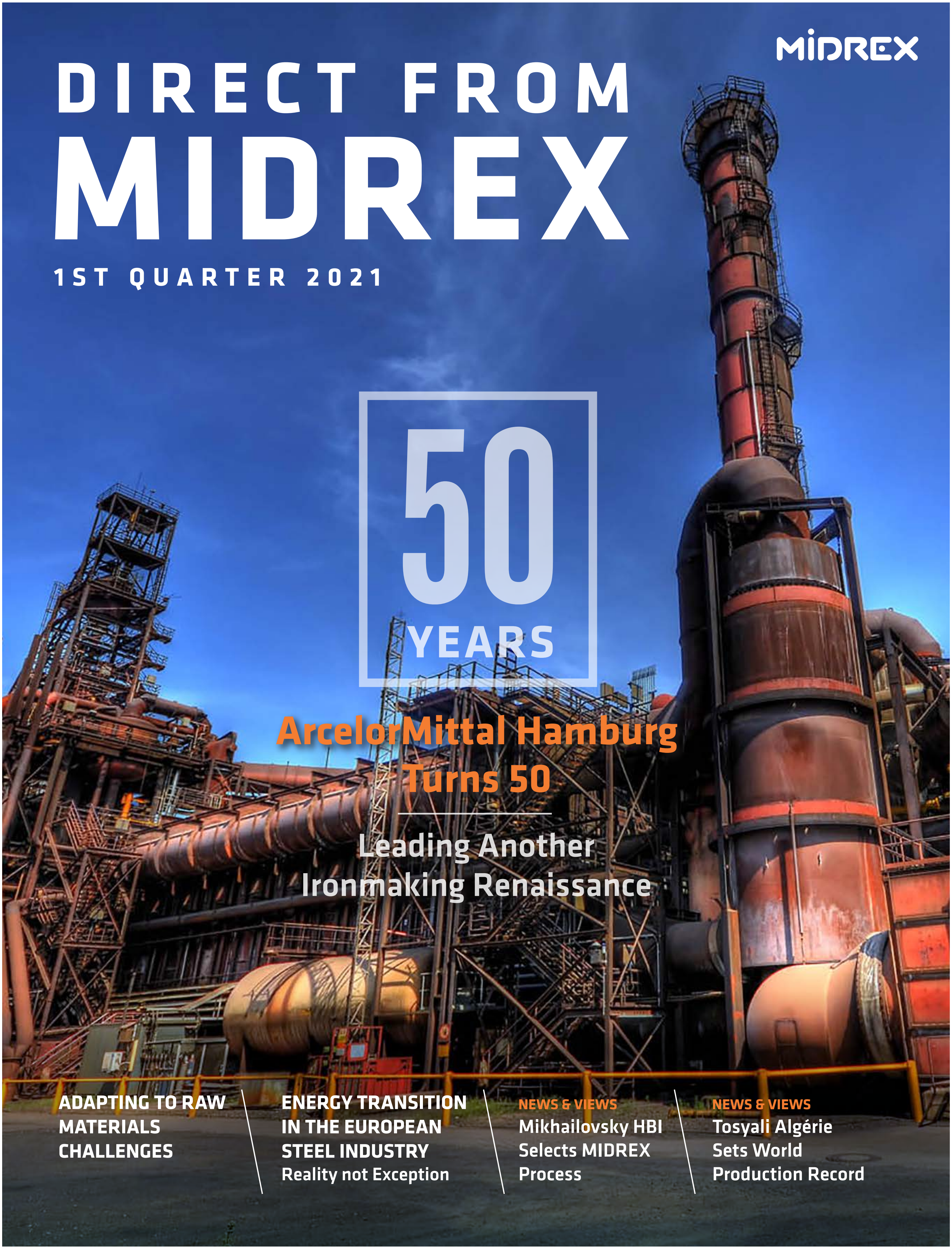

DIRECT FROM MIDREX

1ST QUARTER 2021

50 YEARS

ArcelorMittal Hamburg Turns 50

Leading Another Ironmaking Renaissance

ADAPTING TO RAW MATERIALS CHALLENGES

ENERGY TRANSITION IN THE EUROPEAN STEEL INDUSTRY
Reality not Exception

NEWS & VIEWS
Mikhailovsky HBI Selects MIDREX Process

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Tosyali Algérie Sets World Production Record

COMMENTARY

WHERE WE GO FROM HERE

By Stephen C. Montague
President & CEO

2020 brought changes that no one could have predicted and challenges that have significantly altered what we regarded as "normal." But as uncomfortable as change can be, it encourages innovation, and innovation drives progress. It motivates us to seek and create something better.

No one can make a completely accurate forecast of the future or predict exact timing of major events; that is why we track market trends carefully and count on our agility to make small course corrections along the way with the goal of achieving "sustainability" – the ability to maintain a certain rate or level of performance. But sustainability also means avoiding the depletion of natural resources in pursuing that performance. Our challenge, as an industry, is to seek and preserve a balance between the two.

Moving forward toward a better future involves more than new products and services. It involves caring for people – our teammates and those around us; being positive – in our attitudes and actions; and embracing change – being nimble and willing to make adjustments. Companies have two bottom lines: profits and people, and neither thrives without the other.

I was recently reminded of comments made by the late Dr. John Stubbles more than 20 years ago in an article he wrote for ***Direct From Midrex*** that are as relevant today as they were then: "We are on the threshold of perhaps the most exciting technical era the steel industry has ever known. The process options are mind-boggling; the potential furnace and mill designs imaginative; new products are waiting to happen."

The global awakening to environmental realities is driving research and development projects intended to lead to fossil fuel-free steelmaking. Midrex is involved in several such projects including ArcelorMittal in Hamburg, Germany, where we are working on a demonstration plant that will produce about 100,000 tons of direct reduced iron per year, initially with "grey" hydrogen sourced from natural gas. Conversion to "green" hydrogen from renewable energy sources will take place once it is 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.

We are also seeing increased interest among investors for building new natural gas-based MIDREX® Plants because they offer a solution for today and the right platform for the future. *(Editor's Note: Mikhailovsky HBI signed a contract recently with Primetals Technologies and Midrex Technologies to supply the world's largest HBI plant in Russia. See "**News & Views**" in this issue of **Direct From Midrex**.)* MIDREX NG offers an immediate reduction in CO_2 emissions compared with blast furnace ironmaking and can be easily adapted to replace natural gas with "green" hydrogen. Our solution, called MIDREX H_2, is ready to go as more hydrogen becomes available at competitive prices. The advent of hydrogen-based ironmaking and the increased use by DRI plants of iron oxide pellets containing lower percentages of iron (62-65%) will also encourage the development of a new type of electric melter, and we are already helping to develop solutions for that now.

I think John Stubbles would look around today and say, "I told you so." As we seek to move beyond the challenges of 2020, we must remain aware of opportunities, dedicated to our goals, and be willing to change.

→

This issue of *Direct From Midrex* includes three feature articles: Part 1 of a two-part series on the challenges of sourcing traditional DR-grade iron oxide pellets and the options available to MIDREX Plant operators; a description of one technology for developing e-fuel synthesis, an essential step in producing renewable, low cost hydrogen for iron and steel production; and a celebration of 50 years of operation by the ArcelorMittal Hamburg DRI plant.

ADAPTING TO RAW MATERIALS CHALLENGES

PART 1

OPERATING MIDREX PLANTS WITH LOWER GRADE PELLETS & LUMP ORES

By JOHN LINKLATER
Services Program Manager – Midrex Global Solutions

INTRODUCTION

The changing pricing of the different grades of raw material relative to each other that are available to charge a DR furnace combined with the effect of the different materials on EAF yield and consumption of consumables should be taken into account when looking at the overall effect of making a raw material change. It is not just a simple comparison of one raw material price versus another.

The worldwide production of direct reduced iron (DRI) has steadily increased over the last 50 years, with global production exceeding 100 million tons in 2019.[1] The increased production rates have resulted in an increased demand for direct reduction (DR)-grade pellets. This increased demand, combined with a reduction in DR-grade iron oxide production (due to the temporary closures at two pelletizing facilities), resulted in a shortage of DR-grade pellets in the first half of 2019. This, in turn, resulted in an increase of DR-grade pellet prices and made it difficult for some DR facilities to secure raw material. To make matters worse, as the cost of producing DRI and hot briquetted iron (HBI) increased due to rising raw material costs, steel prices declined worldwide, thus forcing DRI and HBI facilities to look for ways to reduce the cost of their products. Some facilities introduced or increased the use of lump ore in their feed-mix as a method to counter both the difficulty of securing DR-grade pellets and the rising costs. Other facilities began using blast furnace (BF)-grade pellets.

This article is the first of a two-part series that will investigate some of the things to take into consideration when using lower grade oxide pellets or lump ores to operate a MIDREX® Plant. In Part 1, we will look at how the chemistry of the iron oxide pellets affects the use of DRI/HBI in the EAF and the BF. We will explore what makes a pellet DR-grade and compare it with a BF-grade pellet, and discuss the advantages and disadvantages of lump ores and BF-pellets in the feed mix for making DRI products.

PART 1

DRI/HBI USE IN AN EAF VS. A BLAST FURNACE

In a blast furnace, the impurities (gangue) are removed by the formation of liquid slag. The DR process does not form a liquid slag and the impurities are concentrated instead of being removed, as illustrated in *Figure 1*.

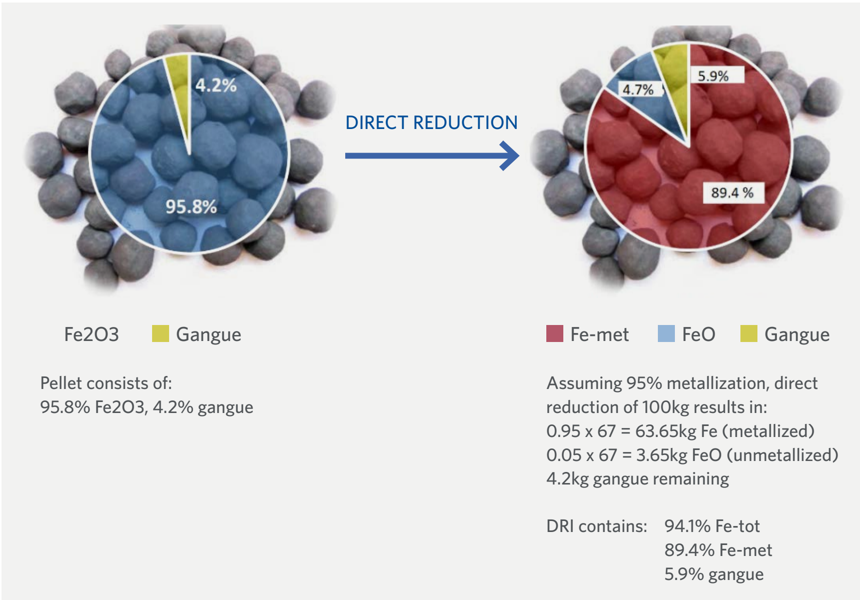

FIGURE 1. *Effect of reduction on gangue concentration[2] (Simplified calculation – factors such as carbon content and slag-formers in final DRI excluded)*

The chemical composition of the iron oxide/final product is of great importance in steelmaking because:

- High gangue content increases electrical power and refractory consumption in electric arc furnace (EAF) steel production.
- Lime, magnesia, silica, alumina, and titania affect the reducibility of the iron oxide and can impose a practical limit on the maximum degree of metallization that can be obtained.
- The maximum allowable sulfur content in the iron oxide for the MIDREX Direct Reduction Process is in the order of 0.01%. A significant level of sulfur release from the iron oxide will reduce the capacity of the reformer if sulfur absorbing equipment is not installed. Almost all commercially available oxide pellets have less than 0.01% sulfur and are suitable for direct reduction. Some types of lump ores contain 0.01% or less sulfur. Cold discharge plants can tolerate at least 0.03% sulfur in the feed, which is close to the acceptable limit for reduced product used for making steel.
- The mechanical properties of the oxide, such as crush strength or drop strength, impact the overall yield of the plant, as oxide fines/dust can be generated during handling and storage. They also affect the number of fines generated in the furnace, which reduces its yield of DRI product.

COMPARISON OF DR-GRADE VS. BLAST FURNACE IRON OXIDE PELLETS

It is important to realize the difference between DR-grade pellets, blast furnace pellets, and lump ore to fully understand the effect of substituting materials. From research and testing in plants by iron ore companies, it has been established that the optimum composition of a DR-grade oxide pellet depends on specific plant conditions. DR-grade pellets are the top tier of quality and come with a premium.

The following factors differentiate between the pellet grades:

- **Fe content** – DR-grade pellets contain 67% Fe or more versus blast furnace-grade pellets, which typically are 65% Fe or less. The higher the iron content, the lower the gangue – notably acidic components like SiO_2 and Al_2O_3. Because the majority of DRI/HBI is melted directly in an oxidizing steelmaking furnace, higher acid gangue will lead to a larger slag volume in the steelmaking furnace and higher iron losses to the slag. This is less of a concern for HBI that will be consumed in a blast furnace under highly reducing conditions. However, the higher Fe content may be needed to meet the density requirement for maritime transport.
- **Reducibility** – the degree of reduction has a significant impact on overall Fe yield. Factors that influence reduction of oxide pellets in the direct reduction shaft furnace are:
  - The gangue percentage will determine the degree of reduction that can be commercially achieved. The best way to evaluate the reducibility of a pellet is to test it in a laboratory.
  - Metallization or the degree of reduction of the pellet has an impact on the energy consumption of the EAF steelmaking furnace. DRI metallization is defined as the percentage of metallic iron in the reduced pellet divided by the total iron in the reduced pellet.

$$\text{Metallization \%} = \frac{Fe_{met}}{Fe_{total}} \times 100\%$$

- **Metallization** – Steelmaking EAFs are not well-suited for converting unreduced FeO to metallic iron. A reduction in metallization increases the required energy to melt the material. DRI or HBI with very low metallization may result in significant iron loss to the slag in the EAF.
- **General pellet chemistry** – The type and percentages of chemical elements will determine the tendency of pellets to stick and form clusters in the shaft furnace. Process upset conditions in the shaft furnace can result in significant iron unit loss to non-prime product, which may or may not be suitable for recycling through the shaft furnace.
- **Sulfur and phosphorus content** – High S and/or P levels in the DRI/HBI may require different slag practices in the EAF to remove the contaminants. There can be product yield loss increases in the slag.

MECHANICAL PROPERTIES

The oxide pellet chemistry and pellet production process will influence the mechanical strength of both the oxide pellet and the resulting reduced pellet. The strength of CDRI pellets are typically 25% to 35% that of the parent oxide pellet. DRI and HBI strength is evaluated by:

- **Tumble test** – standard test
- **Drop test** – nonstandard

The International Iron Metallics Association (IIMA) has published a Quality Assessment Guide available on their website **(www.metallics.org)**.

Mechanical properties will vary from pellet to pellet according to a normal distribution, as illustrated in *Figure 2.*

In some cases, DRI can have a large standard deviation for properties like crushing strength. For most ores and DR furnace operating conditions, there is some percentage of DRI pellets that will break with very low compression force or impact energy. A material with a very high average crushing strength but with 10% of material having very low strength is not necessarily ideal. It is important to consider not only the average strength of the DRI but also the standard deviation and minimum values. This is a demonstration of the importance of ore selection.

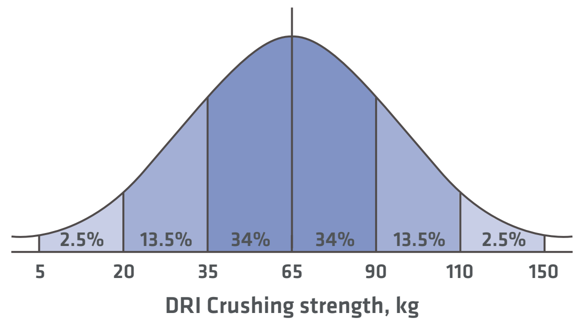

FIGURE 2. *Hypothetic distribution of CDRI pellet crush strength*

Key factors between a DR-grade pellet and a typical blast furnace grade pellet are listed in *Table 1*[2]:

CHEMICAL PROPERTIES

DR-Grade Pellets	Blast Furnace Grade Pellets	Lump Iron Ore
High Iron Content Fe, total iron > 67%.	Fe, total iron 63 - 65%.	Fe, total iron > 67%. (becoming more difficult to source)
Acidic Gangue: Silica SiO_2 1.0 - 3.0 Alumina Al_2O_3 0.2 – 3.0	Acidic Gangue Silica SiO_2 2.5 – 5.3 Alumina Al_2O_3 0.4	Acidic Gangue: Silica SiO_2 1.0 - 3.0 Alumina Al_2O_3 0.2 – 3.0
Basicity 4 (CaO+MgO) (SiO_2+Al_2O_3) Magnesia MgO 0.2 – 0.9 Lime CaO 0.4 – 1.2	Basicity 4 (CaO+MgO) (SiO_2+Al_2O) Magnesia MgO 0.3 – 1.5 Lime CaO 0.6 – 3.6	Basicity 4 (CaO+MgO) (SiO_2+Al_2O_3) Magnesia MgO 0.2 – 0.9 Lime CaO 0.4 – 1.2 Usually required to be added in steelmaking process

PHYSICAL CHARACTERISTICS

DR-Grade Pellets		Blast Furnace Grade Pellets		Lump Iron Ore	
Particle Size Distribution		Particle Size Distribution		Particle Size Distribution	
+16	6.8%	+16	7.3%	+53	0%
+12.7	56.7%	+12.7	56.9%	+37.5	2.4%
+9.53	94.3%	+9.53	92.9%	+31.5	13.2%
+9x16	87.5%	+9x16	85.6%	+25	35.5%
Large to small size ratio	1.33	Large to small size ratio	1.37	+22.5	43.7%
+6.73	97.7%	+6.73	96.6%	+19	58.5%
-3.36	1.7%	-3.36	2.3%	+12.7	85.2%
				+6.73	96.9%
				+3.36	98.8%
				-3.36	1.2%
Low Fines Generation		Higher fines generation than DR-grade		Higher fines generation	
Linder Reduction Metallization (%) - 96.8 Carbon (%) - 1.5		Linder Reduction Metallization (%) - 95.4 Carbon (%) - 1.7		Linder Reduction Metallization (%) - 96.7 Carbon (%) - 1.0	

TABLE 1: *Pellet & Lump Ore Characteristics and Chemical Properties*

COST STRUCTURE OF DR-GRADE IRON OXIDE

DR-Grade pellet pricing structure is made up of several components:

- Linked to the China CFR fines pricing
- Fe content pricing adjustment
- Freight costs
- DR pellet premium

An example is shown in *Figure 3*.

The price of DR-grade oxide pellets carries a premium. The reason for premium is primarily due to:

- **Cost of beneficiation**
  - Upgrading run of mine iron ore to DR-grade is expensive. Note: DRI manufacturers have been pushing for higher quality DR-grade pellets.
  - Additional energy and investment costs for beneficiation technology.
  - Higher yield losses associated with increased beneficiation.
- **Supply Restriction**
  - High quality ore is more difficult to reach
  - DR-grade raw material monopolized by limited suppliers

MATERIAL ALTERNATIVES

At the time of writing this article, the DR-grade premium increases appeared to indicate a shortage in supply. The pricing increases have resulted in facilities looking at methods to reduce their raw material costs. The first apparent choices that appear to be available to a direct reduction facility to cut material costs or negate material shortages are:

- Include or increase lump ore in the feed mix
- Use blast furnace pellets instead of DR-grade pellets either partially or totally.

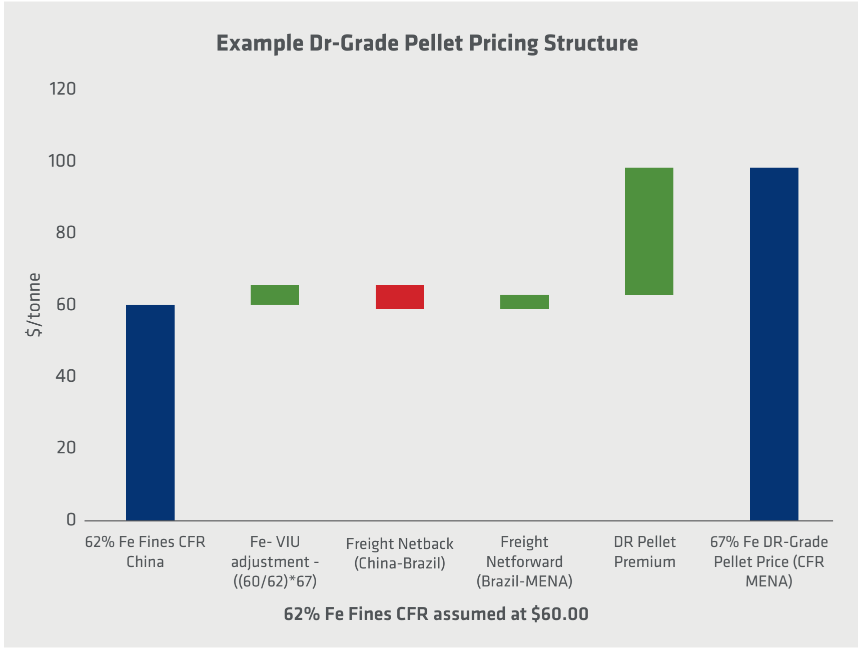

FIGURE 3. *Pricing Structure for DR-Grade Oxide Pellets*[3]

IMPLEMENTING AN ALTERNATIVE MATERIAL

Each of these two immediate feedstock alternatives for a direct reduction plant has its own challenges, which will be looked at below.

Lump Ore

High-grade lump ore is becoming increasingly more difficult to obtain with these ore bodies either in more remote locations, or miners are having to go deeper to mine them. There are several MIDREX Plants that are currently feeding lump ore in combination with DR-grade oxide pellets. Some of the advantages and disadvantages are:

The Advantages of Using Lump Ore

- There can be a financial advantage in using lump ore if premium lump can be obtained.
- The original Midrex designs assumed a 70%/30% pellet/lump mix without a loss in production
- Increasing lump when pellets have not been correctly coated has allowed an increase in bed temperature by reducing "sticking" tendency. However, this advantage is lost if the pellets are correctly coated.
- In merchant HBI plants, the addition of lump ore promotes a higher quality briquette. This can be attributed to an increase in fines in the furnace, which are beneficial to the formation of briquettes.
- Uniform (small deviation in size) lump size can help increase the performance of the plant due to improved bed permeability.

The Disadvantages of Using Lump Ore

- One disadvantage of using lump ore is increased fines generation. This will vary depending on the lump ore characteristics. Generating additional fines in the furnace would have the following effects:
  - Increases the furnace delta (Δ) P.
  - Can promote channeling.
  - Increases yield losses by 1-2%. This is confined to losses in top gas scrubber in a briquette plant. Yield losses would offset any financial advantages and need to be accounted for.
  - Furnace refractory wall buildup due to increased fines.
  - Potential buildup in bustle ports.
- Lump ore also can change the chemistry and impact the final product. When moving to lump ore, attention should be paid to the chemical properties. Some lump has been found to contain high sulfur, which in turn:
  - Temporarily poisons the catalyst in the reformer.
  - Changes water chemistry.
- If lump size is not controlled and has a deviation in size, this can cause uneven flow and non-uniform bed temperatures by promoting channeling of the reducing gases in the MIDREX Shaft Furnace.
- Depending on the lump ore purchased, the bed temperatures might need to be reduced and the NG/ton increased to compensate. This is dependent on how "sticky" the ore is and the quality of the lime coating on the DR-grade pellets.

BLAST FURNACE GRADE PELLETS

There are several grades of blast furnace pellets available, each with its own chemical and physical properties, again showing the importance of laboratory or basket testing:

- Acid blast furnace
- Fluxed blast furnace
- Low Fe blast furnace

The Advantage Of Using Blast Furnace Grade Pellets

- Financial – depends on the price spread between BF-grade and DR-grade premiums. However, the pricing is usually higher than lump ore.

The Disadvantages Of Using Blast Furnace -Grade Pellets

- Lower metallics – reduces liquid steel yield in the EAF
- Increased fines generation – will vary depending on the pellet. Generating additional fines in the furnace would have the following effects:
  - Increases the furnace delta (Δ) P – this requires checking of system pressure (lost seals), PG compressor sizing, and seal gas system sizing.
  - Can promote channeling.
  - Increases yield losses by 1-2%. This is confined to losses in top gas scrubber in a briquette plant. Yield losses would offset any financial advantages and need to be accounted for.
  - Furnace refractory wall buildup due to increased fines.
  - Potential buildup in bustle ports.
- Reduction in productivity – typically increases cost per ton of DRI.
- Might require an increase in lime coating of the pellets.

→

Editor's Note: Part 2 will present 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 will document the method used to adapt to an alternative raw materials strategy and the results that were achieved. Part 2 will conclude with a series summary.

References:

1. 2017 World Direct Reduction Statistics. (2018, May 31). Retrieved from https://midrex.com/assets/user/newsMidrexStatsBook2017.5_.24_.18_.pdf
2. Midrex testing
3. https://www.metalbulletin.com

ArcelorMittal Hamburg Turns 50

Leading Another Ironmaking Renaissance

By ANTHONY ELLIOT
Manager-
Technical Services

GREG WALKER
Project Manager-
Global Solutions

INTRODUCTION

When Willy Korf built Badische Stahlwerke (BSW), his first so-called 'mini-mill' in Kehl in 1968, his large competitors tried to squeeze him out by limiting the availability of scrap steel to use in its electric arc furnace (EAF). He knew that if his revolutionary approach to steel production was to survive and succeed, it would need a source of metallic iron to relieve its dependence on scrap supplies. It so happened that Midland-Ross in the USA was introducing a new direct reduction process, known as MIDREX®, about the same time...and the rest is history.

A PLACE IN DR INDUSTRY HISTORY

When Hamburger Stahlwerke (HSW) was built in south Hamburg in 1970, a MIDREX Plant was included in the project. The plant would supply direct reduced iron (DRI) for the HSW EAF melt shop and also to Korf's BSW mill. The MIDREX Plant was started up in October 1971, and has produced over 18 million tons of DRI in its illustrious 50 years of operation.

The HSW DRI-EAF steelworks was inaugurated in April 1972, and by November 1975, had produced one million tons of wire rods. Today, the steelworks is owned and operated by the ArcelorMittal Group as ArcelorMittal Hamburg and is one of Germany's largest wire rod producers and a leading company worldwide for producing wire rods by the mini-mill concept.

LN Mittal acquired HSW in 1995 and renamed it ISPAT HSW. Through the years, the company name has changed several times, as Mittal expanded his steel operations, culminating with the merger with Arcelor to form the ArcelorMittal Group. The steel mill, which can produce 250 grades of steel, has undergone several upgrades and modifications to increase its liquid steel and wire rod

ArcelorMittal Hamburg, located on the bank of the Elbe River

capacity. Likewise, the MIDREX Plant has been modernized to make it capable of over 600,000 tons/year of DRI (Note: the plant was originally built with a rated capacity of 400,000 t/y).

DRI makes up an average of 45% of the iron charge to the ArcelorMittal Hamburg melt shop. The DRI plant has the lowest annual electricity consumption of all MIDREX Plants and includes a unique system that pneumatically conveys DRI fines and dust from the MIDREX Plant to the melt shop, where they are injected into the EAF.

LEADING ROLE IN THE FUTURE OF IRON & STEELMAKING

The ArcelorMittal Group has developed a low-emissions technology strategy to permanently reduce CO_2 emissions, which targets not only the use of alternative feedstocks but also the direct avoidance of carbon (Carbon Direct Avoidance, CDA). As one aspect of its strategy, ArcelorMittal has launched a first-of-its-kind project in its Hamburg steelworks to use hydrogen on an industrial scale for the direct reduction of iron ore for use in the steel production process. The Hamburg works already has one of the most energy-efficient production processes of the ArcelorMittal Group due to the production and use of natural gas-based DRI. The aim of the new hydrogen-based process is to enable steel production with the lowest CO_2 emissions.

ArcelorMittal commissioned Midrex in September 2019, to design a demonstration plant at its Hamburg site to produce steel with hydrogen. The companies will cooperate on several projects, ranging from research and development to the implementation of new technologies. The first project, incorporating the expertise of Midrex and ArcelorMittal, will demonstrate the large-scale production and use of DRI made with almost 100% hydrogen.

"Our Hamburg site offers optimum conditions for this innovative project: an electric arc furnace with DRI system and iron ore pellets stockyard, as well as decades of know-how in this area," Frank Schulz, CEO of ArcelorMittal Germany, said. "The use of hydrogen as a reducing agent shall now be tested in a new shaft furnace."

From 2023 onwards, the demonstration plant will produce about 100,000 tons of direct reduced iron per year, initially with "grey" hydrogen sourced from natural gas, and later – once available in sufficient quantities and at economical cost – with "green" hydrogen from renewable energy sources.

"With Midrex technology, we have been producing high quality steel in an efficient and innovative way for 50 years," Dr. Uwe Braun, CEO of ArcelorMitall Hamburg, said. "The possibilities of this technology are still not exhausted and we are working together to make steel production fit for a sustainable future through the direct reduction of iron ore with hydrogen. The innovation capacity of DRI technology is enormous, and its potential has not yet been fully developed. We are convinced that we can still achieve a lot with this technology in order

ArcelorMittal Hamburg

MIDREX CDRI Plant
Location: Hamburg, Germany
Start-up: 1971
Cumulative Production: 18+ million
(through 2019)

to produce excellent steel in a climate-neutral manner".

Dr. Braun continued to say, "Our site is the most energy-efficient production plant in the ArcelorMittal Group. The existing MIDREX Plant in Hamburg is already the plant with the lowest CO_2 emissions for high quality steel production in Europe. With the new hydrogen-based DRI plant, we will raise steel production to a completely new level, as part of our worldwide ambition to be carbon neutral by 2050."

"We are delighted to work with ArcelorMittal", Stephen C. Montague, President and CEO of Midrex Technologies, Inc, said. "ArcelorMittal now operates six plants with MIDREX direct reduced iron technology. With number seven, we're going to lead the way in using renewable energy to make DRI for steel production.

"It's only fitting that we and ArcelorMittal have teamed up for this first step towards carbon neutral steel production on an industrial scale," Montague observed. "We are proud that they have chosen to take this momentous step with us."

ENERGY TRANSITION
IN THE EUROPEAN STEEL INDUSTRY
REALITY NOT EXCEPTION

By HORST KAPPES & INGO BOTH,
Paul Wurth S.A. (Luxembourg)

INTRODUCTION

The German Steel Industry sent an open letter to the policy makers in Berlin and Brussels in mid-2017, hoping to receive some relaxation with regard to Emission Trading Cost and final CO_2 emission targets, but to no avail. This was a turning point for the industry. Together with the acceptance of the reality of climate change, it became obvious that the time for CO_2 emission reduction measures has come. Today every steel producer in Europe has made commitments to reduce its CO_2 footprint and each of the programs includes direct reduction plants and the use of renewable hydrogen as the reducing agent.

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. BF/BOF emissions can be 1.6-2.0 kg CO_2/kg steel depending on the technologies used. The natural gas-based MIDREX® Process paired with an EAF has the lowest CO_2 emissions of any commercially proven steelmaking route using virgin iron ore at 1.1 – 1.2 kg CO_2/kg steel. By adding a CO_2 removal system, the MIDREX Process can lower CO_2 emissions even further to less than 1/3 of the emissions from the BF/BOF route if CO_2 can be stored and/or used.

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 reducing the steel industry's CO_2 footprint is the use of 'green' hydrogen produced from renewable energy for DRI production.

> **"When steam can be preferably generated from waste heat sources, such as in steelmaking, high temperature electrolysis is the most efficient technology."**
>
> *Prof. Dr.-Ing. Heinz Jörg Fuhrmann, Chief Executive Officer and Chairman of the Executive Board of Salzgitter AG*

'GREEN' HYDROGEN

Developing efficient electrolyser technology to maturity is a precondition for successful energy transition. In early 2019, Paul Wurth acquired a 20% participation in Sunfire, a leading developer of steam electrolysers for the production of renewable, low-cost industrial hydrogen. The motivation was to actively support and develop fossil-free ironmaking, a critical step in hydrogen-based steel production.

Electrolysis, which uses electricity to split water into hydrogen and oxygen, is a promising technology for hydrogen production on an industrial scale. 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 three constraints for its industrial use: 1) in most countries, electricity is generated primarily with fossil fuels so there remains a large overall CO_2 footprint, 2) hydrogen from electrolysis is not currently available in the volumes required for large industrial users like steelmaking and 3) the cost of hydrogen is too high for many applications at prevailing electricity prices.

There are several technologies at various levels of technical readiness to produce hydrogen from water. One of the most promising of these is solid oxide electrolysis cell (SOEC).

	HYLINK SOEC
Hydrogen production	
Net production rate	750 Nm^3/h
Production capacity dynamic range	5% ... 100%
Hot idle ramp time	< 10 min
Delivery pressure	1 ... 40 bar (g) after compression
Hydrogen purity	up to 99.99% after gas cleaning
Power input and electrical efficiency	
System power consumption (AC)	2,680 kW
Specific power consumption at stack level (DC)*	3.3 kWh/Nm^3
Specific power consumption at system level (AC)*	3.6 kWh/Nm^3
System electrical efficiency**	84%
Steam input	
Consumption	860 kg/h
Temperature	150°C ... 200°C
Pressure	3.5 bar (g) ... 5.5 br (g)
Other specs	
Footprint***	~ 300 m^2
Ambient temperature	-20°C ... 40°C

* Power consumption at ambient pressure
** Lower heating value of hydrogen referred to AC power input
*** Average space requirement for a 2.68 MW system comprising all auxiliary systems

TABLE I. *Sunfire-Hylink SOEC Process Technical Details*

These cells work at high temperature (around 800°C). Sunfire´s electrolysers require 26-28% less electricity, compared to alternative technologies, meaning that 35-40% less renewable energy is necessary for the same H_2 output. Condition to this is the availability of low quality steam (e.g. 140 °C, 3 bar), which can be easily recovered from waste heat sources in metallurgical plants.

Another feature of Sunfire's electrolysers is the capability of producing syngas (CO and H_2) when being fed with CO_2 and steam. This process is called co-electrolysis. Interesting

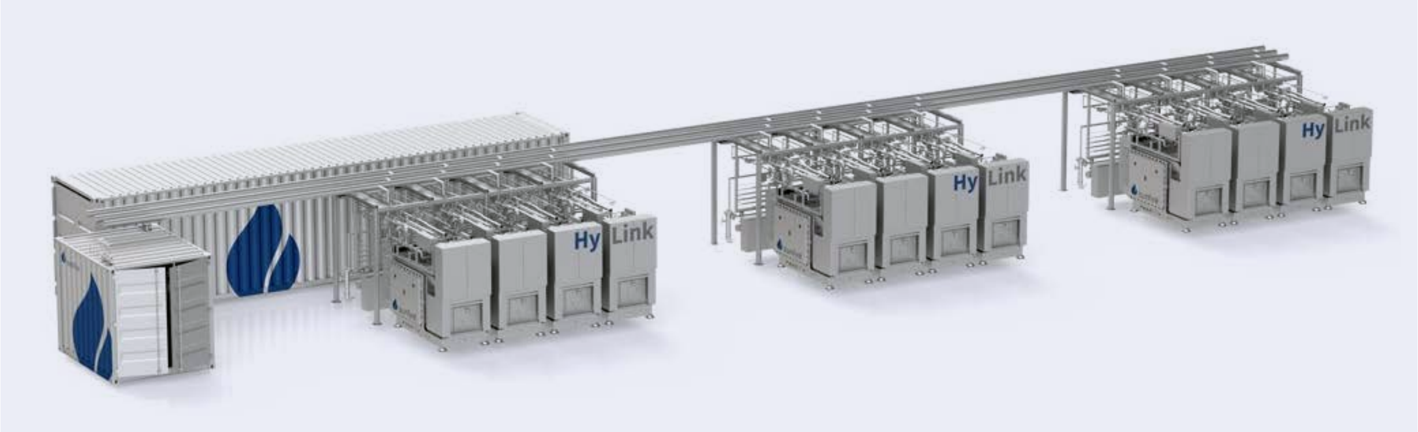

FIGURE 1. *Standard Sunfire-Hylink SOEC Unit*

SUNFIRE-HYLINK SOEC COMPETITIVE ADVANTAGES

- **Cost-Efficient** - Heat utilization makes system ultra-efficient (η > 80 per cent LHV)
- **Productive** - Promises extremely low hydrogen production costs compared to legacy technology (< 3 €/kg), depending on electricity prices
- **Flexible** - Hydrogen production can be changed from part load to full load (5 to 100%) flexibly, in a short timeframe
- **Modular** - Modular design to meet customer's demand for hydrogen
- **Pure** - Renewable electricity and steam for pure hydrogen (99.999 percent)

applications are at hand for metallurgical plants, as well as other domains like synthetic fuel production, using CO_2 from unavoidable CO_2 sources.

A standard Sunfire-Hylink SOEC unit of the 3 MW class is shown in ***Figure 1 (previous page)***.

TABLE I (previous page) shows the technical details of Sunfire-Hylink SOEC process.

Alkaline electrolysis, another technology for producing hydrogen from water, has been used at commercial scale for decades and is well proven. Recently Sunfire acquired Swiss Alkaline Electrolysis Company IHT, which designs and manufactures one of the most reliable and cost effective alkaline electrolysers in the market. IHT has a legacy of more than 70 years of experience worldwide and brings with it a reference plant capacity of 240 MW.

With its two differentiated electrolysis technologies – SOEC and Alkaline – Sunfire can offer the optimal solution for any hydrogen application and strengthens its position as a leading electrolysis technology provider in the green hydrogen revolution. Technical details of Sunfire-Hylink Alkaline process are shown in TABLE II.

	HYLINK ALKALINE
Hydrogen production	
Production rate	1,065 ... 1,090 Nm³/h
Production capacity dynamic range	15% ... 100%
Delivery pressure	5 ... 30 bar (g) without compression
Hydrogen purity	up to 99.999% after gas cleaning
Operation temperature	up to 90°C
Power input and electrical efficiency	
System power consumption (AC)	5,000 kW
Specific power consumption at stack level (DC)*	4.4 ... 4.5 kWh/Nm³
Specific power consumption at system level (AC)*	4.6 ... 4.7 kWh/Nm³
System electrical efficiency**	64 ... 65%
Feedstock	
Water consumption	1m³/h
Elecrtrolyte	25 ... 30% KOH aqueous solution
Other specs	
Proven system runtime	> 20 years
Stack lifetime	up to 90,000 h
Footprint***	~ 300 m²
Ambient temperature	5°C ... 40°C

* Power consumption at operational pressure of 5 or 30 bar (g)
** Lower heating value of hydrogen referred to AC power input
*** Average space requirement for a 5.0 MW system comprising all auxiliary systems

TABLE II. *Sunfire-Hylink Alkaline Process Details*

FIGURE 2. *Standard Stack Sunfire-Hylink Alkaline Unit*

A standard stack Sunfire-Hylink Alkaline unit of 5 MW scale is shown in ***Figure 2***.

HYDROGEN FOR IRONMAKING

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 significantly lower infrastructure cost per volume of gas. Steel mills also have the ability to integrate hydrogen generation with other utilities available on site, such as steam and other gases.

MIDREX Plants already use large amounts of hydrogen produced from reformed natural gas to convert iron oxide into DRI and can be adapted to accommodate more hydrogen as it becomes more available and economically priced. Currently, there are six MIDREX Modules that utilize gas made from coal, with hydrogen-to-CO ratios from 0.37 to 0.56. The FMO MIDREX Plant in Venezuela uses a steam reformer with an H_2/CO ratio that has varied from 3.3 to 3.8 and has operated for decades. Thus, the MIDREX Process has successfully produced DRI with H_2/CO corresponding to the range of 40% to 50% natural gas substitution with hydrogen.

The MIDREX Process has the flexibility to allow the addition of hydrogen to displace natural gas in the feed gas in the range of 0% to 100% with only minor equipment modifications. If hydrogen is abundant and economical at the onset of the project development, the process can be simplified into MIDREX H_2™ ***(Figure 3)***.

Feed Gas		100% Natural Gas	Natural Gas replacement by Hydrogen			100% Hydrogen
			20%	50%	70%	
Reducing Gas	H_2	55%	62%	72%	77%	100%
	CO	35%	28%	18%	13%	0%
	Others	10% (mostly CO_2, H_2O, CH_4, N_2)				
	H_2/CO	1.6	2.2	4.0	5.9	n/a
Carbon in DRI		2.5% 4% w/ ACT	~ 1.5%	~ 1.0%	~ 0.5%	0%
CO_2 emissions (kg_{CO2} /t_{DRI}) *		500 < 250 w/CCUS **	400	250	150	From heater (if fuled by hydrocarbons)

* only includes CO_2 emissions from flue gas (largest source)
** CCUS = carbon capture for Utilization and Storage

FIGURE 3. *MIDREX Process Using Hydrogen*

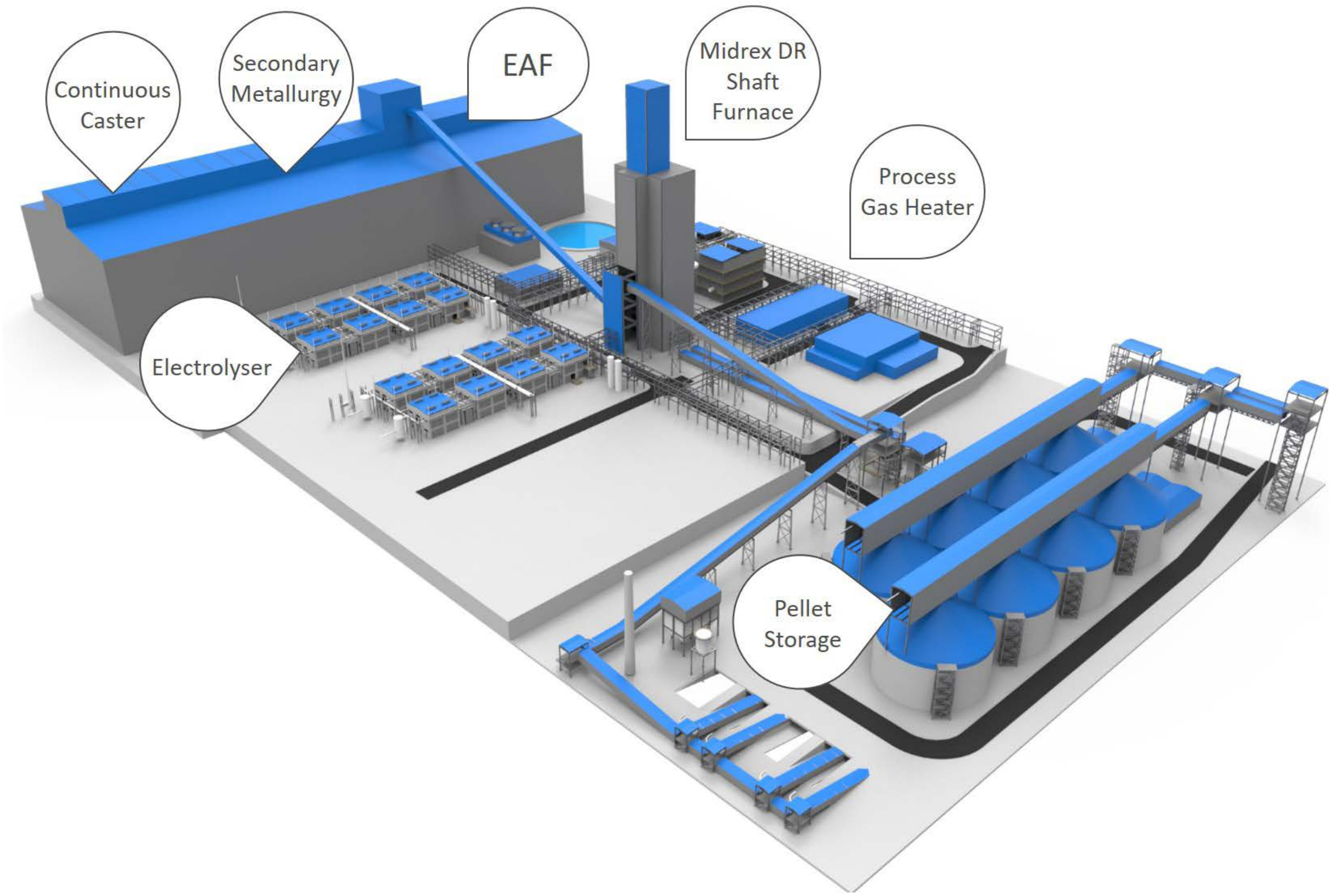

FIGURE 4. *Layout of Fossil-free Integrated DR-EAF Steel Mill with MIDREX H_2 Plant Fueled by Sunfire Electrolysers*

CONCLUSION

Producing iron via the traditional blast furnace route is a large contributor to the emission of greenhouse gases, notably CO_2. Mitigating CO_2 emissions in the iron and steel industry is becoming critical worldwide, as the cost and social impact of CO_2 emissions increases over time. The best possibility for reducing the steel industry's CO_2 footprint is the use of hydrogen as an energy source and reductant in the MIDREX Process for producing direct reduced iron (DRI).

Today, reduction of CO_2 emissions by 50% (over BF/BOF) is achievable and well proven in the DRI-EAF steelmaking route. The MIDREX Process can accept 'green' hydrogen produced from water electrolysis as it becomes available and economical, which will further reduce CO_2 emissions.

Paul Wurth has invested in Sunfire-Hylink, a German electrolyser technology company, in order to produce renewable, low-cost industrial hydrogen. This 'green' hydrogen can be used to support and develop fossil fuel-free ironmaking, and a Sunfire facility could provide the hydrogen for a MIDREX H_2 Plant in a fossil fuel-free steel mill of the future ***(Figure 4).***

Midrex News & Views

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

Mikhailovsky HBI Selects MIDREX Process for World´s Largest HBI Plant

Mikhailovsky HBI, which was jointly established by USM and Mikhailovsky GOK (part of Metalloinvest), has signed a contract with Primetals Technologies and consortium partner Midrex Technologies, Inc. to supply a new Hot Briquetted Iron (HBI) Plant in Zheleznogorsk, Kursk region, Russia. The plant will be designed to produce 2.08 million metric tons of HBI per year. Latest design features will ensure reduced energy consumption and environmental impact. The contract includes engineering, supplies and advisory services. Startup is expected in the first half of 2024.

PICTURED AT THE CONTRACT SIGNING ARE (left to right): ***Aashish Gupta,*** *Executive Vice President and Head of Global Business Unit – Upstream, Primetals Technologies;* ***Etsuro Hirai,*** *Chief Technology Officer of Primetals Technologies and CEO of Primetals Technologies Austria;* ***Nazim Efendiev,*** *CEO of Management Company Metalloinvest;* ***Pavel Mitrofanov,*** *Deputy CEO of USM; and* ***Stephen Montague,*** *President and CEO of Midrex*

Tosyali Algérie Sets World Production Record

Tosyali Algérie A.Ş. (Tosyali), utilizing MIDREX® Technology, in only its second full year of operation, produced more than 2.23 million tons of direct reduced iron (DRI) in 2020, which is a world record for a single direct reduction module. The 2.5 million tons per year (t/y) DRI plant began using hot DRI (HDRI) at the electric arc furnace (EAF) melt shop in February 2019. HDRI made up almost 72% of total production in 2020 (1.6 million tons), with average metallization of about 94% and carbon averaging around 2.2%. Iron ore pellets feeding the DRI plant were supplied predominately by Tosyali Algérie's own 4.0 million t/y pellet plant on site.

Midrex News & Views

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Sean Boyle to Manage Midrex Sales In North America & Europe

SEAN BOYLE

Sean Boyle has been promoted to the position of Key Account Manager - North America/Europe. In his new role, Sean will be responsible for managing all Plant Sales and Aftermarket opportunities for new and existing clients in these regions. Boyle joined Midrex in 2013 as a Mechanical Engineer and served most recently as Manager - Special Projects.

Midrex Gulf Services Recommended for ISO Certification

Midrex Technologies Gulf Services FZCO

Midrex Gulf Services FZCO (Dubai) completed its initial ISO 9001:2015 Certification Audit in January 2021, with no non-conformity findings and the recommendation for certification. It was noted that MGS well exceeded audit standards and had identified and developed the quality documents specific to their operating process and were fully prepared to substantiate their answers to the auditor's questions.

Lauren Lorraine: Editor
Vincent Chevrier, PhD: Technical Advisor

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