY HYDROGEN

Grey hydrogen is created from natural gas, or methane, using steam methane reforming but without capturing the greenhouse gases made in the process. This is currently the most common form of hydrogen production.

BLACK & BROWN HYDROGEN

Black and brown hydrogen, made from black coal or lignite (brown coal) are the opposite of green hydrogen in the hydrogen spectrum and are the most environmentally damaging. Any hydrogen made from fossil fuels through the process of gasification is sometimes called black or brown hydrogen interchangeably.

PINK HYDROGEN

Pink hydrogen is generated through electrolysis powered by nuclear energy. Nuclear-produced hydrogen also are known as purple or red hydrogen.

TURQUOISE HYDROGEN

Turquoise hydrogen is made using a process called methane pyrolysis to produce hydrogen and solid carbon. This is a new entry in the hydrogen color chart and production has yet to be proven at scale. In the future, turquoise hydrogen may be valued as a low-emission hydrogen, depending on the thermal process being powered with renewable energy and the carbon being permanently stored or used.

YELLOW HYDROGEN

Yellow hydrogen is a relatively new designation for hydrogen made through electrolysis using solar power.

WHITE HYDROGEN

White hydrogen is a naturally-occurring geological hydrogen found in underground deposits and created through fracking.

Midrex News & Views

The full news articles are available on **www.midrex.com**

Contract signed for new HBI Plant at Lebedinsky GOK

Metalloinvest

Metalloinvest has contracted with Primetals Technologies Limited and consortium partner Midrex Technologies, Inc. to supply a new HBI plant (HBI-4) at Lebedinsky GOK (LGOK). The plant will be located in Gubkin, Russia, and will be designed to produce 2.08 million metric tons per of HBI (hot briquetted iron) per year. Its modern design features will ensure reduced energy consumption and environmental impact.

The contracted plant can be converted to use up to 100% hydrogen as a reducing agent, which makes possible further reduction of CO_2 emissions. Midrex and Primetals Technologies will be responsible for engineering, supply of main technological equipment, as well as for supervision services.

Investment in the construction of the plant is estimated at over USD 600 million. The project will create 375 highly qualified jobs and is expected to become operational in the first half of 2025 (first product – December 2024).

MIDREX HBI plants HBI-2 and HBI-3 at Lebedinsky GOK. HBI-4 will be built at the green field on the rear left side of this picture. (© Metalloinvest)

Congratulations TenarisSiderca on 45 Years!

TenarisSiderca, the Argentine division of Tenaris, the world's leading manufacturer of steel pipes for the energy industry, celebrated in October the start-up of its MIDREX® Direct Reduction Plant 45 years ago (October 1976). The plant, which is listed at 400,000 metric tons per year, achieved one of the highest shaft furnace productivity per unit volume rates for a MIDREX Plant in 2006 when it produced 939,000 tons of cold DRI (CDRI).

TenarisSiderca depends on its MIDREX Plant for iron units free of contaminants to supplement local scrap supply in the production of high quality oil country tubular steel.

Midrex recognizes the skill and dedication of the staff of the Tenaris Siderca MIDREX Plant and congratulates them and all those who have contributed through the years to this noteworthy achievement.

Jindal Shadeed Celebrates A Decade Of Operational Excellence

The MIDREX® Plant owned and operated by Jindal Shadeed Iron & Steel LLC (Jindal Shadeed) in Sohar, Oman, was started up four months ahead of schedule in December 2010, and is the first MIDREX Plant equipped with the HOTLINK® System for direct charging hot DRI (HDRI) into a close-coupled Electric Arc Furnace (EAF).

The plant has a rated annual capacity of 1.5 million tons (Mt) and is equipped with briquetting machines that allow HDRI to be made into Hot Briquetted Iron (HBI) for export or temporary stockpiling when the adjacent steel mill does not require material. Since 2017, Jindal Shadeed has equaled or exceeded its annual capacity and has produced a cumulative total of more than 15 Mt of HDRI and HBI despite limited natural gas availability for most of its first 10 years.

Following a shutdown for major maintenance and improvements in 2018, and with increased natural gas availability, Jindal Shadeed established a new annual production record in 2019 (16.5% more than rated capacity). The plant operated 8,245 hours in 2019 at an average of 212 tons per hour and twice broke monthly production records. A major portion (~89 %) of its annual production was consumed as HDRI in the Jindal Shadeed steel shop.

In 2020, the plant operated 15.4% above rated capacity and just 1% short of its 2019 record. Jindal Shadeed operated 8,389 hours in 2020, and set a new monthly production record in March. The major portion (~93 %) of its annual production was consumed as HDRI in the adjacent steel shop.

Lauren Lorraine: Editor

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