MIDREX

DIRECT FROM MIDREX

3RD QUARTER 2021

HBI-C-FLEX PROJECT: Addressing a Challenge to the HBI Value Chain

40 YEARS OF DIRECT FROM MIDREX

NEWS & VIEWS 2020 World DRI Production Exceeds 104 Mt

COMMENTARY

HBI: THE MULTI-PURPOSE METALLIC

By David Durnovich
General Manager – Global Solutions
Midrex Technologies, Inc.

Here we are today touting natural gas-based Hot Briquetted Iron (HBI) as the immediate, transitional solution to CO_2 emissions by blast furnaces (see the article in this issue titled, "HBI: Steel's Most Versatile Metallic In the Transition to the Hydrogen Economy"). If we look back almost 40 years to 4Q1982, Midrex was introducing HBI as "A New Product For Big Steel" and promoting its value for thermal balancing and trim cooling in the Basic Oxygen Furnace (BOF).

Through the years, Direct Reduced Iron (DRI) has been identified primarily as a low residual charge material for the Electric Arc Furnace (EAF). However, the increased density of HBI has extended the productivity and environmental benefits of DRI to the Blast Furnace (BF).

HBI is recognized as the preferred form of DRI for ocean transport by the International Maritime Organization (IMO) in its International Maritime Solid Bulk Cargoes (IMSBC) Code. As such, it is shipped from plants located in Russia, MENA Region, Venezuela, USA, and Malaysia, to steel producers throughout the world.

Initially, the use of HBI in the BF was seen as a way to enrich the metallic charge to the BF, as productivity was the driving factor of the time. Two integrated steel mills in the USA used approximately 385,000 tons of HBI in 1993 and increased their usage to close to 500,000 in 1994. One of the mills, AK Steel, reported a productivity increase of more than 22% by operating with HBI as part of the BF metallic charge.

Today, the focus has shifted to reducing CO_2 emissions from BF operations. HBI, which is metallized beyond 90% only needs to be melted; therefore, HBI use in the BF decreases the consumption of reducing agents. It has been demonstrated that a 10% increase in the metallization of the BF burden results in a 7% decrease in the coke rate, which in turn reduces CO_2 emissions. If 100kg HBI/t HM is used, the reducing agent rate (coke equivalent) can be decreased by approx. 25kg/t HM.

However, the productivity boost from adding HBI to the BF charge is still a highly sought-after benefit. voestalpine Stahl, has found that productivity can be increased up to 10% per 100kg HBI/t HM by using HBI from its MIDREX Plant near Corpus Christi, Texas, in its BFs in Linz, Austria (see the article by voestalpine Stahl in 3Q2020 DFM for further details).

I was fortunate enough to be involved in the start-up and operation of the first MIDREX® HBI Plant on Labuan Island, Sabah FT, Malaysia, that was owned by Sabah Gas Industries. The plant made its first commercial shipment of HBI in 1984. In 2020, the plant, now known as Antara Steel Mills (HBI Labuan), operated over its annual rated capacity (650,000 tons/year) and came within 6% of setting an annual production record. Total iron of its HBI was the highest of all MIDREX Plants, averaging 93.04% for the year. All production was shipped by water to third parties.

So, here's to you HBI – the steel industry's most versatile ore-based metallic (OBM). Whether you operate an EAF or a BF/BOF, there is a benefit waiting for you in the use of HBI. It also can be used in Ladle Metallurgy and foundry induction furnaces. The International Iron Metallics Association (IIMA) is studying what they call HBI-C-Flex (see the article by Chris Barrington in this issue) and Midrex is evaluating various forms of HBI.

HBI is truly the multi-purpose metallic, and it will play an ever increasing role as we transition to the Hydrogen Economy.

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This issue of *Direct From Midrex* includes articles about HBI: how it will play a significant role in the decarbonization of the global steel industry, and a project sponsored by the International Iron Metallics Association (IIMA) called HBI-C-Flex, as well as an article recognizing the 40th anniversary of DFM. In addition, the News & Views section contains noteworthy Midrex-related events occurring during 3Q2021.

HBI: STEEL'S MOST VERSATILE METALLIC IN THE TRANSITION TO THE HYDROGEN ECONOMY

By SEAN BOYLE
Key Account Manager - North America/Europe

INTRODUCTION

It is difficult to have a conversation in the steel industry today without the word "hydrogen" coming up and how hydrogen will be used to decarbonize the steel industry. Much is being said and written about needing to achieve carbon-neutrality by 2050, as well as the many challenges and obstacles to reaching that goal. But few suggestions are being offered for what can be done in the immediate future to lower CO_2 emissions that will have the least impact on the financial sustainability of steelmakers – especially those operating traditional integrated mills (coke oven/blast furnace/basic oxygen furnace) to produce high quality metallic iron for steel production.

Carbon-neutral steelmaking is coming, but it will not happen overnight. It will take time for steel producers to adapt their standard operating procedures to the new reality of hydrogen steelmaking. For BF/BOF steelmaking, gradual decarbonization by using natural-gas based Hot Briquetted Iron (HBI) is the most immediate and effective method for reducing CO_2 emissions now available to the steel industry. HBI use will not only reduce CO_2 emissions but also increase BF productivity.

This article will talk briefly about longer term plans for decarbonizing the steel industry with hydrogen and the challenges associated with it but will focus on how HBI, already regarded as "steel's most versatile metallic," is contributing to efforts to reduce CO_2 emissions and could do more moving forward toward the Hydrogen Economy.

THE CARBON CHALLENGE

Carbon has been used for centuries to make steel, and for a good reason – it is the alloying element in producing steel from iron (Fe). Carbon (C) and oxygen (O_2) are used to provide the energy and lower the melting point and therefore, the energy required to melt the iron. So, it's a thermodynamic fact that some form of carbon is going to be required to make steel ***(see Figure 1)***. That is one reason why carbon-neutral steelmaking is a more accurate term and a lot more likely to be achieved as hydrogen is increasingly used in basic steelmaking.

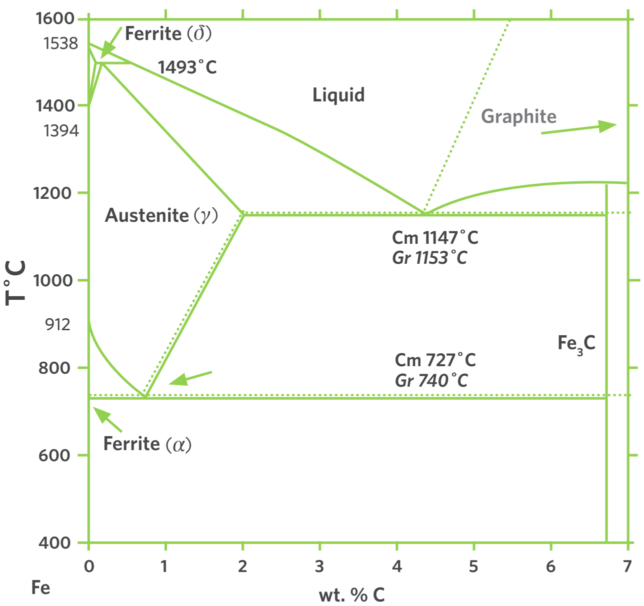

FIGURE 1. *Thermodynamics of Steelmaking*

On a macro basis, there are three ways to lower the CO_2 emitted during iron and steel production:

1. reduce energy consumption so less energy (and carbon) is required per ton of steel
2. sequester the CO_2 underground, either in storage or for enhanced oil recovery
3. use an energy source with less carbon than coal

Option 1 has been a serious focus for many years. Since 1980, the USA steel industry has reduced energy consumption per ton of steel by almost 50%. However, further gains are increasingly difficult, as the processes become more and more efficient.

Option 2 is being developed, and has great promise. However, there are practical limitations, environmental issues, and political entanglements to overcome.

Option 3 may be the most promising and practical solution for significantly reducing carbon emissions in the near-term. Clean-burning natural gas is an attractive alternative energy source and reductant to coal and coke.

All of the energy sources currently used for ironmaking – except natural gas – share an important characteristic: they are comprised almost totally of carbon and generate lots of carbon dioxide as a by-product. Traditional coke-based ironmaking produces from 1.6 to 2.2 tons of CO_2 per ton of iron. On the other hand, natural gas, which is primarily methane (CH_4), has four hydrogen atoms for each carbon atom and therefore, a higher proportion of carbon-to-hydrogen. Since almost all the carbon and hydrogen used in an iron and steelmaking facility is eventually converted to CO_2 and H_2O (water), natural gas produces much less CO_2 than does coal.

Table 1 shows the CO_2 emission rates for combusting methane versus two types of coal.

CO_2 EMISSIONS		
Energy Source	(t/TJ)	(lbs/MMBtu)
Natural gas (CH4)	49	115
Bituminous metallurgical coal	90	212
Bituminous steam coal	94	220

TABLE 1. *CO_2 Emissions for Iron and Steelmaking Energy Sources*

As the table shows, natural gas emits only about one-half the CO_2 per unit of energy as does coal. When iron is reduced with coke or charcoal, each atom of oxygen in the iron oxide (iron ore) requires one atom of carbon. In a blast furnace, the carbon from the coke or charcoal is first partially oxidized to carbon monoxide (CO) using gaseous oxygen (O_2). The oxygen is provided by blast air (heated air enriched with additional oxygen) then injected into the blast furnace at the tuyeres. The carbon monoxide diffuses into the highly porous ore and collects an additional oxygen atom from the iron oxide, creating metallic iron (Fe) and forming carbon dioxide (CO_2).

When methane is used, each molecule of CH_4 is first reformed into one carbon monoxide molecule (CO) and two hydrogen molecules (H_2). Each of these three molecules will take one oxygen atom from each molecule of CH_4, and each of these three molecules will take one oxygen atom from the iron oxide. So, the products of the reduction reaction are two water molecules (H_2O) and one carbon dioxide molecule (CO_2). In other words, only one-third as much CO_2 is generated.

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"If it were possible to produce the entire world's iron with natural gas direct reduction plants, over one billion tons of CO_2 could be avoided per year."

Robert Hunter, *3-4Q2009 Direct From Midrex*

Near Future (Transition):
NG/H_2 based DRI + EAF

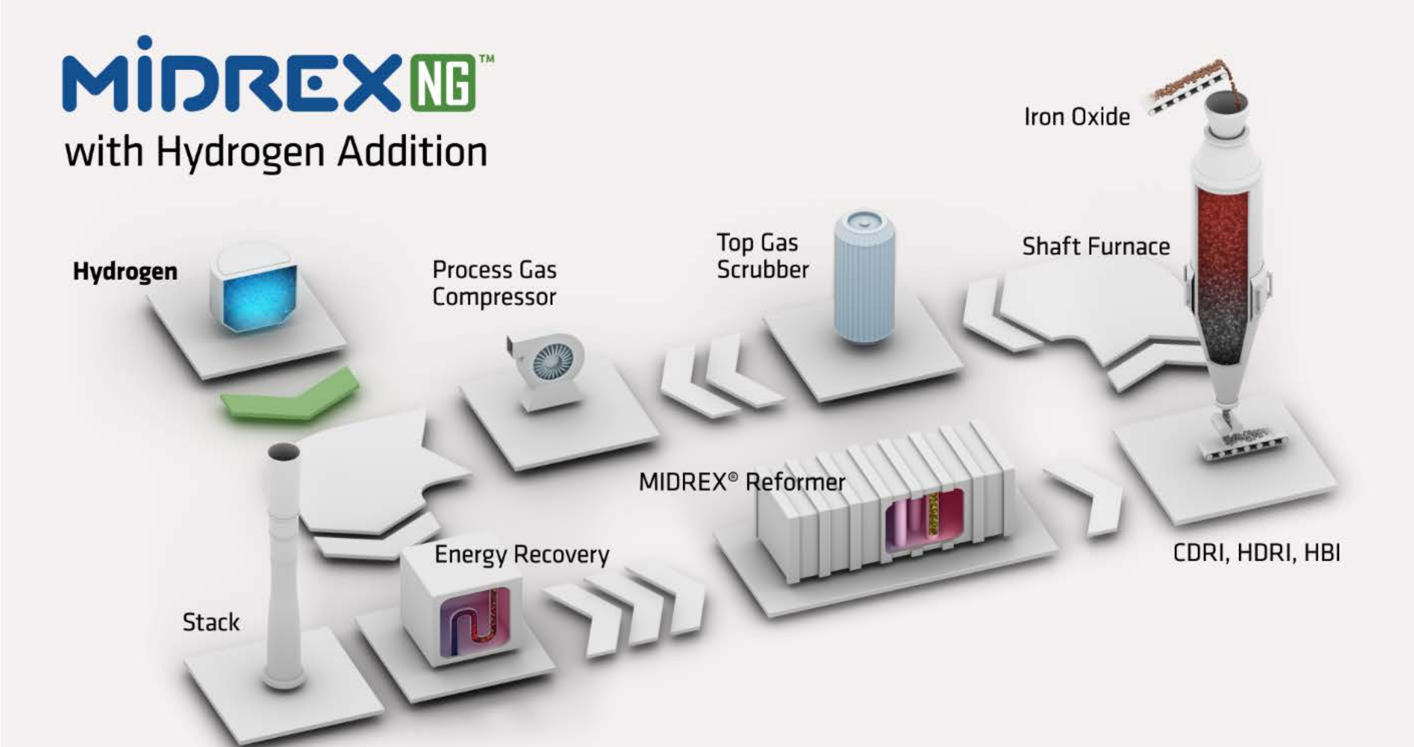


FIGURE 2. *MIDREX NG with Hydrogen Addition*

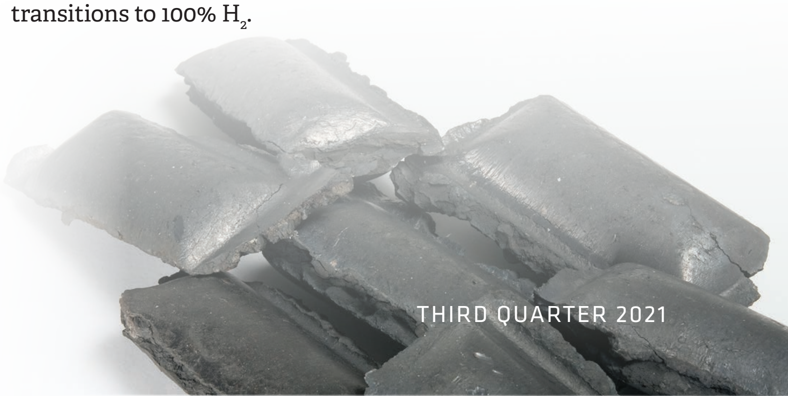
HYDROGEN-BASED DIRECT REDUCTION

Before talking specifically about HBI and how it can contribute to a reduction in CO_2 emissions, let's briefly look at using hydrogen to produce DRI products (cold DRI [CDRI], hot DRI [HDRI], and HBI) and some of the major challenges that this route has before it is viable.

MIDREX® Plants already use ~55% hydrogen in the reducing gas, with some plants using up to 80% H_2. The hydrogen is derived from the reforming of natural gas.

Figure 2 and ***Figure 3*** show flowsheets that illustrate the near-term transition to H_2 addition in a MIDREX NG™ (natural gas) Plant and the future use of 100% H_2. ***In Figure 2***, a desired amount of additional hydrogen is introduced. The key piece of equipment to highlight is the MIDREX Reformer, which performs two major functions: 1) reforming the natural gas and CO_2 to H_2 and CO, and 2) heating the reducing gas. The reformer is adaptable for the entire transition from 0% H_2 up to 100% H_2 – it becomes purely a heater when using 100% H_2 ***(see Figure 3)***.

The flowsheet in ***Figure 3*** is for a plant designed from the beginning to operate with 100% hydrogen – known as MIDREX H2™ – and shows the Reformer being replaced with a Heater. The flowsheet is basically the same and includes the same equipment, but the design basis for some equipment has changed. Hydrogen has a lower molecular weight than the typical process gas in a MIDREX NG Plant, so the Process Gas Compressors will be modified. The design of the Top Gas Scrubber is modified to handle the additional water being condensed out of the top gas from the furnace due to the higher percentage of hydrogen. Also, the design of the heat recovery is optimized for a given set of operating conditions that will change as the MIDREX Process transitions to 100% H_2.



Future:
H_2 DRI + EAF

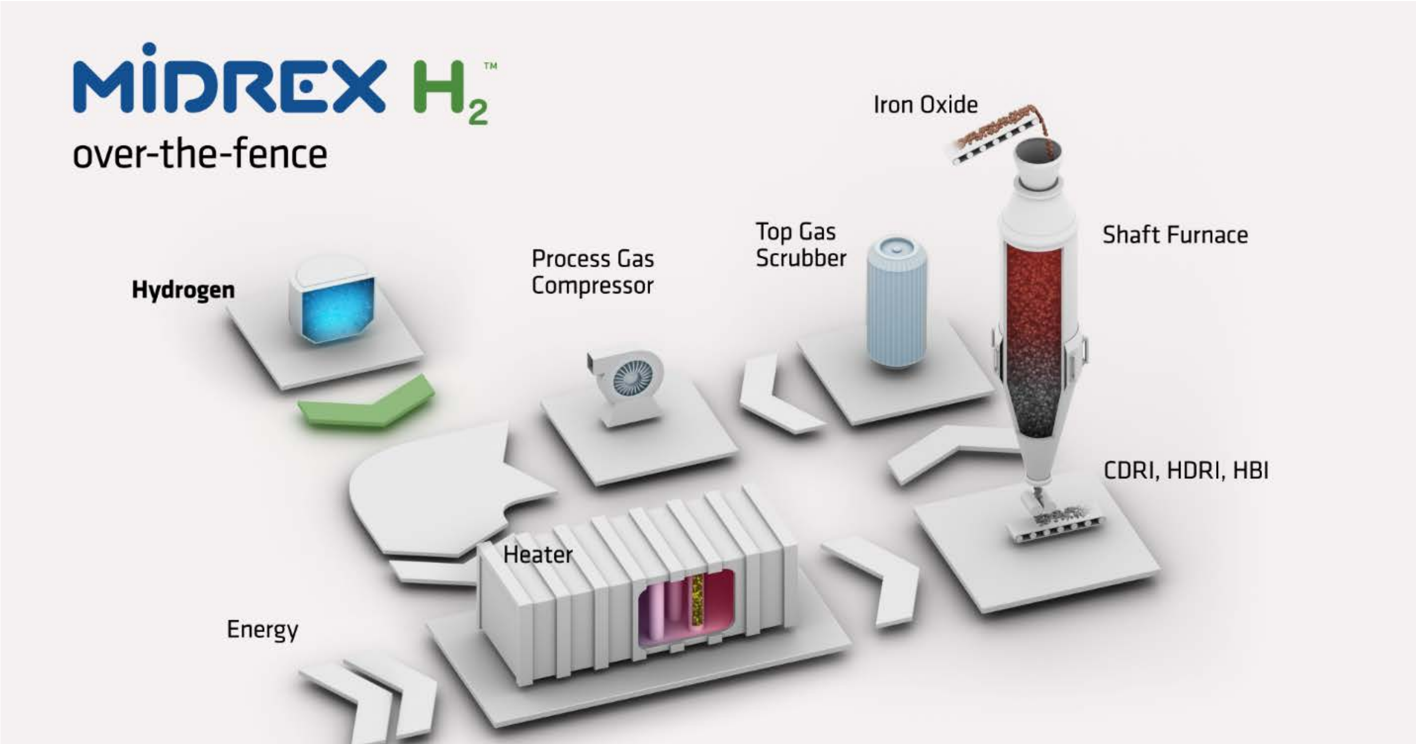


FIGURE 3. *MIDREX H2*

The expected consumption of hydrogen in a MIDREX H2 Plant is 600-650 Nm³/t DRI (54-58 kg/t DRI) for process requirements only. Therefore, a 2.0 million tons/year plant would require an 800 MW electrolyzer – electrolyzer capacity that has yet to be demonstrated commercially (assuming 200 Nm³/h of H_2 per 1 MWh).

It's not that electrolyzer technology is not available; it's the manufacturing of the equipment that is lagging. Current manufacturing just can't support this level of production. Also, the cost of electrolysis units is still very high and there is a wide range among suppliers.

When the capital cost of electrolyzers and the current price of electricity are looked at together ***(Figure 4)***, it is obvious that significant improvements are required to make hydrogen-based iron and steelmaking the economical choice.

Given these figures, the price of hydrogen would need to be below $0.50/kg to be competitive with a natural-gas based MIDREX Plant (assuming a natural gas price of $4.0/MMBtu).

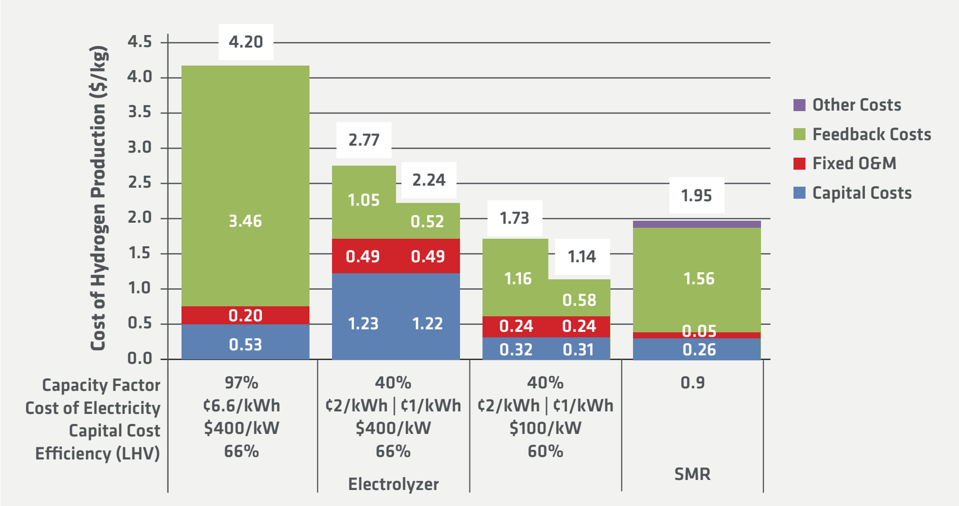


FIGURE 4. *Cost Challenge of H2 Iron & Steelmaking* [(1)]

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> "Natural gas is hydrogen in disguise"
>
> Lourenco Goncalves, CEO, Cleveland-Cliffs, Inc.

A PRACTICAL WAY TO KEEP BFS OPERATING

A report issued in June 2021 by Global Energy Monitor, recommended that three main targets need to be met by the global steel sector to align with the goal for mid-century global energy net-zero carbon emissions:

1. Steelmaking capacity needs to be aggressively shifted from the dominant blast furnace-basic oxygen furnace (BF-BOF) steelmaking route to electric arc furnace (EAF) steelmaking.
2. All remaining BF-BOFs need to be outfitted with best available technology (BAT) or retired; and
3. Novel low-emissions and net-zero steelmaking technologies, including hydrogen-DRI production, need rapid development, scaling up, and deployment.[2]

Replacing the BF/BOF steel making route with DRI/EAF would significantly reduce CO_2 emissions, but the capital expenditures would be enormous, not to mention the disruption due to construction time, learning curves, and the required shifts in corporate cultures. However, keep in mind that in order for iron and steelmaking to be carbon-neutral, the power source also needs to be carbon-neutral – and that is even a bigger challenge than decarbonizing the steel industry.

The use of HBI in the BF to reduce CO_2 emissions should be considered Best Available Method (BAM) if not Best Available Technology (BAT). It has been proven to reduce CO_2 emissions 20% or more.

HBI is the densified form of DRI that is ideal for ocean carriage due to its resistance to water pick-up (reduced risk of oxidation) and for use as a metallic charge to the BF and BOF due to its increased mass and density. HBI is made by compressing DRI discharged hot (≥ 650˚ C) into pillow-shaped briquettes typically 30x50x100 mm in size with a density of ≥ 5 g/cm³. No binder is required in the production of HBI by the MIDREX Process.

HBI has been around for decades but its full impact is just beginning to be realized by the steel industry. Environmental and productivity gains using HBI in the various steel production routes are well-documented. Typically, HBI contains over 90% Fe (with metallization up to 96%) and therefore, these metallics do not require further reducing in the BF; they only need to be melted. In addition to providing a method to reduce CO_2 emissions, charging HBI into a BF is a way to increase productivity when a steel mill either needs to make up for a shortage of hot metal demand in relation to the BF/caster capacity or to provide sufficient hot metal during a reline or repair of a BF. In fact, using HBI in the BF charge may be the best chance to keep some integrated steel works in operation for years to come.

HBI USE IN THE BF

The parent company of Midrex, Kobe Steel, Ltd. (KSL), has combined the direct reduction technology of Midrex and the KSL engineering business with the blast furnace operation technology and know-how of Kobe Steel's iron and steel business to demonstrate an enhanced method of BF operation. The KSL technology envisions charging up to 30% HBI produced with a hydrogen-rich gas to significantly lower coke rate and thus, reduce CO_2 emissions ***(Figure 5)***.

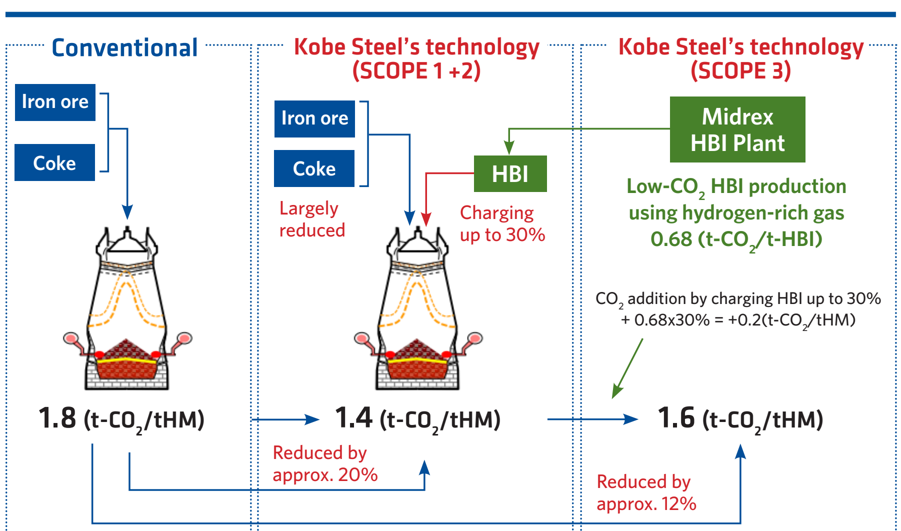


FIGURE 5. *Kobe Steel Technology for BF Operation with HBI Produced with Hydrogen-rich Gas* [3]

KSL recently performed a demonstration using 305 kg of HBI per ton of hot metal (THM), which translated into a 20% reduction in the reducing agent rate from 518 kg/THM to 415 kg/THM ***(Figure 6)***.

The coke rate was reduced during the demonstration test by 85 kg/THM, to a world's lowest level of 239 kg/THM ***(Figure 7)***. The coke rate was an improvement of more than 20% over the previous test with HBI, which lowered the rate by 34 kg/THM. With coke priced at $400/t, that is a savings of $32/THM in coke alone.

An example of how HBI is being used in BFs and the benefits it provides is voestalpine in Linz, Austria, which uses HBI from its own plant in Corpus Christi, Texas, USA, ***(Figure 8, below)*** in its blast furnaces.

The use of different charging rates of HBI in the Linz BFs was examined over the period from 2017-01-01 to 2018-01-31 based on daily average data. When 100 kg HBI/t HM is charged to the BF, the following conclusions can be drawn:

1. Reducing agents (CE) can be decreased by 21.9 - 27.5 kg/t HM, whereas the coke rate can be decreased by 10.9 - 18.1 kg/t HM.
2. Productivity can be increased up to 7.3 - 10.1% at constant oxygen levels.
3. Gas utilization drops by approximately 0.4 - 1.1% because HBI is a pre-reduced material and less oxide is charged to the BF. The decrease in quantity of charged oxide also reduces the quantity of CO and H2 which are transformed into CO_2 and H_2O.
4. The calorific value of top gas rises by 12.3 - 23.5 Wh/Nm^3 due to the higher contents of CO and H_2.

FIGURE 8. *voestalpine Texas HBI Plant*

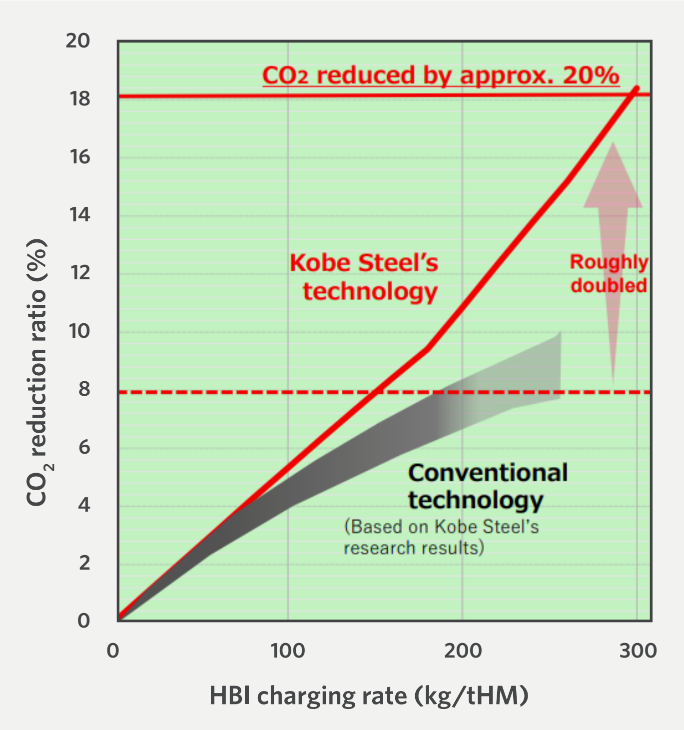


FIGURE 6. *CO_2 Reduction in BF Operations [3]*

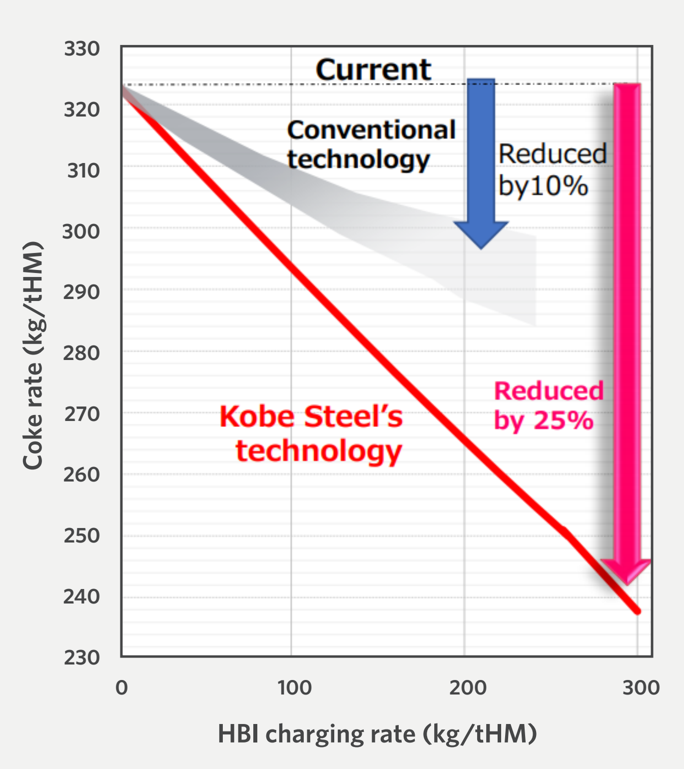


FIGURE 7. *Reduction in Coke Rate Using HBI [3]*

5. A correlation between the top gas temperature, cooling apacity, and permeability and the use of HBI cannot be seen.
6. The S-content of hot metal is lower and C-content higher (high quality) with a charge of 100 - 150 kg HBI/t HM compared to when no HBI is charged. The S- and C-content in hot metal does not depend only on the charged HBI quantity, which reduces the sulfur containing reducing agents, but also on other factors, such as the slag rate, the quantity and nature of the high S-content recycling material, and the melting rate. [4]

SOURCING HBI

If we accept that the most effective, currently available means of lowering the amount of CO_2 generated by the steel industry is to use HBI produced by a natural gas-based direct reduction plant in the BF, the important question becomes: "How to source HBI?"

HBI can be sourced two ways by an integrated steel mill: 1) buy HBI from a dedicated merchant HBI plant or from a DRI plant with the capability to produce HBI; or 2) build a natural gas-based DRI plant with HBI capabilities either onsite near steelmaking operations or off-shore where there are sufficient supplies of reasonably priced natural gas.

For most BF producers, merchant HBI plants are the most obvious sources of supply. Merchant HBI allows those who do not wish to own and operate their own plant to purchase material in the open market. To date, BF operators have chosen to obtain HBI in this manner. HBI plants dedicated to merchant supply exist in Venezuela, Libya, Russia, Malaysia, and US ***(Figure 9, next page)***. With the exception of Russia, HBI supply has shipments have been limited for several of these suppliers due to political and economic issues. Although DRI plants equipped with briquetting machines have the capability of producing HBI, their first priority is to supply hot DRI (HDRI) to their own steel operations. Therefore, BF operators would be subject to the uncertainty of the spot market.

To have greater control of HBI supply, without having to rely on merchant sources would require building a dedicated facility, as some EAF steelmakers have historically done. In regions where natural gas is not readily available or sufficiently allocated for HBI production, off-shore sourcing may be a practical option. Europe is the first to pursue the off-shore HBI sourcing solution, but it will not be the last. BF producers in India and China, who are faced with limited or high cost natural gas, much like in Europe, have an even greater incentive to search for ways to decrease smog derived from the burning of coal.

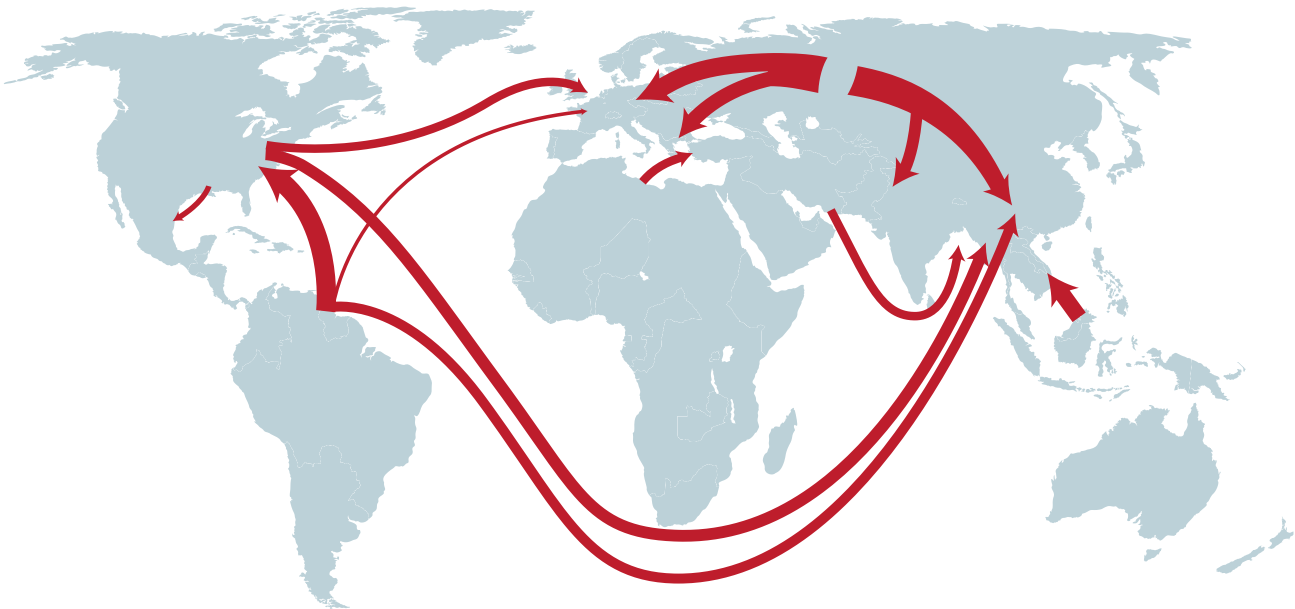
CONCLUSION

Sustainability is ultimately the key issue for every steelmaker going into the future. DRI products, which until recently have been viewed by integrated steelmakers as an EAF-specific charge material, may actually present a long-term, scalable solution going forward. The use of HBI as a charge material in the blast furnace is now being seen as an effective way to help displace CO_2 emissions while increasing hot metal production of the BF.

Investing either directly or through long-term supply contracts in natural gas-based direct reduction plants to make HBI in strategically-located sites around the globe is a reality. The voestalpine Texas plant, the plants at LGOK in Russia, the original MIDREX HBI Plant in Labuan, Sabah, Malaysia, and newest HBI plant owned and operated by Cleveland-Cliffs, Inc., are producing and shipping millions of tons each year.

The BF market shows tremendous potential for merchant HBI sales. However, the amount of HBI available to the merchant market is extremely limited. In order to meet even the most conservative estimate of future demand, additional HBI plants need to be built. Midrex has been the leading supplier of HBI technology since the early 1980s and looks forward to supplying the additional capacity that will be needed with the broadest range of energy and raw materials options in the industry.

Major Trade Routes for International Trade of DRI Products



The map shows the major routes of international transport of DRI in 2020. The width of the lines indicates the amount of DRI products that traveled over the individual routes. **NOTE: Domestic and smaller trade routes are not shown.**

The arrows do not originate and terminate at specific countries. Rather, sums for dispatch and arrival were totaled by region and the arrows flow from region to region. For instance, the wide arrow originating from the north coast of South America shows DRI and HBI coming from the Caribbean (Venezuela plus Trinidad and Tobago) and being transported to North America, Asia and Europe.

FIGURE 9. *MAJOR TRADE ROUTES FOR DRI PRODUCTS* [5]
(Land, domestic, and smaller routes are not shown)

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1. DOEH2@Scale: https://www.energy.gov/sites/prod/files/2018/08/f54/fcto-h2-scale-kickoff-2018-3-ruth.pdf.
2. “Pedal to the Metal 2021 – No Time to Delay Decarbonizing the Global Steel Sector,” a report by Global Energy Monitor, 1254 Utah Street, San Francisco, CA 94110, authors: Caitlin Swalec, Research Analyst for The Global Steel Plant Tracker, and Christine Shearer, Program Director for Coal.
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4. “Using HBI in Blast Furnaces – Results Achieved by voestalpine Linz,” an article by Anna Griesser and Thomas Buergler, voestalpine Stahl GmbH, published in *3Q2020 Direct From Midrex.*
5. Midrex Technologies, Inc.: *2020 World Direct Reduction Statistics.*

HBI-C-FLEX PROJECT:

Addressing a Challenge to the HBI Value Chain

By CHRIS BARRINGTON, *Chief Advisor, International Iron Metallics Association (IIMA)*

INTRODUCTION

Hot Briquetted Iron (HBI) continues to grow in importance as a merchant feedstock for the global steel industry, with a significant volume of trade involving maritime transport. The pace of growth can be expected to accelerate as the steel industry progresses along the pathway towards decarbonization of production.

Maritime transport of HBI is governed by the regulations of the International Maritime Organisation (IMO), which include specific provisions for all forms of Direct Reduced Iron (DRI). Therefore, it is essential that changes in the characteristics of HBI are properly reflected in maritime regulations.

Several emerging trends have the potential to challenge the status quo with respect to safe shipment of HBI, notably decarbonization of steelmaking and the expected medium-to-long term shift to hydrogen-based HBI, and in the shorter term, the trend towards flexible and higher carbon content of HBI. IIMA has started a project called HBI-C-Flex to evaluate the impact of these trends on reactivity of HBI and safe shipment.

THE GENESIS OF HBI-C-FLEX

This story has its beginnings in the 1970s, when HBI started its journey to becoming an established part of the global steelmaking raw materials supply chain – indeed this author travelled to Venezuela in 1975 to procure a trial cargo of FIOR briquettes for the EAF steelmaking industry in the UK. As is well-known, HBI was developed as a densified form of DRI in order to overcome the risk of self-heating inherent with shipping DRI. Over the years, the Venezuelan HBI producers, working together with IIMA's predecessor organisation the Hot Briquetted Iron Association (HBIA), developed a generic specification for HBI that was aimed at safe maritime transport. A key element of this specification was density >5,000 kg/m³, accepted after much debate by IMO in 2008 for inclusion in the International Maritime Solid Bulk Cargoes Code (IMSBC Code) that came into legal effect in 2011.

HBI has the bulk cargo shipping name "DIRECT REDUCED IRON (A) briquettes, hot moulded" in the IMSBC Code with the following description:

Direct reduced iron (DRI) (A) is a metallic grey material, moulded in a briquette form, emanating from a densification process whereby the DRI feed material is moulded at a temperature greater than 650°C and has a density greater than 5,000 kg/m³. Fines and small particles (under 6.35 mm) shall not exceed 5% by weight.

Fast-forwarding several years, IIMA's Technical Committee noted the developing interest in DRI/HBI with variable carbon content, ranging from the traditional level of 0.5-1.6% up to as much as 4.5%. A consequence of HBI with higher carbon content is lower density, which in turn raises the question of safe maritime transport and the IMSBC Code; i.e., at what density does the reactivity of HBI increase to the point that it behaves more like DRI with its attendant risk of self-heating thus requiring more comprehensive safety precautions, notably the need for ships' holds carrying DRI to be inerted with a blanket of nitrogen?

Information and scientific data behind the selection of a density of >5,000 kg/m^3 for safe shipment have proven difficult to find. Much of the research on this topic was conducted in the pre-digital era and it appears that many of the relevant files have been lost or destroyed for one reason or another. Therefore, we decided to conduct a literature search as the first step. The Austrian metallurgical research organisation K-1 MET, together with the Ferrous Metallurgy Department of Leoben University, was commissioned to carry out the project, which was designated HBI-C-Flex.

BROADENING THE SCOPE

Fast-forwarding again to the present, one of the over-arching preoccupations of the global steel industry is the goal of an 80-95% reduction of CO_2 emissions in steel production relative to 1990 by the middle of the 21st century. A key component of this vision of carbon-neutral steelmaking is a progressive, but not necessarily total shift from the integrated Blast Furnace/Basic Oxygen Furnace (BF/BOF) to the Direct Reduction/Electric Arc Furnace (DR/EAF) steelmaking route, with hydrogen-based DRI and natural gas-based DRI with CCUS (carbon capture, utilization, and storage) progressively replacing conventional DRI.

Figures 1 and 2 are based on data for the Sustainable Development Scenario from the steel chapter of the International Energy Agency's "Energy Technology Perspectives 2020 report [1].

The total DRI production of 411 Mt predicted for 2050, when compared with the 108 mt produced in 2019, represents an increase of 280%. This article will not

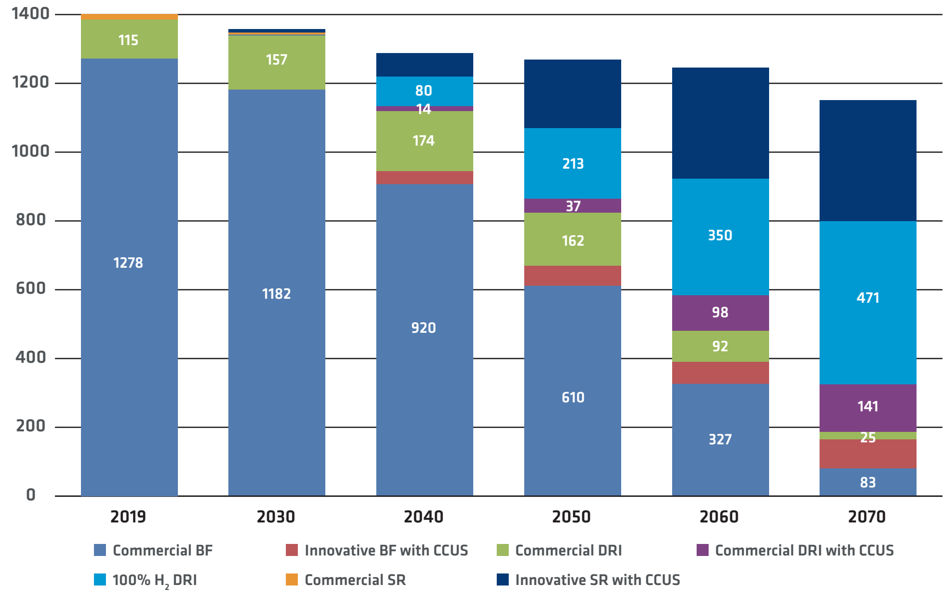


FIGURE 1. *Iron Production by Technology in the Sustainable Development Scenario (mt)* [2]

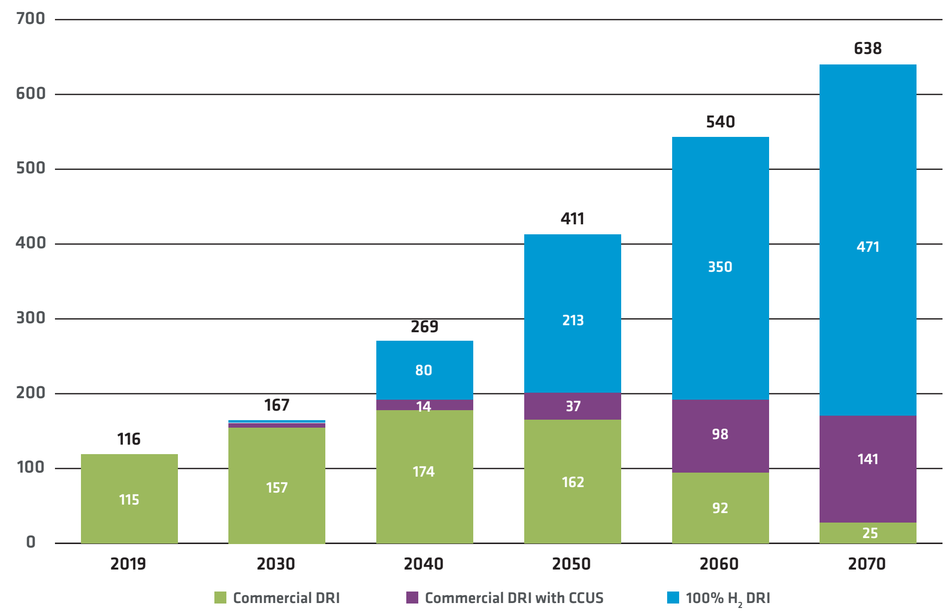


FIGURE 2. *DRI Production by Technology in the Sustainable Development Scenario (mt)*

debate the likelihood that such a scenario will eventuate, but two aspects are relevant from the perspective of HBI-C-Flex.

Firstly, the question of where will all this DRI be produced: integrated with steel plants, integrated with iron ore operations, or somewhere in between? The answer is probably all of the above. But whatever the case, it seems highly likely that a significant proportion of DRI will be produced in the form of HBI and transported internationally by sea. Furthermore, an increasing proportion of this HBI will be hydrogen-based and contain little or no carbon. What are the implications of this for safe shipping?

Secondly, this greatly increased DRI production will have profound implications for iron ore supply. The market for DR-grade pellets (and pellet feed) is currently very tight and IIMA's analysis suggests that the current and planned supply of DR-grade pellets will be fully utilized by around 2030. This means additional supply will be needed and/or the direct reduction industry will have to utilize a proportion of lower grade feedstock. In the latter case, the issue of HBI density and safety of shipping again arises.

Thus the scope of the HBI-C-Flex Project has become multi-tracked:

- HBI with little or no carbon (H_2-based)
- HBI produced from lower grade iron ore
- HBI with high carbon content

RESULTS OF THE LITERATURE SEARCH

Whilst the search revealed a reasonable number of scientific papers and articles, none of them provided the basis for the >5,000 kg/m^3 density threshold. The impact of the chemical composition and mineralogy of the source iron ore, as well as the reduction conditions were barely investigated and discussed. Nor was there a clear interpretation of the effects of the carbon content. Importantly, considering the interaction between the various parameters influencing DRI reactivity, assessing each of them in isolation is not practicable. A reasonable interpretation might be that the choice of >5,000 kg/m^3 was a case of "applied science" with a practical outcome.

Therefore, we concluded that a systematic study is required to investigate the various parameters considered as being the principal drivers of reactivity and thus the self-heating hazard. The study should seek to establish a correlation between these parameters and DRI/HBI reactivity and thereby fill the knowledge gap in the literature. A laboratory-scale concept has been developed to study DRI/HBI reoxidation behaviour, taking into consideration the principal HBI production process steps from direct reduction of the iron ore to hot briquetting of the final product.

Ultimately, we hope to develop (1) a standardized approach to measuring DRI reactivity, (2) a predictive model relating the self-heating tendency with cargo properties, and (3) a process and guidance for risk assessment and control to underpin the paramount goal of safe handling and transport of HBI at sea and on land.

At IMO, the various types of DRI have a higher-than-average profile due to incidents in the past, meaning that to arrive at a basis for either a new schedule for lower density HBI or an amendment to the existing DRI (A) schedule, a well argued, scientifically based, and peer reviewed case will have to be presented. It should be noted that the IMO process for addition of hazardous cargoes to the IMSBC Code can be very lengthy, thus necessitating careful and thorough preparation with safe shipment being at the top of the agenda.

THE NEXT STEP

HBI-C-Flex is a project that has important implications for industry participants along the HBI value chain in its broadest sense. The study as outlined above would be a multi-year project and given the accelerating pace of movement along the pathway to carbon-neutral steelmaking, IIMA intends to engage with potential project sponsors over the coming weeks to secure support to commence this vital research.

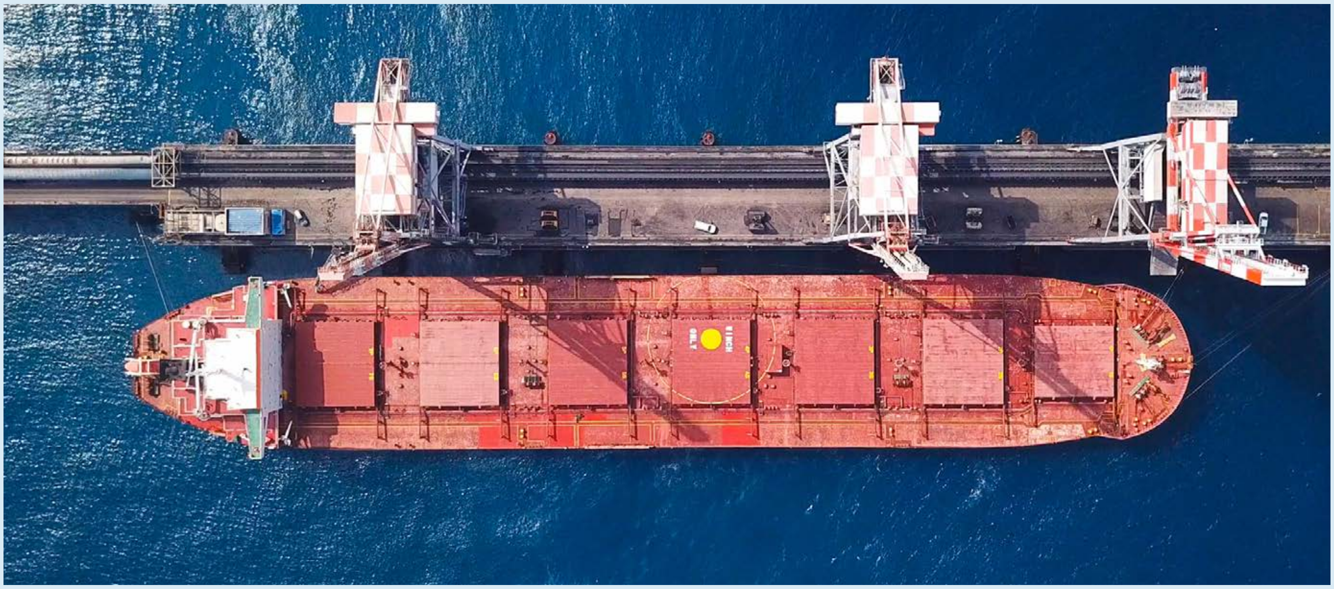
For further information or to discuss participating in the HBI-C-Flex Project, please contact Chris Barrington, Chief Advisor, International Iron Metallics Association (IIMA), at: cbarrington@metallics.org.

Reference Notes:

1. Data kindly provided by IEA
2. The Sustainable Development Scenario (SDS) sets out the major changes that would be required to reach the main energy-related goals of the United Nations Sustainable Development Agenda, including an early peak and subsequent rapid reduction in emissions, in line with the Paris Agreement, universal access to modern energy by 2030 and a dramatic reduction in energy-related air pollution. The trajectory for emissions in the Sustainable Development Scenario is consistent with reaching global "net-zero" CO_2 emissions for the energy system as a whole by around 2070.

The IMSBC Code: Regulatory framework for international shipment of solid bulk cargoes

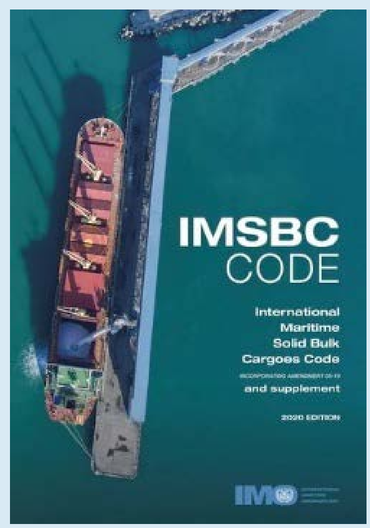
By CHRIS BARRINGTON, *Chief Advisor, International Iron Metallics Association (IIMA)*



INTRODUCTION

International maritime shipment of solid bulk cargoes is governed by the London-based International Maritime Organisation (IMO), a specialized agency of the United Nations that is responsible for measures to improve the safety and security of international shipping and to prevent marine pollution from ships. The IMO sets standards for the safety and security of international shipping. It oversees every aspect of worldwide shipping regulations, including legal issues and shipping efficiency.

The International Convention for the Safety of Life at Sea, 1974 (SOLAS Convention), as amended, deals with various aspects of maritime safety and contains, in chapter VI, the mandatory provisions governing the carriage of solid bulk cargoes. These provisions are extended in the International Maritime Solid Bulk Cargoes Code (IMSBC Code). The primary aim of the IMSBC Code is to facilitate the safe stowage and shipment of solid bulk cargoes by providing information on the dangers associated with the shipment of certain types of solid bulk cargoes and instructions on the procedures to be adopted when the shipment of solid bulk cargoes is contemplated.



CLASSIFICATION OF DRI PRODUCTS

The IMSBC Code, which replaced the Code of Safe Practice for Solid Bulk Cargoes (BC Code), came into legal effect in 2011 and is updated every second year, the current edition being the 2020 edition. Appendix 1 of the code contains individual schedules for more than 300 solid bulk cargoes, including three types of Direct Reduced Iron (DRI).

CARGOES ARE DIVIDED INTO THREE GROUPS, A, B AND C:

GROUP A → Consists of cargoes which possess a hazard due to moisture that may result in liquefaction or dynamic separation if shipped at a moisture content in excess of their transportable moisture limit (this is a revised definition, yet to be formally adopted).

GROUP B → Consists of cargoes which possess a chemical hazard that could give rise to a dangerous situation on a ship.

GROUP C → Consists cargoes which are neither liable to liquefy (group A) nor to possess chemical hazards (group B)

A sub-set of Group B cargoes is Materials Hazardous only in Bulk (MHB). These are materials that when carried in bulk, possess chemical hazards other than the hazards covered by the classification system of the International Maritime Dangerous Goods Code. These materials present a significant risk when carried in bulk and require special precautions. Such hazards are Combustible solids (CB), Self-heating solids (SH), Solids which evolve flammable gas when wet (WF), Solids which evolve toxic gas when wet (WT), Toxic solids (TX), Corrosive solids (CR) and Other hazards (OH).

IMSBC Code schedules include sections for description, characteristics, hazard, hold-cleanliness, stowage and segregation, weather precautions, loading, precautions, ventilation, carriage, discharge, clean-up and emergency procedures.

The three forms of Direct Reduced Iron (HBI, DRI, and HBI/DRI Fines) are classified as MHB SH and/or WF (WF relates to evolution of hydrogen).

The three schedules for the three forms of Direct Reduced Iron are:

- Direct Reduced Iron (A) Briquettes, hot-moulded *(this is HBI and is Group B)*
- Direct Reduced Iron (B) Lumps, pellets, cold-moulded briquettes *(this is DRI and is Group B)*
- Direct Reduced Iron (C) (By-product fines) *(this is DRI/HBI Fines and is Group B)*

Self-heating occurs as a consequence of the re-oxidation of DRI, a mainly exothermic reaction, and if not controlled can lead to ignition of the cargo. This hazard is especially the case for DRI (B) due to its porous or sponge-like structure and, when in a cargo hold, the large surface area accessible to air/oxygen.

Evolution of hydrogen occurs when DRI comes into contact with moisture/water, especially seawater, the reaction mechanism being the aqueous corrosion of iron.

DESCRIPTIONS & HAZARD PROFILES

The IMSBC Code schedules for DRI contain the following description and hazard profiles:

DRI (A): A metallic grey material, moulded in a briquette form, emanating from a densification process whereby the DRI feed material is moulded at a temperature greater than 650°C and has a density greater than 5,000 kg/m³. Fines and small particles (under 6.35 mm) shall not exceed 5% by weight. A loading requirement for DRI (A) is that moisture content shall be <1%.

Hazard: Temporary increase in temperature of about 30°C due to self-heating may be expected after material handling in bulk. The material may slowly evolve hydrogen after contact with water (notably saline water). Hydrogen is a flammable gas that can form an explosive mixture when mixed with air in concentration above 4% by volume. It is liable to cause oxygen depletion in cargo spaces. This cargo is non-combustible or has a low fire risk.

DRI (B): A highly porous, black/grey metallic material formed by the reduction (removal of oxygen) of iron oxide at temperatures below the fusion point of iron. Cold-moulded briquettes are defined as those which have been moulded at a temperature less than 650°C or which have a density of less than 5,000 kg/m³. Fines and small particles under 6.35 mm in size shall not exceed 5% by weight.

Hazard: Temporary increase in temperature of about 30°C due to self-heating may be expected after material handling in bulk. There is a risk of overheating, fire and explosion during transport. This cargo reacts with air and with fresh water or seawater to produce heat and hydrogen. Hydrogen is a flammable gas that can form an explosive mixture when mixed with air in concentrations above 4% by volume. The reactivity of this cargo depends upon the origin of the ore, the process and temperature of reduction, and the subsequent ageing procedures. Cargo heating may generate very high temperatures that are sufficient to ignite the cargo. Build-up of fines may also lead to self-heating, auto-ignition and explosion. Oxygen in cargo spaces and enclosed spaces may be depleted.

DRI (C): A porous, black/grey metallic material generated as a by-product of the manufacturing and handling processes of DRI (A) and/or DRI (B). The density of DRI (C) is less than 5,000 kg/m³. A loading requirement for DRI (C) is that the moisture content must be <0.3%.

Hazard: Temporary increase in temperature of about 30°C due to self-heating may be expected after material handling in bulk. There is a risk of overheating, fire and explosion during transport. This cargo reacts with air and with fresh water or seawater, to produce hydrogen and heat. Hydrogen is a flammable gas that can form an explosive mixture when mixed with air in concentrations above 4% by volume. Cargo heating may generate very high temperatures that are sufficient to lead to self-heating, auto-ignition and explosion. Oxygen in cargo spaces and in enclosed adjacent spaces may be depleted. Flammable gas may also build up in these spaces. All precautions shall be taken when entering cargo and enclosed adjacent spaces. The reactivity of this cargo is extremely difficult to assess due to the nature of the material that can be included in the category. A worst case scenario should therefore be assumed at all times.

Each schedule details the precautions to be taken to mitigate the risks associated with the hazards of the cargo in question. For all types of DRI, monitoring of the cargo temperature and hydrogen concentration are essential. In all cases, material with temperature > 650°C shall not be loaded.

For DRI (A), the **Ventilation** section states: surface ventilation only, either natural or mechanical, shall be conducted, as necessary, during the voyage for this cargo. On no account shall air be directed into the body of the cargo. When mechanical ventilation is used, the fans shall be certified as explosion-proof and shall prevent any spark generation, thereby avoiding the possibility of ignition of hydrogen-air mixture. Suitable wire mesh guards shall be fitted over inlet and outlet ventilation openings. Ventilation shall be such that escaping gases cannot enter living quarters in hazardous concentrations.

For DRI (B), the **Loading** section states: prior to loading, provision shall be made to introduce a dry, inert gas at tank top level so that the inert gas purges the air from the cargo and fills the free volume above. Nitrogen is preferred for this purpose. All vents, accesses and other openings, such as coaming drains, that could allow the inert atmosphere to be lost from cargo spaces carrying this cargo shall be closed and sealed.

The **Precautions** section states: the ship shall be provided with the means to ensure that the requirement of this Code to maintain the oxygen concentration below 5% can be achieved throughout the voyage. The ship's fixed CO_2 fire-fighting system shall not be used for this purpose. Consideration shall be given to providing the vessel with the means to top up the cargo spaces with additional supplies of inert gas, taking into account the duration of the voyage.

The **Ventilation** section states: the cargo spaces carrying this cargo shall remain tightly sealed and the inert condition maintained during the voyage.

The precautions and measures for DRI (C) are essentially the same as for DRI (B).

With respect to DRI Fines, it is important to note that the vast majority of shipments of this material contain moisture content < 0.3% required for DRI (C), typically 5-6%, but in any case less than the transportable moisture limit. For such material, the principal hazard is evolution of hydrogen rather than self-heating. Therefore, shipments have for many years and continue to be covered by exemptions in accordance with section 1.5 of the IMSBC Code which permit the higher moisture content and require mechanical ventilation as the principal methodology for dealing with the hydrogen hazard, a practice safely employed by the industry for many years.

For the last ten years or so, attempts have been made at the IMO to introduce a new IMSBC Code schedule for DRI Fines with higher moisture, embodying mechanical ventilation as the principal safety precaution. Concerns about the effectiveness of ventilation have been raised and, underlying this process are long memories of past incidents with DRI Fines, notably the tragic loss in 2004 of six lives and the M/V Ythan, a bulk carrier en route from Venezuela to Asia with a full cargo of DRI Fines. Industry, working collaboratively through IIMA, co-sponsored an updated draft schedule, designated DRI (D), together with Canada and the USA, which is currently going through the IMO process (much delayed by the COVID-19 crisis). IIMA can provide further information.

IMO INTERNATIONAL MARITIME ORGANIZATION

The IMSBC Code can be purchased in hard copy or electronic format via the IMO website. At the time of writing, the text of the 2020 version of the IMSBC Code can be downloaded **here**.

CELEBRATING 40 YEARS OF

DIRECT FROM MIDREX

160	480	6	6
ISSUES	ARTICLES	COVERS	EDITORS

THEN VS NOW

THEN	NOW
7.92 Mtpy TONS/YEAR OF DRI PRODUCTION	**104.4** Mtpy TONS/YEAR OF DRI PRODUCTION
4.1 Mtpy MIDREX PLANTS TONS/YEAR OF DRI PRODUCTION	**62.6** Mtpy MIDREX PLANTS TONS/YEAR OF DRI PRODUCTION
13 MIDREX MODULES	**90+** MIDREX MODULES

1981 — 2021

CELEBRATING 40 YEARS OF *DIRECT FROM MIDREX*

In the 40 years that Direct From Midrex has been published, the company name has changed a number of times, Midrex ownership has passed from Willy Korf to Kobe Steel, Ltd., Midrex has had five presidents, and DFM has had six editors and has undergone several facelifts. Each editor brought his or her creativity and vision to DFM. As a result, the covers were modernized to keep pace with the times, but the content remained true to its purpose – to be the journal of the direct reduction industry.

40 YEARS OF DIRECT FROM MIDREX

Frank Griscom, DFM's first editor, recalls when he joined Midrex in spring 1981, "Direct reduction was an emerging industry back then. Direct reduced iron (DRI) was regarded as a niche product. We wanted to develop a broader appreciation for the value of DRI as a way to drive demand for more direct reduction plants and to position the MIDREX® Process as the leading direct reduction technology."

What prompted the idea of DFM?

Prior to 1981, DFM had been a sporadically published, external newsletter. So, we made the decision to transform it into a controlled circulation, quarterly industry journal as a means to pursue both of our marketing goals: to develop the market for HBI and to establish Midrex as the foremost direct reduction technology supplier.

What was the biggest change to DFM over the years?

DFM was originally printed and distributed from Midrex headquarters at the end of each quarter to a mailing list we managed. Starting with the 3Q2020 issue, we transitioned it to a digital format. Now you can read DFM on whatever electronic device you have, from wherever you are, whenever you want.

What was the most exciting article you have read or worked on in DFM?

Beginning with an article in 3Q1984, I was involved in getting the first MIDREX HBI Plant established in the merchant metallics market. I was fortunate enough to spend time at the plant on Labuan Island, Malaysia, with a camera crew shooting a video to promote the plant and its product. Later, I worked with the plant's marketing staff in Kuala Lumpur to produce a series of brochures about the various uses of HBI. Over the years while I was editor of DFM, we published articles documenting the success of using the plant's HBI that I like to think have contributed to the reputation HBI enjoys today.

Lauren Lorraine, editor of DFM since 2018, wants to build on the quarterly's legacy and reach those who are hearing about direct reduction for the first time due to its vital role in decarbonizing iron and steelmaking, as well as new teammates joining Midrex.

Last year DFM adopted a digital format to make it easy and convenient to view the journal on mobile devices and to increase the searchability of articles. By leveraging readership surveys and other analytics, we will use a data-driven approach to provide relevant and valuable content to our audience. We have been pleased with the response and feedback thus far and intend to continually improve the functionality of DFM.

We want to thank the readers of Direct From Midrex. We appreciate your loyalty throughout the last 40 years. And thank you to all of our authors, former editors, and graphics designers without whom we would not have been able to sustain a technical journal that is both relevant and informative to our audience.

Midrex News & Views

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

2020 World DRI Production Exceeds 104 Mt

WORLD DIRECT REDUCTION STATISTICS FOR 2020 PUBLISHED

Annual global direct reduced iron (DRI) production in 2020 was 104.4 million tons (Mt) in 2020. DRI output was down 3.4 % from the record 108.1 Mt produced in 2019. Once again, the combination of India and Iran produced well over half of the global DRI.

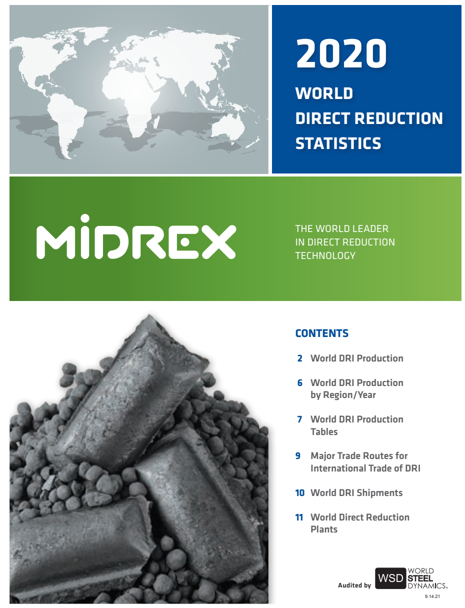
From 2015-2019, worldwide DRI output increased by 35.5 Mt, or nearly 49%, primarily driven by the increase in coal-based DRI in India, the high capacity utilization of existing and new gas-based plants in Iran, and the ramp up of new capacity, such as Tosyali Holding's MIDREX® Plant in Algeria. However, the onset of the global COVID-19 pandemic in early 2020 had a ripple effect on DRI production, as well as the completion and start-up of new capacity.

The production of hot DRI (HDRI), which is fed directly to a nearby melt shop for energy savings, was 11.4 Mt (a 1.0% increase compared to 2019), making up 10.9% of the total in 2020. The production of hot briquetted iron (HBI) – a compacted form of DRI suitable for shipping and use in the blast furnace – is estimated to have been 9.1 Mt, a 6.2% decrease from 2019.

MIDREX Plants produced 62.63 Mt in 2020. The production for 2020 was calculated from the 35.47 Mt confirmed by MIDREX Plants located outside of Iran and 27.16 Mt for the MIDREX Plants in Iran. Over 8.2 Mt of HDRI were produced by MIDREX Plants worldwide, which were consumed in nearby steel shops to assist them in reducing their energy consumption per ton of steel produced and increasing their productivity.

MIDREX Technology continued to account for ~80% of worldwide production of DRI by shaft furnaces in 2020. MIDREX Plants have produced a cumulative total of more than 1,165 Mt of all forms of DRI (CDRI, HDRI, and HBI) through the end of 2020.

2020 World Direct Reduction Statistics is available for download at **www.midrex.com**



The DRI production data used in this article is part of **2020 World Direct Reduction Statistics**, which was compiled by Midrex Technologies, Inc. as a resource for the global iron and steel industry. To prepare the annual statistics, Midrex requests inputs from every known direct reduction producer either directly or indirectly through partner organizations. Where plant information is not available directly from producers, Midrex deduces that information from publicly available data.

World Steel Dynamics (WSD) audited the data collection and preparation processes used by Midrex to confirm that the methodology and accuracy of the data to be published is representative of the global direct reduction industry in 2020.

Midrex News & Views

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

German Federal Government to Provide €55 Million for ArcelorMittal's Hydrogen DRI Plant

(**Editor's note:** This article is adapted from a 7 September 2021 ArcelorMittal news release, found here: https://bit.ly/3nPp5Av

During a recent visit to ArcelorMittal Germany's steel plant in Hamburg, Federal Environment Minister Svenja Schulze pledged the Federal Government's support for the construction of Germany's first industrial scale hydrogen-based direct reduced iron (DRI) plant.

ArcelorMittal Hamburg, located on the bank of the Elbe River

This demonstration plant, which will use hydrogen exclusively as the chemical agent to reduce iron ore into DRI, is intended to lay the foundation for a steelmaking process that means steel can be produced with zero carbon-emissions[1], using electric arc furnaces (EAFs) fed with hydrogen-reduced DRI and scrap metal, powered by renewable electricity.

The Federal Government has expressed its intention to provide €55 million of funding support towards the construction of the plant, which is half of the €110 million total capital expenditure required. The next step is for the European Commission to approve the Federal Government's intention to provide funding before the installation of the new plant can begin. Production is scheduled to start in 2025.

DRI is currently produced using natural gas to reduce iron ore. In a transition phase, the process of reducing iron ore with hydrogen will first be demonstrated using hydrogen generated by the separation of waste gas from the Hamburg MIDREX® Plant. Once available in sufficient volumes and at an affordable price, green hydrogen - made from the electrolysis of water using renewable energy - will be used. By 2030, ArcelorMittal plans to produce more than one million metric tons (tons) of zero carbon-emissions steel a year in the Hamburg plant alone, thereby saving around 800,000 tons of CO_2 emissions annually.

The plant is an important component of ArcelorMittal Germany's Steel4Future strategy, which involves the conversion of its four German plants - in Hamburg, Bremen, Duisburg and Eisenhüttenstadt - to zero carbon-emissions steel production in the coming years.

This year ArcelorMittal Hamburg turned 50, as the MIDREX Plant was started up in 1971, and has produced over 18 million tons of DRI in its illustrious decades of operation. 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.

[1] On a Scope 1 and 2 basis. Scope 1 emissions are direct emissions that result from activities within an organization's control. Scope 2 refers to indirect emissions from energy purchased by the organization, for its own use.

Midrex News & Views

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

Cleveland-Cliffs HBI Plant Producing Beyond Rated Capacity

Cleveland-Cliffs' HBI plant in Toledo, Ohio, USA, is performing well beyond its rated capacity on an annualized basis, according to a report by Metal Expert. Through July 2021, the plant designed and supplied by Midrex Technologies, Inc. was producing hot briquetted iron (HBI) at an annualized rate of 2.1 million tons. The HBI plant, which was commissioned at the end of 2020, reached its nominal capacity within six months following start-up.

Cliffs CEO Lourenco Goncalves was reported to attribute having his own supply of HBI to an increase in hot metal output by his company's blast furnaces (BFs) and a cost savings over the price of prime scrap, which he pointed out is becoming scarce. In addition to the economic benefits, Goncalves said that the use of HBI in the BFs alone reduced Cliffs' carbon emissions by 163,000 tons during the quarter.

From Cleveland-Cliffs YouTube Channel

Cleveland-Cliffs recently unveiled plans to reduce its carbon emissions by 25% by 2030, compared to 2017 baseline levels. Integral to those plans is the use of natural gas in HBI production and investments in carbon capture technology.

Midrex India Celebrates 10 Years

This month marks the 10th anniversary of the opening of Midrex Technologies India Private, Ltd. (Midrex India) in Gurugram, near New Delhi, India. Midrex India provides regional sales and support services for Midrex Group companies, as well as financial and administrative services for the Midrex offices in Dubai and Shanghai.

Midrex India was instrumental in executing a field services contract at JSW Toranagallu and the MIDREX® Plant upgrade project at the JSW Dolvi.

Our India office is made up of highly dedicated teammates. Aashima Vadhera is a member of the Midrex executive staff and serves as Director – Finance, Asia, Middle East and North Africa. Her team provides financial and administrative support to the project execution, marketing, and sales efforts for the Midrex activities throughout Asia/MENA. The office is also responsible for the marketing activities for Midrex in India. Kedar Palekar and Amit Jha lead these activities which include business development and managing client relationships.

"We are very proud of our teammates in India," said KC Woody, COO of Midrex. "They have supported a dynamic market in India and have made an invaluable contribution to our Globalization Initiatives. We are confident our teammates at Midrex India will continue to be key contributors to the success of the group and our clients."

Dempsey Named VP – Commercial
Teeters to Lead Midrex Engineering


WILL DEMPSEY


JOHN TEETERS

Will Dempsey has been appointed Vice President – Commercial to head all commercial activities including plant sales, contracts and licensing, marketing, and the aftermarket group, Global Solutions. John Teeters will replace Dempsey as Director – Engineering, with responsibility for all engineering disciplines associated with the execution of major projects including new plants, plant upgrades, and technology development.

In his 10 years at Midrex, Dempsey has developed an extensive background in process engineering, including lead design and commissioning roles. He is a graduate of North Carolina State University with a Bachelor of Science degree in chemical engineering.

Teeters, a graduate of North Carolina State University with Bachelor of Science and Master of Science degrees in mechanical engineering, has more than 25 years of engineering and project management experience in ironmaking, liquified natural gas (LNG), chemical processes, fiber-optics, and pharmaceutical glass including more than 10 years with Midrex serving in lead engineering, commissioning, and training roles.

Lauren Lorraine: Editor

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All references to tons are metric unless otherwise stated.

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