

# DIRECT FROM MIDREX

2ND QUARTER 2017



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## COMMENTARY

# TAKING THE PULSE ... A DEEPER LOOK AT THE DRI INDUSTRY IN 2016

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## EDITOR'S NOTE:

*Midrex has recently published the annual 2016 World DRI Statistics compiled from data collected by Midrex Technologies, Inc. and audited by World Steel Dynamics. The full publication can be downloaded from: [www.midrex.com](http://www.midrex.com). The following commentary takes a look at 2016 production data through the lens of historical perspective.*

The Direct Reduction Iron-making industry is still very much in its early years. To some this is obvious, to others it may seem odd based on five decades of production; none the less, the statement is true. Much more growth is anticipated. More importantly, more capacity will be needed to satisfy the global steel industry's need for prime metallics.

Worldwide production of direct reduced iron (DRI) was 72.76 million metric tons in 2016, slightly greater than the 2015 figure of 72.64 million tons, but still down from the peak we saw in 2013. Some could see this as the industry "stalling," espe-

cially in light of 2016's production being more than 2 million tons less than the 2013 peak of nearly 75 million tons produced; however, that viewpoint would discount a variety of powerful factors.

Considering the slowdown of the world steel industry in late 2015 and early 2016, the fact that production of DRI held constant was positive for the DRI industry. Market forces aside, there were some other interesting trends globally. Many plants that produced both HBI and HDRI shifted production to take advantages of hot transport to the EAF. HBI production stayed relatively the same thanks to new merchant production. In addition, the industry saw a substantial amount of production taken off-line due to idling or closing of facilities; yet when looking at the world production, these losses are not immediately seen. If the industry was truly stalling in terms of growth, the world total would be far lower that it was rather than slightly increasing..

## India increased DRI production while decreasing DRI production... what!?!?

As a whole Indian DRI production was up by almost 800,000 tons over 2015 due to a combination of causes. India has been the largest producing nation of DRI

products for the decade in great part because of rotary kilns producers, who account for roughly two-thirds of the DRI made in India.

Gas-based shaft furnace DRI plants were aided by lower costs for imported liquefied natural gas and by the stabilization of the coal gasification plants that supplied reducing gas to direct reduction shaft furnaces. In turn, gas-based DRI output in India rose remarkably, by over 70%, versus 2015. At the same time, production by the hundreds of rotary kiln coal-based plants dropped by about 5%. Production shifted and a number of the kilns were shuttered, but their share of market was taken by the surviving operations, which upped their output or were offset by the rise in shaft furnace DRI production.

## Production off in some markets ...

Several countries saw declines in shaft furnace DRI production. Probably the most notable was Venezuela (yet again), where production fell to 1.6 million tons, its lowest level in 35 years. The drop was due to many reasons, all of which are attributable to the dire economic situation. At its peak, the country produced 9 million tons of CDRI and HBI.







## COMMENTARY

The next largest fall was by Trinidad and Tobago, which slipped by more than 1 million tons, as the three ArcelorMittal plants were shuttered in late-2015 and did not operate in 2016. At the time of this writing, they were in the process of liquidation, seeking a new owner. The MIDREX® Plant in Trinidad owned by Nucor continued in steady operation, supplying CDRI to Nucor steel works in the United States. Declines of 0.3-0.5 million tons occurred in Argentina, South Africa and Malaysia. In the case of Argentina, the fall was largely due to lower oil prices and a corresponding drop in demand for oil and gas tubular steels.

### New capacity came online or ramped up in others ...

Growth in the United States DRI industry was due to the increase toward nameplate capacity by the Nucor Louisiana plant and the start-up of the new voestalpine HBI plant in Texas late in the year. US production was up by more than 700,000 tons over 2015.

The greatest increases in DRI production were seen in Iran, India and the United States, which combined to produce 3 million tons more than in 2015. The United Arab Emirates, Russia and Libya also enjoyed substantial gains.

The surge of DRI in Iran from 14.6 million tons to over 16 million tons was part of the longstanding growth trend of the national steel industry. Capitalizing on large iron ore resources and extraordinary reserves of natural gas, the country plans to continue expanding very rapidly over the ensuing decades, using direct reduced iron. By comparison, Iran made only 2.25 million tons of blast furnace hot metal during 2016.

Increases in production of 200,000-300,000 tons occurred in the UAE, Russia and Libya. In the UAE, production climbed toward capacity due to plant expansions in the previous years; in Russia, plants continued to ramp up; and in Libya, production recovered from political instability.

The same five nations from 2015 remained the top DRI producers in 2016 (India, Iran, Saudi Arabia, Russia, Mexico). However, Russia and Mexico exchanged places, as the increases in Russia moved it up to fourth position. Combined, these five nations represented 71% of world DRI production in 2016.

### ...and more on the way!

More than 4 million tons of new capacity will be online this year with even more capacity under construction slated to start up in 2018 and 2019. This includes the afore-mentioned voestalpine Texas HBI Plant, North America's first HBI

facility, which began production in September of last year. Metalloinvest's LGOK HBI-3 1.8 mtpy HBI facility began operation earlier this year and will bring the site's total HBI production up to 4.2 million tons of annual capacity.

An additional 5 million tons of capacity are currently under construction in Algeria alone. These are Tosyali Algeria and AQS-Algerian Qatar Steel, both of which are 2.5 HDRI/CDRI combo MIDREX® Direct Reduction Plants. And more recently, Cliffs Natural Resources announced its intention to build a 1.6 million ton per year HBI plan in Toledo Ohio, USA.

At first glance, 2016's production may seem less than spectacular ... but considering the circumstances, it has been quite remarkable. This year's production will definitely surge ahead and we may even see a new world production record as newer plants find their footing. ■





## IMPACT OF HBI USE IN INTEGRATED STEEL PLANTS

# Environmental Impact and OPEX Comparison

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**EDITOR'S NOTE:** *As economic and environmental pressures continue to increase for the traditional BF/BOF route of steel production, many steelmakers are faced with the challenge of lowering emissions while simultaneously maintaining production. Sustainability is ultimately the key issue for every steelmaker going into the future, but how to achieve this goal in light of new challenges is the question at hand. Shale gas exploration has led to low cost natural gas in North America and other areas of the world, creating interest in new direct reduced iron (DRI) facilities and DRI product including hot briquetted iron (HBI), which were once viewed by integrated steelmakers as an electric arc furnace (EAF)-specific charge material, may actually present a long term, scalable solution that is achievable for steelmakers going forward. HBI usage as charge material especially in the blast furnace (BF) is now seen as a powerful way to help displace CO<sub>2</sub> emissions and increase hot metal production of the facility. This is no longer a hypothetical scenario, as the first DRI Plant built to specifically supply HBI to BF's is operating near Corpus Christi, Texas, USA.*

### INTRODUCTION

**A** major challenge for all industries worldwide is how to comply with more stringent environmental emissions standards. This will be essential for sustainability. The general consensus is that emissions restrictions will get tighter for all industries globally and this will severely affect the ability of many integrated steelmakers going forward. Carbon dioxide (CO<sub>2</sub>) has become the symbol for the plight of society against industry over the greenhouse gas (GHG) effect. Although not the most powerful GHG, CO<sub>2</sub> is the most abundant one and the one that is capturing the most attention.

Total production of CO<sub>2</sub> by human activities is around 35 billion tons per year. Iron and steelmaking accounts for almost 7% of mankind's entire carbon footprint [1]. Ironmaking alone constitutes 80-85% of iron and steel's total CO<sub>2</sub> output. Integrated mills are the largest contributor of CO<sub>2</sub> by both volume and percentage, with coke-fueled blast furnaces currently producing well over 90% of the world's iron.





Based on the world steel industry's coal consumption, it is estimated that blast furnace ironmaking (including the processing step to make coke from metallurgical coal) generates approximately 1.8 tons of CO<sub>2</sub> for every ton of iron produced. As no proven carbon capture system exists for blast furnaces, the best way for integrated steelmakers to reduce CO<sub>2</sub> emissions is simply by not creating the emissions in the first place.

Shuttering a certain percentage of BF capacity will no doubt be necessary in the next few decades, but economics will prevent simply replacing blast furnace-basic oxygen furnace works with direct reduction-electric arc furnace mills. Some DR/EAF capacity is and will continue to replace older, inefficient BF/BOF capacity, but it is not a feasible solution for the industry as a whole.

A practical way to keep blast furnaces operating is needed. The solution could still involve the benefits of direct reduction ironmaking but from an operational standpoint rather than as an outright replacement of BF capacity.

This article will explore possible combinations and integrations of iron and steelmaking routes within an integrated steel mill by using direct reduced iron (DRI) in its physically enhanced form, hot briquetted iron (HBI), and show the environmental benefits, as well as the related OPEX implications. Various plant configurations will be schematically presented with quantified examples and the main process gas and energy balances.

## USE OF HBI/DRI IN INTEGRATED STEEL PLANTS

For most of its history, DRI has been essentially one product form. However, after decades of development and use, DRI is now better defined as three specific products with different uses within the iron and steel industry, as depicted in **Figure 1**. These are: Cold DRI pellet and lump (CDRI), which is cooled before handling and used mostly in the EAF and BOF; Hot DRI (HDRI), pellet and lump specifically developed for the EAF, is discharged from the shaft furnace without cooling and charged into a melter;

DRI PRODUCTS	CDRI	HBI	HDRI
			
Product Form	Pellet & lump	Briquettes* (density ≥ 5.0 grams per cubic centimeter (g/cc))	Pellet & lump
Product Temperature	Ambient	Ambient	550° C or Higher
Where used	EAF & BOF	EAF, BOF & BF	EAF
Charging Method	Continuous & Batch	Continuous & Batch	Continuous & Batch
Description:	CDRI (Cold DRI) is a high quality metallic ideal for use in a nearby EAF. It can also be transported via rail to another site when proper precautions are made. It is not recommended for ocean transport.	HBI (Hot Briquetted Iron) is a premium form of DRI and is the industry and regulatory preferred method of preparing DRI for long term storage and transport. HBI is commonly used in EAFs and can also be added to the Blast Furnace and BOF.	HDRI (Hot DRI) is discharged hot from the shaft furnace and transported to an EAF for melting and provides the optimum way for DRI users to increase productivity and reduce cost.
IMO Restrictions for transport	Inerting (N <sub>2</sub> ) or passivation REQUIRED for cargo during the transport	No Special Precautions	N/A
Number of MIDREX® Plants currently in operation	50	12	7

**FIGURE 1. Forms of direct reduced iron (DRI)** \* The MIDREX® Process requires less oxide coatings than competing DR technologies, which allows for easier briquetting of DRI and stronger physical HBI characteristics.



and Hot Briquetted Iron (HBI), which is DRI discharged from the shaft furnace at  $\geq 650^{\circ}\text{C}$  and compacted to a density  $\geq 5\text{gm/cc}$ , is suitable for all applications including Blast Furnace (BF). **Figure 2** shows the chemical and physical characteristics of HBI.

The chemistry of HBI depends largely on the chemistry of the iron oxide feedstock. Carbon level can be adjusted by the operating parameters of the direct reduction process. The result is a high iron content, low residual charge material for iron and steel production. The compacted form also allows for longer term storage without risk of severe re-oxidation.

### USE OF HBI IN THE BLAST FURNACE (BF)

The addition of metallic iron in the blast furnace (BF) is not a new idea. Even using DRI as the metallic charge has been discussed and written about for decades. However, with economic and environmental pressure mounting on integrated steelmakers, the rhetoric is now turning into action. BF operators are realizing that the flexibility afforded them by using HBI, the physically-

enhanced form of DRI, can translate into increased productivity, greater operational control and reduced emissions, all of which contribute to the sustainability of their plants.

The size and shape of HBI is comparable to standard blast furnace burden materials and can be charged using the existing blast furnace stock house and charging systems. Therefore, it is easier to charge than scrap, and HBI will not cause the sticking or hanging problems sometimes encountered with scrap. Also, scrap must be carefully selected to ensure that the hot metal is not contaminated with unwanted elements, such as copper and other residual metals and that it is suitably sized for blast furnace charging.

Since the iron in HBI is already metallic when charged to the BF, hot metal production is greatly increased (8% for each 10% of metallization of the BF burden) and coke savings are similarly impressive (7% for each 10% of metallization of the BF burden), as shown in **Figure 3**. In addition,  $\text{CO}_2$  emissions are reduced due to lower coke consumption.



FIGURE 2. Chemical and physical characteristics of HBI



HBI has been used as part of the regular, routine operation of a commercial blast furnace in North America for over 25 years, as well as in other blast furnaces around the world. It has been shown that charging 30% HBI yields approximately a 24% increase in production of hot metal. HBI is the preferred form of DRI for use in the BF because CDRI does not have the mechanical properties needed to resist the over burden pressure in a large modern blast furnace and tends to react with the off-gas in the top of the furnace. The high density of HBI makes it much less reactive. HBI also has proven to be a useful alternative to scrap in the BOF.

Blast furnace burden enrichment using HBI can be economically attractive under various conditions. Five of the most likely are:

- Hot metal availability is insufficient to meet orders for finished product and additional downstream capacity is available.
- An imbalance exists between scheduled shipped steel tonnage and the number of blast furnaces; therefore, the plant operates two or three blast furnaces when the hot metal output of one-and-a-half or two-and-a-half furnaces is really required.
- One blast furnace is offline for repair or rebuild and the remaining blast furnace or furnaces must maximize hot metal output to make up the deficit.
- At some locations, it also could be possible to shutter aging coke batteries and related equipment, such as for coal processing and handling and coke oven gas processing.
- The costs of operating an older, smaller furnace can be eliminated by increasing the capacity of a newer, larger one.

In each of these cases, the use of HBI to enhance hot metal production is frequently more attractive than other alternatives, such as purchasing premium scrap or slabs for the metallic charge or being unable to produce the amount of steel when the market demands it.

### EXPERIENCE USING HBI AT AK STEEL

Since the 1980s, AK Steel has added HBI to the charge mix of the blast furnace in Middletown, OH. For several years, AK Steel typically charged 30% of the burden as metal, primarily HBI from Venezuela, together with some steel scrap. Furnace productivity averaged over four tons per day per cubic meter of working volume, among the best in the world. Also, total fuel consumption was remarkably lowered to about 440 kg per metric ton of hot metal.

### EFFECTS OF ADDING METALLIC IRON AS A PORTION OF THE BLAST FURNACE CHARGE

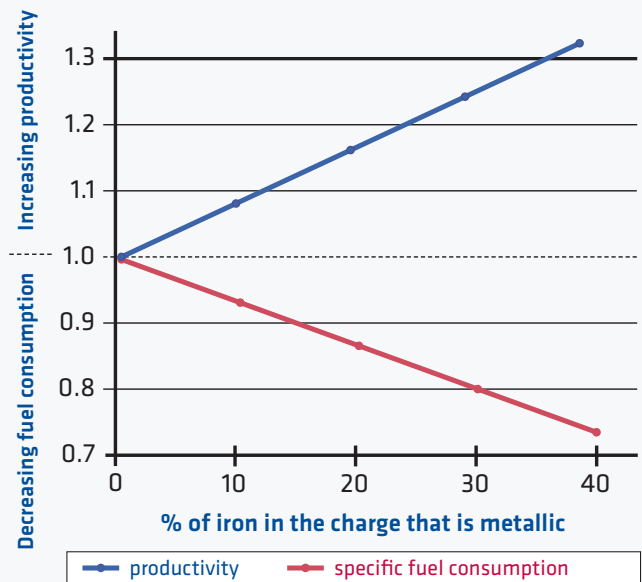


FIGURE 3. Effects of adding metallic iron to the BF charge

The benefit this provided AK Steel was primarily an increase in productivity. With the blast furnace as the limiting operation of the entire steel works at Middletown, additional tonnage from the blast furnace meant more tons of salable product.

Prior to using HBI to increase the productivity of the Middletown blast furnace, AK Steel operated another blast furnace about 30 miles away in Hamilton, Ohio, which was used to supplement hot metal output of the Middletown furnace. This was necessary to keep the steel shop running at the desired rate. Once the Middletown furnace raised its production rate by charging HBI, the Hamilton furnace could be closed. Tom Graham, then president of AK Steel, stated at the World Steel Dynamics 1994 Steel Survival Strategies conference that the closure of the Hamilton blast furnace saved AK \$60 million dollars per year in fixed costs. Those were 1994 dollars; today the equivalent figure would be over \$100 million.

### SOURCING HBI FOR BF USE

If we accept that the most effective, currently available means of lowering the amount of CO<sub>2</sub> generated by the steel industry is to use HBI produced by a natural gas-based direct reduction plant in the blast furnace, the important question is how does a





plant 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; 2) build a natural gas-based DRI plant with HBI capabilities either onsite or near operations or off-shore where there are sufficient supplies of reasonably priced natural gas. In the case of on-site installation of new DRI plant, possible synergies by the utilization of steel-making gasses can be also exploited, as described hereafter.

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, blast furnace operators have chosen to obtain HBI in this manner. HBI plants dedicated to merchant supply exist in Venezuela, Libya, Russia and Malaysia. Except for Russian HBI supply, in recent years political and financial issues have limited the activities of several of these HBI suppliers.

Although DRI plants equipped with briquetters have the capability of producing HBI, their first priority is to supply 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 many 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.

One steel company has already chosen this route. voestalpine of Austria is operating a 2 million metric tons per year MIDREX® HBI plant near Corpus Christi, Texas, USA. The company is capitalizing on the low natural gas prices in North America to supply its BFs in Linz and Donawitz, Austria. Current plans are for about half of the plant's output to be supplied to voestalpine's steel plants, with the remaining HBI to be sold to parties interested in supply over the long-term.

When Wolfgang Eder, CEO and Chairman of the Management Board of the voestalpine Group, announced the decision to invest in the HBI plant in Texas, he pointed out that the use of a natural gas-based direct reduction process will significantly improve the overall carbon footprint of voestalpine and serve as an important step in achieving the Group's ambitious internal energy efficiency and climate protection objectives.

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.

## STUDY OF POSSIBLE INTEGRATION STRATEGIES OF DRI PLANTS WITHIN AN INTEGRATED STEEL PLANT

The following chapters depict the various scenarios resulting from the application of natural gas-based and syngas-based MIDREX® technology within an integrated plant, exploiting the possible combinations given by the process gas available and the different process routes to produce liquid steel. An overview of the expected OPEX implications, environmental benefits and resulting plant configuration will be provided.

### Iron and Steelmaking Calculation Strategy

The steelmaking industry is composed of several process routes and by a wide spectrum of existing plant set-up and configurations. However, it was decided to compare different scenarios by fixing the final production target for all the scenarios to a capacity of 4 Mtpy and keeping open all balance parameters.

Considering the large ranges of final steel products available in the market and the related different plant configurations, it was decided to compare all the different scenarios with hot rolled coil as final product.

### System Boundaries

To properly compare several process routes, as well as their possible combination/interaction, a key point is boundary definition. In fact, steelmaking presents a wide variety of processes with a complex raw materials, gasses and energy balance. Selected system boundaries are shown in *Figure 4 (next page)*.





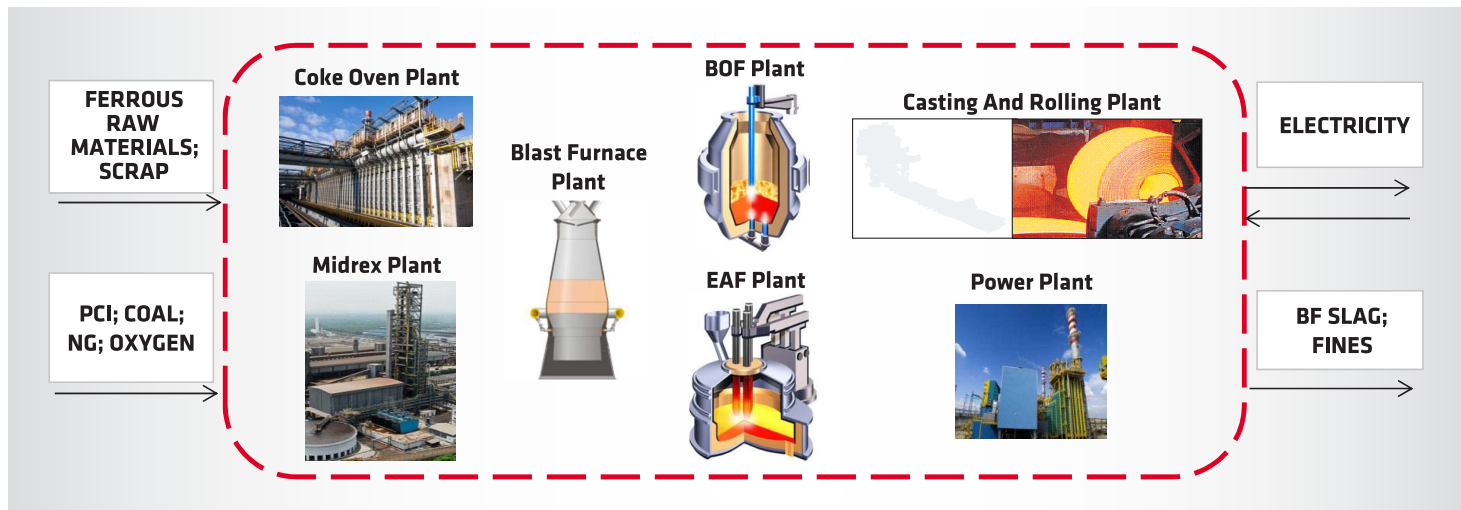


FIGURE 4. System boundaries for calculation

A few key points and considerations were assumed:

- Power plant was included in the system boundaries to take care of the surplus of process gasses generated in the plant and not directly consumed.
- Agglomeration steps, such as sintering and pelletizing were not included in the system boundaries in order to treat at par the BF route (which normally includes the sintering within the integrated plant) and the DR route (which is based on purchase of pellets from pellet plants normally located near the mines externally of the plant). This choice is representative of a reasonable share of blast furnaces operating with high pellet burden, which is typical of many North American ones and a few operating in the EU.

### Steelmaking Gasses

The main gasses involved in the steelmaking process and their typical lower heating value (LHV) considered in the gas and energy balances are given in TABLE I. Their typical distribution across the system boundaries is shown in Figure 5.

GAS	V [kJ/Nm³]
Blast Furnace Gas (BFG)	3450
Coke Oven Gas (COG)	16800
BOF Gas (BOFG)	8400
Natural Gas (NG)	33800

TABLE I. Typical steelmaking gasses and their LHV

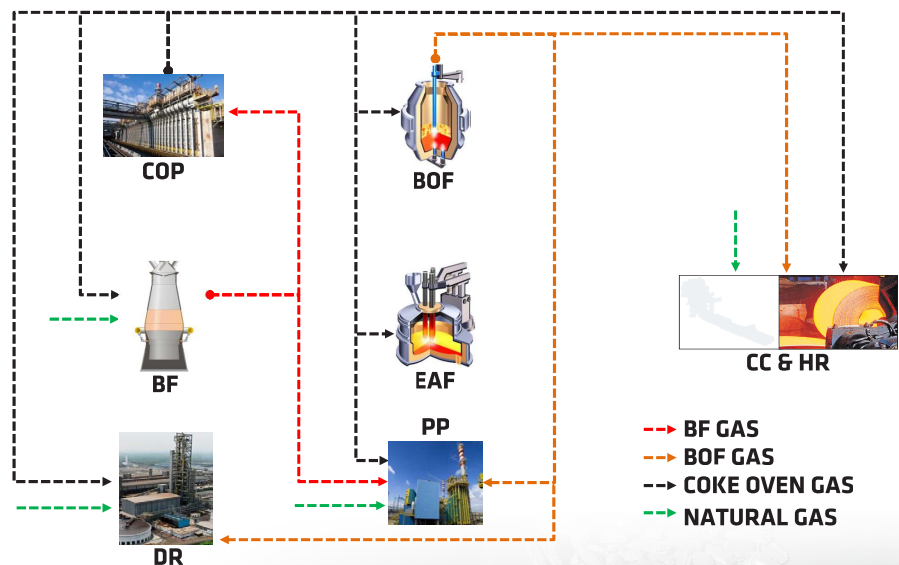


FIGURE 5. Main gaseous flows with-in system boundaries



Material/Media/Utility	UNIT	€/UNIT	REFERENCE
Natural Gas	GJ	4,83	Based on Amsterdam TTF index
Electricity	kWh	0,09	Eurostat
Oxygen	Nm3	0,05	Assumed
CO <sub>2</sub> certificate	tonCO <sub>2</sub>	8	Assumed
CO <sub>2</sub> (CO <sub>2</sub> separation)	tonCO <sub>2</sub>	50	Assumed
Labour	hour	30	Assumed
Coke/coal Fines	ton	-50,7	Assumed, based on coal price
Ferrous Fines	ton	-46,0	Assumed, based on pellet price
BF Slag	ton	-20	Assumed
Scrap	ton	302	Based on Metal Bulletin
DR Grade Pellets	ton	78	Based on Metal Bulletin
BF Grade Pellets	ton	69	Based on Metal Bulletin
Coking Coal	ton	76	Based on Metal Bulletin
PCI	ton	49,7	Assumed

TABLE II. *Material, media and utility prices considered (Exchange rate EUR/USD 1,11)*

The gas balance is done for each scenario, assuming the relevant specific consumption of each plant. The total gas consumption is then calculated, considering resulting plants capacity for the given scenario. The surplus gasses, not directly consumed by the process, are then used in the power plant (with an assumed efficiency of 34%) to produce electrical energy, which is consumed within the plant or sold externally. In several scenarios, an internal energy deficit arose in the plant; therefore, thermal and process balance was maintained by purchasing natural gas where required.

### Raw Material and Gas Prices

Main raw materials, media and utilities prices considered in this paper are presented in TABLE II. The figures were taken from main statistical databases or assumed in line with main market trends considering an EU scenario related to late 2015/early 2016 period.

### CO<sub>2</sub> Calculation

Direct (Scope I) CO<sub>2</sub> emission per ton of hot rolled coil of each scenario was determined by calculating the balance between the amount of each material/media input, entering into system boundaries, and the material/media output produced by multiplying such amounts by the specific emission factor of each material/media. Carbon content in the final steel product was not considered.

Indirect emissions (Scope II) related to the electrical energy imported to the plant were considered.

CO<sub>2</sub> specific emission factors considered are reported in TABLE III.

Overall CO<sub>2</sub> emissions per ton of hot rolled coil were then calculated by adding Scope I and Scope II, as well as the credits for electrical energy exported out of system boundaries (Scope III) and the credits related to the export of BF slag (Scope III). It should be noted that in several cases neither credit for BF slag nor for export of electrical energy produced by the steelmaking plants is included in the calculation. This could substantially change the end results considering that emission savings in the cement industry accountable to BF slag use are substantial, as seen in TABLE III (next page).





Emissions relevant to the production, extraction and transportation (Scope III) of incoming raw materials and media outside of system boundaries were not considered.

### Selection of Scenarios

Scenarios definition considered the possible flows of the main materials within system boundaries, as shown in *Figure 6*, and the corresponding effect on each sub-plant unit.

The intermixing of the typical flows of the BF-BOF route and the ones typical of the DRI-EAF route possible within the system boundaries, such as HBI feeding of the BF or the BOF or HM feeding of an EAF can be seen in *Figure 6*.

### The following scenarios were selected:

#### a) Scenario 1: Base Case

The typical BF-BOF route was used as the base case. Benchmarking blast furnace operation (having a coke rate of 303kg/tHM and a PCI rate of 200 kg/tHM) and BOF parameters (with scrap input of 200kg/tHM) was selected.

#### b) Scenario 2: HBI to BF

Keeping the BF-BOF route to produce steel, a MIDREX® Plant was added to the system feeding HBI to the blast furnace. The effect of HBI feeding to the blast furnace burden is well known since industrial trials have been executed since 1966<sup>[4]</sup> and have continued up to the present days, as in AK Steel<sup>[5]</sup>. Main effect of the increased metallization content of blast furnace burden is a reduction of coke rate coupled with an increase of furnace productivity (7-8% per each 10% of burden metallization content<sup>[6]</sup>).

A maximum blast furnace input of 300kgHBI/tHM was selected considering the effect of BF thermal equilibrium shifting of the HBI, resulting in low top gas temperature.

As an already optimized and highly efficient BF operation was envisaged, fuel rate reduction due to HBI charging was only possible by lowering the PCI rate.

MATERIAL TYPE	UNIT	kg CO <sub>2</sub> /UNIT
Coking Coal	kg	3,11
PCI	kg	3,00
NG	MJ	0,06
Electricity (IEA [2] - OCED Europe)	kWh	0,331
BF Slag credit	ton	945 <sup>[3]</sup>

TABLE III. Specific CO<sub>2</sub> emission factors considered

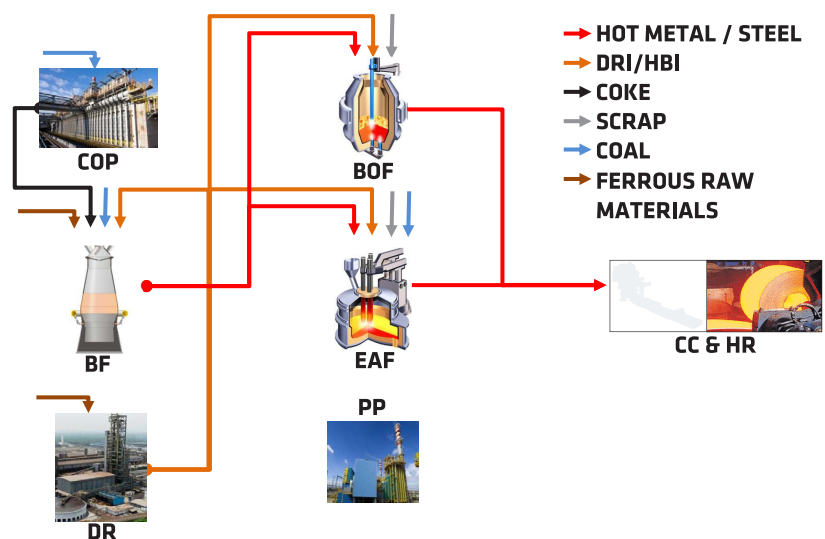


FIGURE 6. Main materials flows within system boundaries

To reduce the OPEX and maximize the synergies of a MIDREX® Plant within the integrated route, the DRI plant was fuelled by NG and by COG. The share of 2GJ/tDRI by COG was selected, as higher energy share would result in a different MIDREX® Plant configuration (MXCOL®), which was analysed in a different scenario.

The benefit of productivity increase with HBI charging to BF is not considered in the study, as it would be reflected in a CAPEX reduction rather than in the operating costs considering that overall production is fixed.

#### c) Scenario 3: HBI to BOF

Keeping the BF-BOF route to produce steel, a MIDREX® Plant was added to the system feeding HBI to the BOF to replace in part purchased scrap. The maximum replacement of 95kg/tLS of HBI was considered, as higher rates have proven to create a slopping problem<sup>[7]</sup>. MIDREX® Plant set-up was considered, as described in Scenario 2 above.



ITEM	UNIT	SCENARIO						
		1	2	3	4	5	6	7
		Reference Case	HBI to BF	HBI to BOF	HBI to BF and BOF	Midrex - EAF	55%BF-BOF / 45% HDRI-EAF	MXCOL with Recycling
<b>BF</b>								
Coke Rate	kg/T <sub>HM</sub>	305	303	305	303	0	305	305
PCI	kg/T <sub>HM</sub>	200	90	200	90	0	200	200
Pellet Rate	kg/T <sub>HM</sub>	1611	1185	1611	1185	0	1611	1611
HBI	kg/T <sub>HM</sub>	0	300	0	300	0	0	0
BF Capacity	MTPY <sub>HM</sub>	3,9	3,9	3,9	3,9	0,0	2,2	3,3
<b>COP</b>								
COP Capacity	MTPY <sub>COKE</sub>	1,3	1,3	1,3	1,3	0,0	0,7	1,1
<b>MIDREX</b>								
Natural Gas	GJ/T <sub>DRI</sub>	0,0	8,0	8,0	8,0	10,0	8,1	0,0
Coke Oven Gas	GJ/T <sub>DRI</sub>	0,0	2,0	2,0	2,0	0,0	2,0	7,6
BOF Gas	GJ/T <sub>DRI</sub>	0,0	2,0	2,0	2,0	0,0	2,0	7,6
DRI Capacity	MTPY <sub>DRI</sub>	0,0	1,2	0,4	1,6	4,9	2,2	0,8
<b>BOF</b>								
HM	kg/t <sub>LS</sub>	910	910	910	910	0	910	910
HBI	kg/t <sub>LS</sub>	0	0	95	95	0	0	0
Scrap	kg/t <sub>LS</sub>	210	210	125	125	0	210	210
BOF Capacity	MTPY <sub>LS</sub>	4,3	4,3	4,3	4,3	0,0	2,4	3,6
<b>EAF</b>								
HM	kg/t <sub>LS</sub>	0	0	0	0	0	0	0
HBI	kg/t <sub>LS</sub>	0	0	0	0	1140	1140	1140
Scrap	kg/t <sub>LS</sub>	0	0	0	0	0	0	0
EAF CAPACITY	MTPY <sub>LS</sub>	0,0	0,0	0,0	0,0	4,3	1,9	0,7
<b>ENERGY BALANCE</b>								
Purchased Electricity	kwh/t <sub>HRC</sub>	0	117	3	148	782	484	325
Export Electricity	kwh/t <sub>HRC</sub>	7,5	0,0	0,0	0,0	0,0	0,0	0,0

TABLE IV. Results





#### d) Scenario 4: HBI to BF and BOF

The maximum utilization of HBI within the BF-BOF route was considered. MIDREX® Plant set-up was considered, as described in Scenario 2.

#### e) Scenario 5: MIDREX – EAF

The typical DR-EAF route was analysed. The most common MIDREX® NG (natural gas) flowsheet was considered. In order to optimize the OPEX and CO<sub>2</sub> emission, 100% hot DRI (HDRI) directly charged into the EAF was selected, reducing the EAF electrical consumption to 385kwh/tLS [8].

#### f) Scenario 6: Parallel Route with BF-BOF and MIDREX-EAF

A combined route to produce steel adopting a combination of BF-BOF and MIDREX-EAF was considered.

In order to maximize the COG availability within the system rolling mill, reheating furnaces fuelled by a mixture of BFG and available BOFG and fully BFG fuelled BF hot stove plant were considered.

In order to reduce the dependency on natural gas (and therefore also reducing the CO<sub>2</sub> emissions and OPEX), the share of the DRI/EAF route was selected so that a full exploitation of the

COG produced in the BF-BOF route to saturate the 2GJ/tDRI of the MIDREX® Plant was achieved.

#### g) Scenario 7: Full Exploitation of Steelmaking Gasses to Produce HBI

To avoid dependence on natural gas to produce DRI, Midrex developed the MXCOL® flowsheet, fuelled up to 100% by COG as feedstock<sup>[9]</sup>. Accordingly, the parallel installation of a BF-BOF and a MXCOL-EAF was considered. The share of MXCOL/EAF capacity was selected to completely exploit all the available COG and BOFG available within system boundaries.

### Results

The material, energy and gas balance were developed for each scenario. Main results of each scenario, capacity of each plant, as well as energy import/export are reported in TABLE IV.

OPEX and CO<sub>2</sub> emission of the various scenarios are indicated in Figure 7, based on prices shown in TABLE II.

The following clarifications should be noted:

- The DRI plant was coupled with the partial or full use of the steelmaking gasses, with the aim of reducing both CO<sub>2</sub> emissions and OPEX of the system. Therefore, the

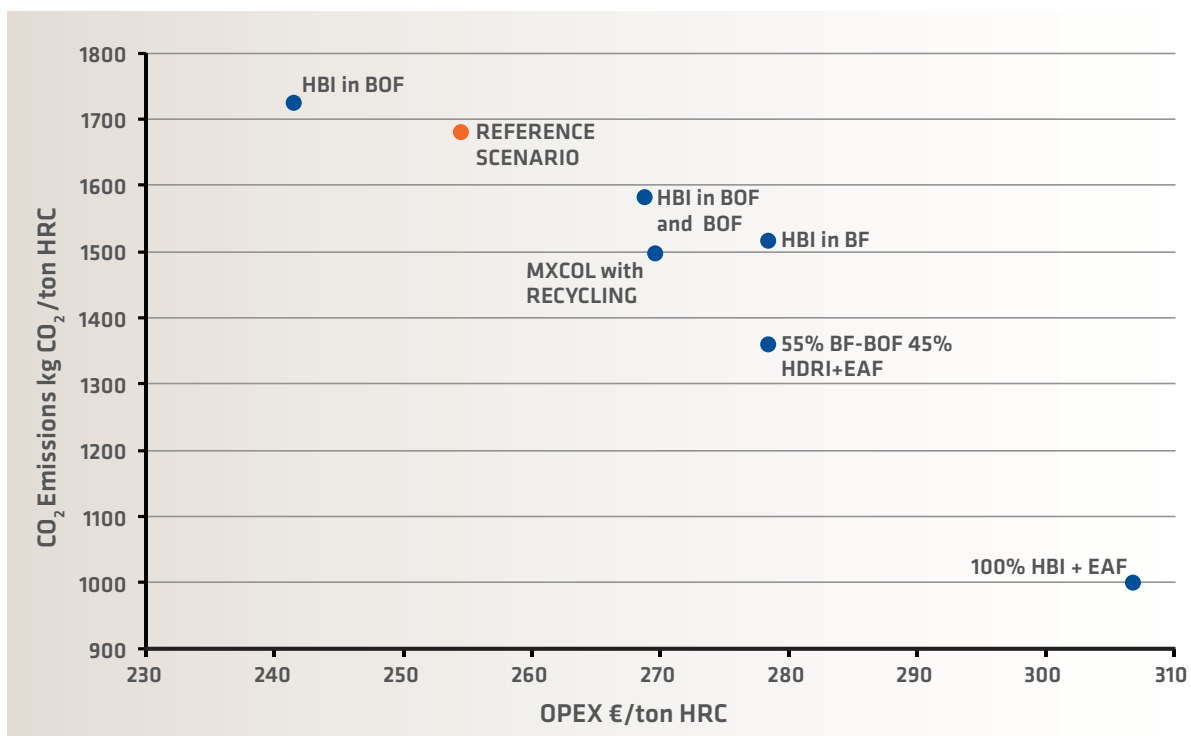


FIGURE 7. Results: OPEX and CO<sub>2</sub> emissions



system energy balance was driven toward an increased import of external electrical energy. In this sense, the plant is increasingly dependent on the reliability of the surrounding electrical infrastructure and to the price and CO<sub>2</sub> specific emission of the electrical energy. Considering the increasing share of electrical energy produced by renewable resources within the EU, it is expected that specific CO<sub>2</sub> emission related to electrical generation will further decrease in the future years. This will result in a further reduction of overall CO<sub>2</sub> emissions, as most of the scenarios are based on strong electrical imports. The gap of such cases compared to the reference scenario, which is electrically independent, will therefore increase.

- In all cases (except scenario 7), DRI is fully or partially produced by natural gas and therefore its price and availability play a key role in the beneficial implementation of such scenarios. The effect of natural gas price was analysed in the chapter, "Effect of Price Scenarios."
- Depending on the relative price of captive HBI and

purchased scrap, it can be economically attractive to self-produce the HBI to replace the scrap in the BOF, as in Scenario 3. However, overall CO<sub>2</sub> emissions are increased because scrap is not associated with any CO<sub>2</sub> emission while CO<sub>2</sub> is emitted to produce the HBI.

- For scenarios in which BF-BOF and DRI-EAF routes are coexisting, determination of the share between the two routes should be carefully evaluated case by case. For instance, if the BF-BOF share is reduced, less steelmaking gasses will be available for use within the DRI route.
- Within the above EU price scenario, DRI production increases the operating costs. It follows that CO<sub>2</sub> reduction can be achieved on a competitive basis only if a proper price environment will be set. <sup>[10]</sup>

### Effect of Price Scenarios

To evaluate the effect of natural gas price, all the scenarios were re-calculated considering a North American condition. In this sense, natural gas and electricity prices were changed while

Material/Media/Utility	UNIT	€/UNIT	REFERENCE
Natural Gas	GJ	1,82	Based on Henry HUB index
Electricity	kWh	0,06	US Government, Texas
Oxygen	Nm3	0,05	Assumed
CO <sub>2</sub> certificate	tonCO <sub>2</sub>	0	Assumed
CO <sub>2</sub> (CO <sub>2</sub> separation)	tonCO <sub>2</sub>	50	Assumed
Labour	hour	30	Assumed
Coke/coal Fines	ton	-50,7	Assumed, based on coal price
Ferrous Fines	ton	-46,0	Assumed, based on pellet price
BF Slag	ton	-20	Assumed
Scrap	ton	302	Based on Metal Bulletin
DR Grade Pellets	ton	78	Based on Metal Bulletin
BF Grade Pellets	ton	69	Based on Metal Bulletin
Coking Coal	ton	76	Based on Metal Bulletin
PCI	ton	49,7	Assumed

TABLE V. Material, media and utility prices: North America scenario (Exchange rate EUR/USD 1,11)





other raw materials prices were kept constant. No CO<sub>2</sub> credit cost was considered and an electricity specific emission factor of 0,522 kgCO<sub>2</sub>/kwh<sup>[2]</sup> was used related to late 2015/early 2016 period. Updated prices are shown in TABLE V.

Updated OPEX and CO<sub>2</sub> emission of the various scenarios according to the North American scenario are shown in Figure 8.

The considerable reduction of the natural gas price compared to the EU scenario resulted in a complete change of the OPEX associated with the various scenarios; in particular, a relative improvement of the OPEX of the scenarios involving HBI production. The different CO<sub>2</sub> emissions are accountable to the higher specific CO<sub>2</sub> emission associated with electrical production in the US.

### CONCLUSION - Lowering the Carbon Footprint Is a Path to Integrated Steel's Sustainability

As worldwide environmental regulations get more and more stringent, steelmakers will need to find ways to maximize their resources while curbing emissions. Integrated mills are the largest contributor of CO<sub>2</sub> by both volume and percentage. Ironmaking alone accounts for 80-85% of total steel industry emissions. Simple process chemistry shows that only so much can be done to limit emission when converting FeO into Fe by the traditional

coke oven-blast furnace method. Operational changes, such as using HBI in the blast furnace can shrink the carbon footprint of integrated steelmakers by decreasing the coke rate and increasing productivity.

Natural gas-based DRI production produces 1/3 the amount of CO<sub>2</sub> as blast furnace iron production. As a result, from mine to finished steel, the DR/EAF route produces at least 50% less CO<sub>2</sub> than the BF/BOF route. However, it is foreseeable, particularly in Europe and North America, that there will be political pressure to keep many of the large, integrated facilities online in order to keep people employed and support local and national economies. This pressure could in fact lead to the building of DRI plants, especially those that produce HBI. The building of DRI plants and increased HBI usage is a much more realistic approach than trying to replace an entire network of integrated facilities with complete DR/EAF complexes.

Long term there will be shuttering of some older, less efficient blast furnaces by increasing the productivity and reducing the emission of more efficient facilities. The use of HBI made by a natural gas-based direct reduction plant is a positive first step, followed by an effort to maximize all essential resources to their fullest. HBI is expected to see significant growth for use in blast furnaces, as exemplified by the decision of voestalpine AG to

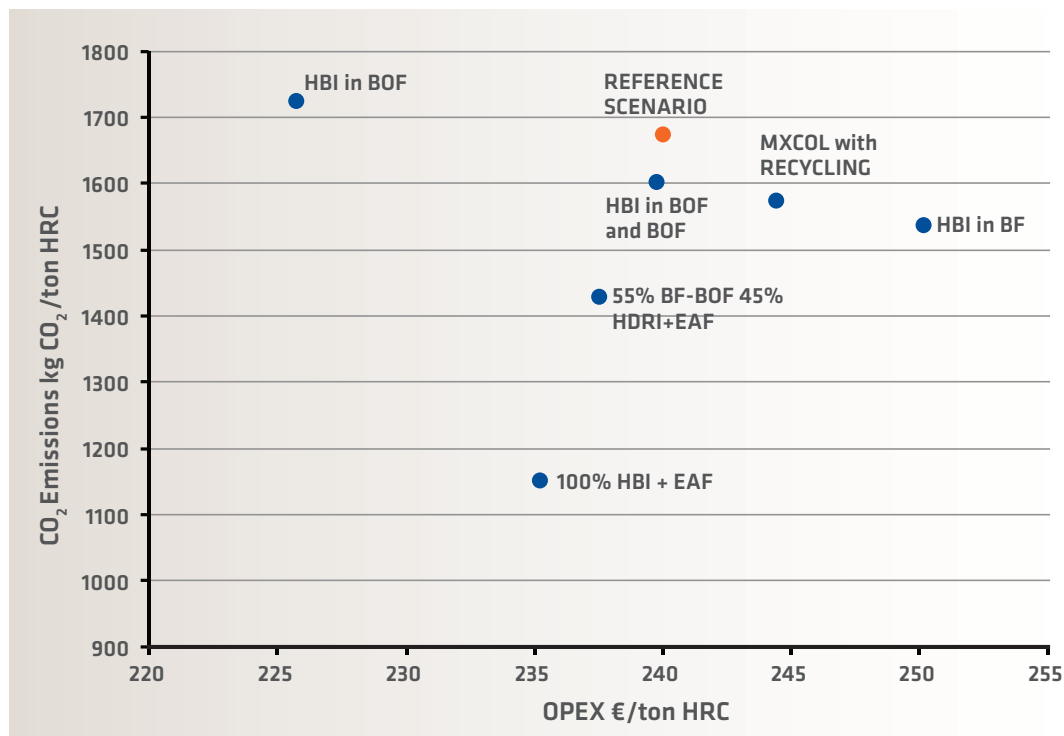


FIGURE 8. Results: OPEX and CO<sub>2</sub> emissions (North American scenario)



build a 2 million metric tons per year MIDREX® HBI Plant in Texas, USA, in order to supply HBI for its blast furnaces in Austria.

It is our opinion that the true impact of direct reduction is yet to be realized by the steel industry. Low cost natural gas, a mainstay of shaft furnace direct reduction technology, is encouraging DRI production in North America and elsewhere. HBI has been used to increase hot metal output in the blast furnace since the 1980s, primarily when the meltshop was hot metal short. However, the environmental benefits of HBI use may be the best alternative for keeping some integrated steel works in operation for years to come.

Thanks to its international presence, technical know-how, expertise and the recent addition of a MIDREX licence, Paul Wurth/SMS Group is open to proactively support the steelmaking industry in seeking to achieve the GHG reduction targets in the years to come. ■

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# - 2016 -

## MIDREX® Direct Reduction Plants OPERATIONS SUMMARY



**MIDREX® Plants produced 47.14 million tons of direct reduced iron (DRI) products in 2016, 3.0% more than in 2015 and 0.02 million tons more than in 2014.** The production for 2016 is estimated from the 31.13 million tons confirmed by MIDREX® Plants located outside of Iran and the 16.01 million tons within Iran, as reported by the World Steel Association, all from MIDREX® Plants. Over 5 million tons of Hot DRI (HDRI) were produced by MIDREX® Plants and consumed in nearby steel shops, assisting these steel shops to reduce their energy consumption per ton of steel and to increase their productivity.

MIDREX® Plants continued to account for approximately 80% of worldwide production of DRI by shaft furnaces. Production of DRI products gradually increased as the world steel industry adjusted to the 'new normal' of greater than 100 million tons per year (Mt/y) of steel exports from China. DRI production growth occurred mainly in Iran, where the commissioning of new plants caused output to be 10% greater than the prior year. Despite continued exports of steel from China, which dampened steel production in many locations worldwide, at least five plants established new annual production records and at least 10 plants established new monthly production records. Twelve additional MIDREX® Modules came within 10% of their record annual production and at least 10 MIDREX® Modules operated in excess of 8000 hours.

Production of CDRI/HBI/HDRI appeared to increase timidly towards the end of the year.

After having fallen dramatically in 2015, iron ore prices recovered partially in 2016, nearly doubling from just over \$40/t in January to almost \$80/t in December. *Note: This is in reference to the world bellwether figure for 62% sinter fines, as delivered to northeast China.* This number was still far short of the high of nearly \$190/t experienced in 2011. The changes in price are primarily driven by supply growth by the major world miners (Vale, Rio Tinto and BHP) and demand growth by the major world consumer, China. Rising prices in 2016 reflected greater than expected fixed asset investment within China simultaneous to carefully controlled supply increases by the major miners. The continued closure of the Samarco mine and pelletizing plant strongly supported ore prices, especially for DR grade pellets.

Meanwhile, the price for DRI also grew markedly. For instance, the delivered price of HBI to Italy increased by more than \$100/t between January and December.

One new MIDREX® Module producing HBI started up in 2016: voestalpine Texas LLC, located near Corpus Christi, Texas, USA, a wholly owned subsidiary of voestalpine Steel Division of Austria, produced its first HBI in September.

MIDREX® Plants have produced a total of more than 920 million tons of DRI/HBI through the end of 2016.



## 2016 PLANT HIGHLIGHTS

*Note: No DRI production data was received from the plants located in Iran at the time of this publication.*

### ACINDAR

ACINDAR's MIDREX® Plant started off the year operating close to maximum capacity but ended the year at reduced capacity after the typical winter natural gas curtailments due to a downturn in the local market for long products. In 38 years of operation, ACINDAR's MIDREX® Plant has produced 29.15 million tons, the most by a single MIDREX® Module to date.

### ANTARA STEEL MILLS

The first MIDREX® Plant designed to make HBI produced 2% under annual rated capacity due to market constraints.

### ARCELOMITTAL HAMBURG

In its 45th anniversary year, AM Hamburg's MIDREX® Plant, the oldest in operation (since 1971), comfortably exceeded annual rated capacity in 2016, averaging over 79 t/h, and came within 1% of its record annual production set in 2004 and its monthly production record set in August 2015 while maintaining DRI quality of 95% metallization.

### ARCELOMITTAL LAZARO CARDENAS

AMLC produced 8% over its rated capacity of 1.2 million tons. Production rate averaged more than 180 t/h for the year. AMLC surpassed 29 million tons cumulative production since its start-up in August 1997.

### ARCELOMITTAL MONTREAL

After setting annual production records for two consecutive years in 2013 and 2014 and almost equaling its 2014 production record in 2015, Module II's production was within 5% of its 2014 record production despite reducing production near year end. Module I's production for the year was well over rated capacity despite being down for the first three months of the year due to market conditions. Module I and Module II almost equaled their monthly production records, both falling short by less than 1%.

### ARCELOMITTAL POINT LISAS

All three of AMPL's MIDREX® Modules remained shut down throughout the year.

### ARCELOMITTAL SOUTH AFRICA (SALDANHA WORKS)

Operation of the COREX® export gas-based MXCOL® Plant was limited by the availability of gas from the COREX® Plant, which was down for major maintenance during August and September. The MXCOL® Plant used on average more than 68% South African lump ore for the year.



ACINDAR



ArcelorMittal Montreal



ArcelorMittal Hamburg



ArcelorMittal Lazaro Cardenas



ArcelorMittal South Africa





## COMSIGUA

COMSIGUA operated at reduced capacity for about one-third of the year due to the limited supply of locally produced pellets. COMSIGUA has produced 15 million tons of HBI since initial start-up in 1998.

## DELTA STEEL

The two Delta Steel MIDREX® Modules did not operate.

## DRIC

DRIC's two MIDREX® Modules in Dammam, Saudi Arabia, were limited by the demand of their neighboring Al-Tuwairqi steel shops. Module 2, which operated over 8100 hours in 2016, was within 5% of its annual production record and set a new monthly production record in February.

## ESISCO

Due to the high price and reduced availability of natural gas in Egypt, as well as the competition of foreign steel products, ESISCO did not operate.

## ESSAR STEEL

With the economic equation moving in favor of DRI production due to a drop in natural gas prices in India, Essar restarted Modules 4, 3 and 2 in February, May and October, respectively. Modules 5 and 6 operated the whole year, using off-gas from Essar's COREX® Plant as part of their energy input. Module 6 twice broke its previous monthly production records, in March and December.

## EZDK

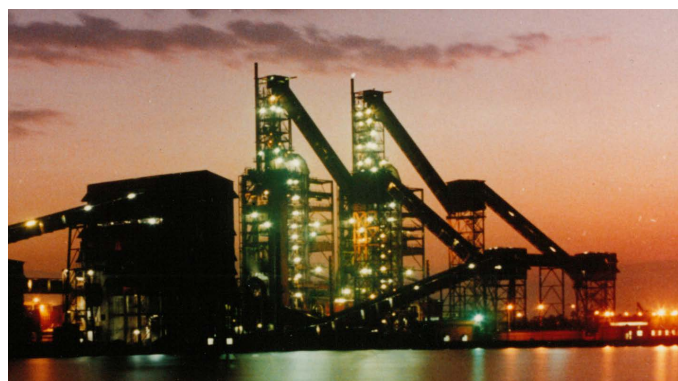
Limited by natural gas availability in Egypt, EZDK's MIDREX® Modules production increased to just over 1.75 million tons, which is about 58% of their maximum capacity. Since its initial start-up 30 years ago, Mod 1, rated for 716,000 t/y, has produced 24 million tons despite a slowdown in the last few years and operating for only about 3 months in 2016 due to the limited availability of natural gas. EZDK has focused on maximizing production of DRI with the natural gas available to them.

## FERROMINERA ORINOCO

Ferrominera Orinoco's MIDREX® HBI Plant in Puerto Ordaz operated at reduced capacity of seven months, producing approximately 21% of its total annual rated capacity due to limited availability of locally produced oxide pellets in Venezuela.



*Comsigua*



*Essar Steel*



*EZDK*



*Hadeed Modules A and B*





## HADEED

Hadeed exceeded rated capacity for the 32nd consecutive year in Modules A and B and for the 24th consecutive year in Module C. Modules A and B averaged an exceptional 8630 hours of operation and were within 10% of their production records. Hadeed's Module E produced within 1% of its rated capacity despite a major maintenance shutdown in October. Module E fed over 50% of its production as HDRI to an adjacent EAF while producing the balance as Cold DRI (CDRI) for another of Hadeed's EAFs. Hadeed's four MIDREX® Modules have produced more than 82 million tons of DRI to date.

## JINDAL SHADEED

In 2016, Jindal Shadeed produced 1.3% less than its production record set in 2015, limited by the availability of natural gas. The plant operated 8114 hours during the year. This MIDREX® Plant is designed to produce mainly HDRI, with HBI as a secondary product stream. A major portion of its production (80%) was consumed as HDRI by Jindal Shadeed's own steel shop adjacent to the DR plant.

## JSPL (ANGUL)

Jindal Steel and Power Ltd.'s (JSPL) combination HDRI and CDRI plant in Angul, Odisha State, India, set a new monthly production record in January. This is the first MXCOL® DRI plant using synthesis gas from coal gasifiers to produce HDRI and CDRI for the adjacent steel shop. Operation began in 2014, and in 2016, more than 84% of its DRI production was supplied hot to the steel shop.

## JSW STEEL (DOLVI)

JSW Steel's MIDREX® Plant producing CDRI came out of a major maintenance shutdown in early January and set a new annual production record, operating 8331 hours at increased production rates and exceeding the previous record set in 2009 by 12%. The plant also set a new monthly production record in December and operated 122 days in February through June without a stoppage. A new system installed at the end of 2014 to reduce DR plant natural gas consumption operated throughout the year. The system adds Coke Oven Gas (COG) from JSW Steel's on-site coke oven batteries to the MIDREX® Shaft Furnace. The MIDREX® Plant, rated for 1.0 million tons per year, has produced over 25 million tons and has operated over 8000 hours on average per year since its start-up in September 1994.



*Hadeed Module E*



*Jindal Shadeed*



*JSPL (Angul)*



*JSW Steel (Dolvi)*



*JSW (Toranagallu)*



### JSW STEEL (TORANAGALLU)

JSW Steel's cold/hot DRI plant using COREX® export gas in Toranagallu, Karnataka State, India, started up in August 2014, set a new annual production record and broke monthly production records twice in 2016. This is the second plant of its kind, the first one being the COREX®/ MIDREX® Plant at Saldanha, South Africa.

### LEBEDINSKY GOK

LGOK's MIDREX® HBI-2 Module produced 13% over its rated capacity, only 3.3% under its record production in 2015, with 8288 hours of operation in 2016. This comes on the heels of an also commendable 8254 hours of operation in 2015.

### LION DRI

The Lion DRI plant, located near Kuala Lumpur, Malaysia, continued operating at reduced production levels into January, when it was shut down due to insufficient market demand for locally produced steel products in Malaysia.

### LISCO

The production at the three MIDREX® Modules in Misurata, Libya, increased 53% over 2015 totals but continued to be restricted by natural gas supply.

### NU-IRON

In its 10th anniversary year, Nucor's MIDREX® Plant in Trinidad and Tobago operated within 5% of its annual production record after establishing annual production records the previous two years. Average DRI metallization for the year was the highest of all MIDREX® Plants at 96.07%, with 2.74% carbon in the DRI. At the end of November, Nu-Iron was restarted using oxygen injection to further boost production.

### OEMK

OEMK produced over 3.0 million tons in 2016, with Modules 1 and 4 setting new annual and monthly production records. Modules 2 and 3 came within 3% of their annual production records. The average operating hours for OEMK's four modules was an exceptional 8459 hours in the year. OEMK's four modules have produced over 63 million tons since start-up of the first module in December 1983.

### QATAR STEEL

In its 9th full year of operation, Qatar Steel's dual product (CDRI and HBI) Module 2 produced 6.6% below its record production



LGOK HBI-2



LISCO



Nu-Iron Trinidad and Tobago



OEMK





after establishing new annual production records each of the five previous years. This **MIDREX® Module** operated 18% over its rated annual capacity of 1.5 million t/y, totaling 1,762,564 tons for the year, and broke its monthly production record twice, in March and in May, with hourly production rates of 231 and 232 t/h, respectively. Almost the entire production from Module 2 was CDRI, with metallization averaging 94.7% for the year. The production of Module 1 was only 7.2% below its record annual production.

### SIDOR

Production from all four of Sidor's **MIDREX® Modules** was 0.66 million tons, limited by oxide pellet and natural gas availability. Module 2C remained shut down the whole year.

### SULB

SULB's 1.5 million tons/year combo **MIDREX® Plant** (simultaneous CDRI and HDRI production) in Bahrain was limited by market demand in its 3rd full year of operation but did establish a new monthly production record in March, averaging 196.5 t/h. HDRI sent directly to the steel mill accounted for 67% of DR plant production, while over 70% of the CDRI produced was shipped to third parties by sea.

### TENARISIDERCA

In its 40th anniversary year, TenarisSiderca operated well below maximum capacity and was down from February through August due to limited DRI demand by the steel shop and natural gas curtailments during the winter months.

### TUWAIQI STEEL MILLS

The Tuwairqi Steel Mills 1.28 million tons/year **MIDREX® Plant** located near Karachi, Pakistan, did not operate due to market conditions

### VENPRECAR

VENPRECAR's HBI production was restricted by the limited availability of iron ore pellets in Venezuela.

### voestalpine TEXAS

The new voestalpine Texas **MIDREX® Plant** located near Corpus Christi, Texas, USA, designed to produce 2.0 million tons of HBI per year, was successfully started up at the end of September and exported its first shipment of HBI to the steel mills of voestalpine AG in Austria in 2016.



*Qatar Steel*



*SULB*



*TenarisSiderca*



*voestalpine Texas*





## MIDREX News & Views

# World's largest single module HBI plant completes Performance Guarantee Test at voestalpine Texas LLC

**I**t was announced this quarter that the 2.0 million metric ton per year MIDREX® HBI plant at voestalpine Texas LLC passed its performance test in early February of 2017. The voestalpine Texas MIDREX® HBI plant is both the largest single module of its kind in the world, as well as North America's first HBI merchant facility. voestalpine Texas LLC is the local presence in South Texas of the voestalpine Group and a 100% subsidiary of voestalpine Steel Division.

The Performance Guarantee Test (PGT) began on January 29, 2017. Measurements included HBI production, HBI physical and chemical characteristics, the plant's key natural gas and electricity consumption, water quality measurements and environmental / emissions impacts. The PGT was successfully completed on February 11, 2017, and the plant achieved 100% of tested performance guarantee parameters during the first attempt of the PGT.

Primetals Technologies and Midrex were responsible for engineering, supply of bulk materials, mechanical and electrical equipment and advisory services for the MIDREX® plant. The MIDREX® plant produces high-quality HBI from iron ore pellets using the MIDREX® Direct Reduction Process and through the use of natural gas significantly reduces the carbon footprint of the voestalpine Group. This is an impor-

**MIDREX**  
Designed for Today,  
Engineered for Tomorrow



tant step in the achievement of the voestalpine Group's ambitious internal energy efficiency and climate protection objectives. The price of natural gas in the USA is about one-quarter of the price in Europe. Around half of the planned two million tons of HBI will be supplied to the Austrian steel plants in Linz and Donawitz. The other half will be sold to partners interested in a supply over the long term. ■





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- designed to work reliably
- designed to make life easier

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by Midrex to work for **you.**

Christopher M. Ravenscroft: Editor

**DIRECT FROM MIDREX** is published quarterly by  
Midrex Technologies, Inc.,  
2725 Water Ridge Parkway, Suite 100, Charlotte,  
North Carolina 28217 U.S.A.,  
Phone: (704)373-1600 Fax: (704)373-1611,  
Web Site: [www.midrex.com](http://www.midrex.com) under agreement  
with Midrex Technologies, Inc.

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

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