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3RD QUARTER 2018



MIDREX TECHNOLOGIES INC.

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BILLION TONS
of MIDREX® DRI

MIDREX
= 1969-2018 =

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COMMENTARY

WHAT DO WE REALLY DO?

By John Kopfle
Director – Corporate Development



At Midrex Technologies, we design, build, start-up, and improve MIDREX® DRI Plants. If you ask a member of the Midrex team what they do at work, they might respond: “I design MIDREX® Plants” or “I purchase equipment used in MIDREX® Plants” or even “I help construct and start-up MIDREX® Plants.” All these job descriptions are true. However, direct reduced iron (DRI) is not a finished product. It is used primarily in electric arc furnaces (EAF) to make new steel – steel that is used to construct buildings, roads, automobiles, and appliances. Thus, the impact of MIDREX® Plants goes far downstream, even beyond steel.



Ultimately, working at Midrex allows us to make a major contribution towards the supply of goods and infrastructure that builds economies around the world. In a very real way, steel enables people to achieve a more secure and fulfilling life for their families. Imagine children in Egypt who attend a school constructed using rebar made with MIDREX® Iron, or a family in India that has electricity for the first time because of transformers that are made from steel that was created using DRI from a MIDREX® Plant, or a farmer in Texas whose tractor was made from steel plate using MIDREX® Iron.

We are proud of the fact that MIDREX® Plants make a considerable impact on local and national economies.

As many as 1,000 construction jobs are needed for 2-3 years while a MIDREX® Plant is being built. After a plant is started up, 150-300 permanent, full-time, well-paying jobs are created in operations, maintenance, administration, and product sales. If the MIDREX® Plant is part of a larger steelworks, the number of jobs created will be even greater.

The annual economic impact of a steel complex on the local and national economy can be several billion dollars. In addition to the direct economic impact, the multiplier effect - accounting for additional growth resulting from investment - can range from 2-to-5. This means that every dollar of investment creates an additional one-to-four dollars of income. This is why industrial facilities are highly sought after by government leaders.

Every day, Midrex team members conduct research experiments, perform engineering calculations, make sales visits, buy proprietary equipment, and provide aftermarket service. The work we do is truly satisfying because we know it is likely to contribute to a better standard of living for someone. We are especially proud of the part Midrex plays in helping transport, feed, educate, and care for people all around the world.

So, what do we really do? We supply and support MIDREX® Plants, which helps create greater wealth and prosperity worldwide to make peoples' lives better. ■



DRI TECHNOLOGY INNOVATION – VARYING THE CARBON IN HBI

Results of Lab Trials of MIDREX ACT™



By Vincent Chevrier, PhD; Director–Research & Technology Development, Midrex Technologies, Inc.

INTRODUCTION

Modern electric arc furnaces (EAF) make better use of chemical energy; therefore, EAF steelmakers have greatly increased the use of carbon and oxygen as energy sources to reduce electricity consumption and increase productivity. Ore-based metallics, such as pig iron and direct reduced iron (DRI), are frequently added to the EAF scrap charge for their pure iron units. However, many EAF steelmakers have espoused the practical benefits of higher carbon levels in DRI in recent years, making it more like pig iron in chemical composition.

By nature, the more carbon added to DRI products, the less iron the product will contain. There is no universal optimum carbon level established for DRI products, as the physical and chemical requirements are different for cold DRI (CDRI), hot DRI (HDRI), and hot briquetted iron (HBI) and are further influenced by the amount included in the metallic charge and the steel grade being produced. No application is the same, and product usage can vary greatly over time within a company, and even within a melt shop.

HBI currently is produced in the 1-2% carbon range because increasing carbon levels beyond that range would lower the

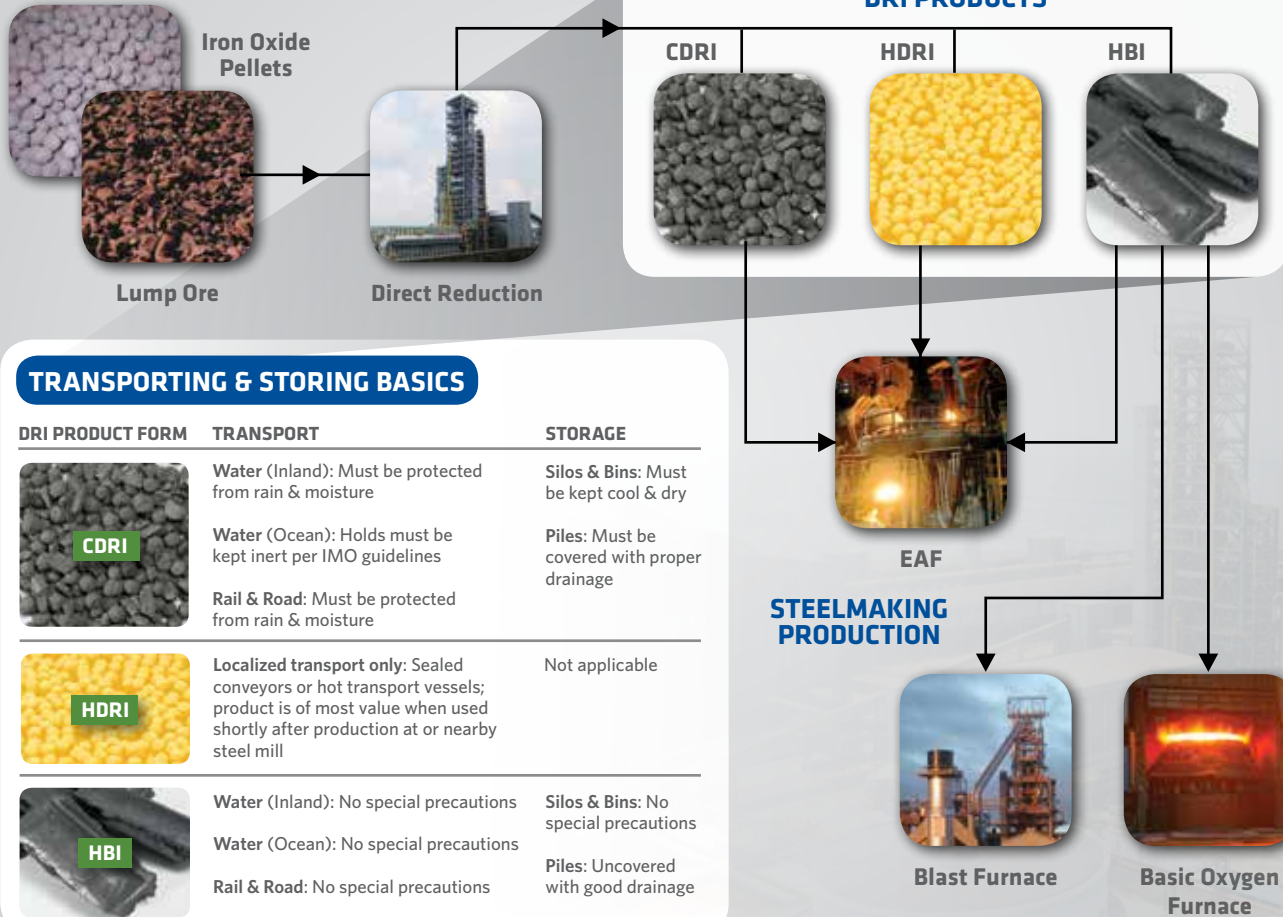
briquetting temperature, which in turn would adversely impact product quality. In 2017, Midrex introduced the patented **Adjustable Carbon Technology (ACT™)**, which allows the plant operator to add carbon in DRI without sacrificing temperature and to independently control carburization and temperature over a wide range of operating conditions. This technology is available for both existing and new MIDREX® Plants and can be a unique differentiator for merchant HBI plants, as product quality can be tailored to the specific needs of the customers while maintaining the physical strength of the HBI which enables very high yield during transportation, handling, and melting.

THE NEED FOR VARIABLE CARBON IN DRI PRODUCTS

Although the primary appeal of DRI products in EAF steelmaking is for its virgin metallic iron units, the percentage of carbon within the DRI also can play a key role for the steelmaker (*Figure 1*). The percentages of carbon in DRI and the advantages of that carbon are situationally based on various steelmaking conditions (*Figure 2*). In the EAF, carbon is used: (1) to reach the required melt chemistry specification of the steel desired or for further refining; (2) to reduce any remaining FeO in the scrap or DRI; and (3), as an additional energy source to help melting.



FLOW OF DRI PRODUCTS



TRANSPORTING & STORING BASICS


DRI PRODUCT FORM	TRANSPORT	STORAGE
 CDRI	Water (Inland): Must be protected from rain & moisture Water (Ocean): Holds must be kept inert per IMO guidelines Rail & Road: Must be protected from rain & moisture	Silos & Bins: Must be kept cool & dry Piles: Must be covered with proper drainage
 HDRI	Localized transport only: Sealed conveyors or hot transport vessels; product is of most value when used shortly after production at or nearby steel mill	Not applicable
 HBI	Water (Inland): No special precautions Water (Ocean): No special precautions Rail & Road: No special precautions	Silos & Bins: No special precautions Piles: Uncovered with good drainage

FIGURE 1. Flow of DRI products in steelmaking

Carbon in DRI is first used to reduce any FeO to metallic iron (each 100 kg of FeO requires 16.7 kg of carbon). Therefore, DRI at 96% metallization will need less than 1.0% carbon for this purpose, while 93% met DRI will require about 1.5% carbon. Any remaining carbon is available for oxidation and can be burned to provide additional heat energy, supplementing the heat from the electric arc. Carbon can be added through injection into the EAF or charged as contained carbon in the DRI itself.

Carbon contained in the DRI can be very valuable to the steelmaker if it can be adequately utilized (Figure 2). The idea is to use the additional carbon to help melt the steel quicker

to reduce tap-to-tap time and increase productivity. This is the primary reason that many EAF producers who mix scrap and DRI/HBI desire carbon levels above 3%. However, it must be noted that excessive carbon in the DRI will be in the bath until it is blown down with oxygen.

Thus, even though additional carbon can be viewed as an extra form of energy, it is possible to have too much carbon. This is defined as carbon that does not add any value to the production or further decrease the tap-to-tap time of a steel heat. Any carbon above specification of the steel after the iron is melted needs to be removed. The extra time consumed in decarburizing



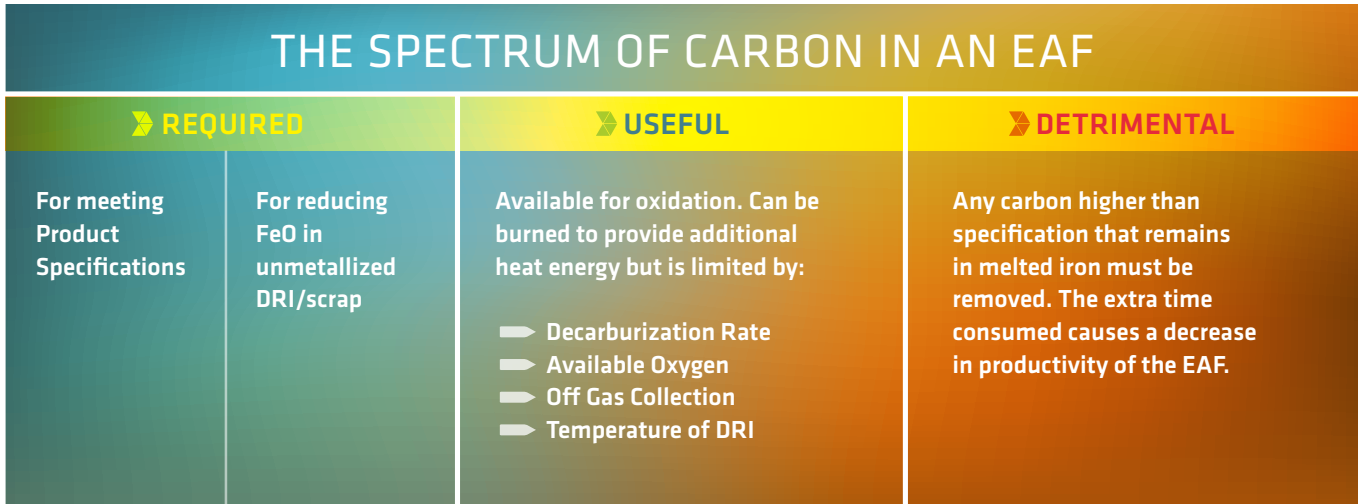


FIGURE 2. The spectrum of carbon in DRI products

causes a decrease in productivity of the EAF.

EFFECT OF VARIABLE CARBON ON PHYSICAL PROPERTIES OF HBI

Commercial HBI plants of any process have not produced HBI above 3% carbon in large quantities due to degradation of the HBI. Carburization by methane is endothermic, leading to lower briquetting temperature, which is very detrimental to the briquette quality. Temperature and carbon control are decoupled with MIDREX ACT™, giving HBI producers the ability to adjust carbon while maintaining a high briquetting temperature. So, in addition to the known benefits of HBI in terms of yield and reactivity during transportation, HBI of various carbon levels can be produced with desirable physical properties of strength and density.

While the overall effect of carbon and temperature on HBI properties has been experienced by plant operators for years, there is very limited data available. Only one pilot-scale study has been published by Tenova HYL/Köppern⁽¹⁾, but it was very limited in scope. To our knowledge, there has never been a complete study on the effect of carbon and temperature independently on HBI properties.

According to the theories of powder metallurgy and compaction of metal powders, the overall strength of the resulting compact is proportional to the amount of plastic deformation during compaction. During plastic deformation, highly metallic particles interlock and form metallic bonds or “cold-weld”. The amount of plastic deformation is a function of the overall ductility and compaction parameters of the material, such as pres-

sure and temperature. An increase in compaction pressure and compaction temperature increases the amount of plastic deformation, therefore, increasing the overall mechanical properties. Conversely, an increase in the amount of carbon present in the iron as iron carbide (Fe₃C) will decrease the material’s ductility and lower the amount of plastic deformation and the mechanical properties of the compaction. Losses in compaction strength of iron due to carbon addition can be offset by an increase in compaction pressure and temperature.

TESTING METHODOLOGY AND ASSESSMENT OF HBI QUALITY

The development of MIDREX ACT™ involved various tests to better understand how the technology would impact DRI product quality, especially the density of HBI, and to minimize scale-up risks. Our approach was to conduct several bench-scale tests that were cheaper and easier to perform, then increase to pilot-scale, and ultimately move to commercial-scale. For our study, we started with hot compaction tests, then moved to our hot briquetting pilot plant, and finally confirmed trends in industrial plant trials.

Drawing from the vast experience and plant data of Midrex, all tests performed in the lab used commercial pellets and conditions like in existing MIDREX® HBI plants for benchmarking purposes. It is important to note that these tests were meant to be comparative, not absolute. Results from hot compaction cannot be extrapolated to an operating HBI plant because there are too many variables that cannot be replicated on a small scale. We were looking for trends and confirmation that those



trends could be scaled up.

Density is a very important characteristic for merchant HBI and affects how it is shipped around the world over international waters. The International Maritime Bulk Cargoes Code (IMSBC), published by International Maritime Organization (IMO), defines HBI as, "Direct Reduced Iron (A), produced by reducing iron oxide lumps, pellets, or fines and compressing at a temperature of at least 650°C to achieve an apparent density of 5.0g/cm³." It should be noted that domestic HBI shipments by rail or truck are not subject to the density requirements of the IMSBC.

Compacts and briquettes produced for the trials were analyzed at the Midrex Research and Technology Development Center. HBI apparent density was measured according to ISO 15968:2000, and HBI tumbling index according to ISO 15967, although Midrex uses 6.7mm screen rather than 6.3mm and hot compactions are tumbled in a 0.5m tumble drum for 100 and 300 revolutions.

HOT COMPACTION TESTS

Hot compaction tests (also called piston-tests) are designed to simulate the hot briquetting process by placing approximately 180g of HDRI into a die that is pressed hydraulically. While the productivity is very low, this method gives us the ability to control many variables for parametric studies and does not require large DRI samples.

We have access to DRI produced in MIDREX® Plants or we can produce our own DRI in small, medium, or large batches (*Figure 3*). With these furnaces, we can replicate DRI produced in operating plants, make DRI with untested iron ore, and make DRI outside of typical production ranges as needed for testing. All furnaces have full control of reduction/carburization time, temperature, and gas composition so we can optimize the desired metallization (%met), carbon (%C), and cementite (%Fe₃C). The limitations are that these furnaces are externally heated (i.e. not adiabatic), batch processes and the bed does not move, as in a MIDREX® Shaft Furnace. For the hot compaction tests, we used the medium furnace that produces batches of 1,500g of DRI.

TEST PROCEDURE

The hot compaction equipment design and test procedures were developed in collaboration with Köppern Equipment, Inc. The DRI samples and dies were pre-heated according to our



FIGURE 3. Reduction furnace and hot compaction test apparatus

established procedure, which also defines heating rates and soak times.

The pre-heated die is placed under the piston press and the hot DRI vessel is placed on top of the die. Hot DRI is then discharged into the die by opening a slide gate on the bottom of the preheat vessel. For safety reasons, the steel door must be locked. Compression is triggered by two buttons on opposite sides of the door. Pressing force and pressing time are controlled by the PLC. Despite all the controls in place, proper execution and timing by the technician is critical to obtain quality data. For each data point, a total of 6 compacts are made: three samples are used for compression testing and for chemical analysis while the remaining three are used for tumble drum testing.

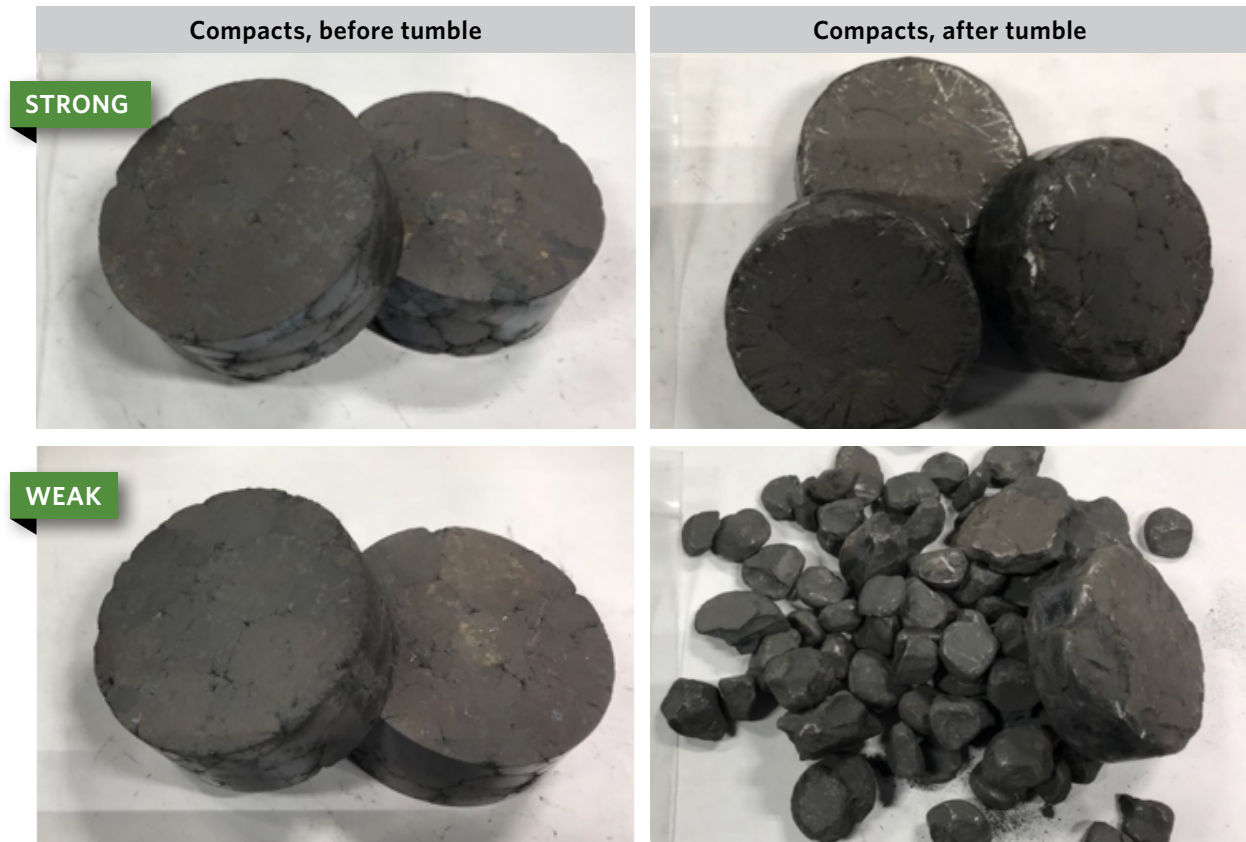


FIGURE 4. Compacts before and after tumble

Validation tests were performed to verify repeatability and reproducibility. Based on Midrex experience with commercial HBI, we used oxide pellets from two different plants and made DRI in the lab according to our procedures. One supply of oxide is notoriously difficult to briquette commercially, while the other is much easier. Under the test protocol developed, we saw a difference between strong and weak compacts as shown in *Figure 4*.

A complete parametric study was performed and documented by Andrew Ruthenbeck of the Midrex Research & Development Technology Center⁽²⁾ to quantify that effect over a larger scale than what can be achieved in commercial HBI production. However, in this article, only the key findings are presented.

EFFECT OF TEMPERATURE

From many years of plant operation, it is well known that the DRI temperature during the briquetting process is the dominant factor in HBI quality. The next series of tests was designed to quantify that effect over a larger

scale than what can be achieved in commercial HBI production. Temperature also affects factors like segment life, but this cannot be studied at laboratory scale.

The temperature in *Figure 5* is the pre-soak temperature of the DRI

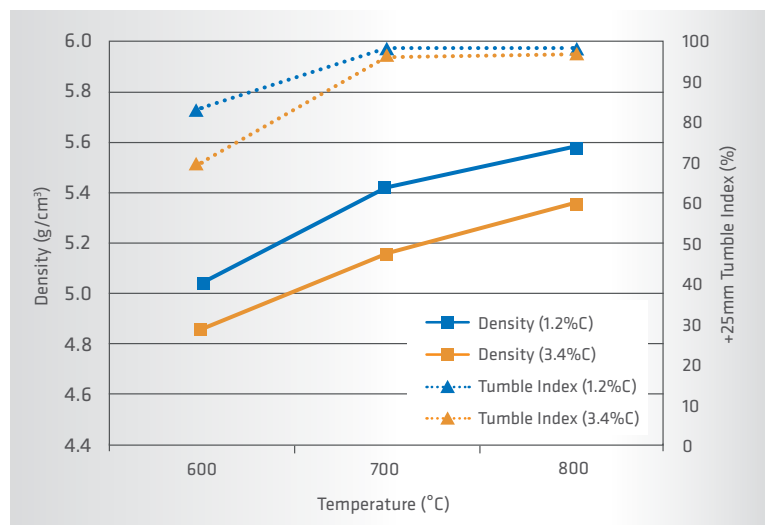


FIGURE 5. Effect of DRI temperature on compact quality, for low and high carbon DRI (200MPa)



prior to compaction. Some temperature loss is expected during the handling of the DRI prior to the compaction, but it cannot be measured accurately. Regardless, *Figure 5* shows that the DRI temperature has a strong effect on both density and strength.

EFFECT OF CARBON

In this test, DRI was produced in the lab-scale reduction furnace at various levels of carbon from two commercial iron ore pellets. It was produced at a high degree of metallization to minimize carbon loss during reheat – all compacts finished above 97% metallization. Similarly, carburization was designed to achieve an elevated level of cementite to account for losses in reheating.

Figure 6 shows the expected decrease in density, as iron is being displaced by carbon, which is less dense. The curves are explained solely by mass balance and no other factor comes into play. This means we can extrapolate HBI density as a function of carbon for existing plants interested in MIDREX ACT™.

Tumble index decreased with increasing carbon, as expected. However, the decrease in strength was not steep in the range of interest. If the key parameters of DRI temperature and pressing force are maintained, strong compacts can be produced at higher levels of carbon. Even above 4.5% carbon, there is sufficient plastic deformation to create the strong metallic bonds for a strong compact.

LESSONS LEARNED

Not surprisingly, this parametric study confirmed the theory, and the observed behaviors in a commercial plant- temperature and pressing force- have a strong influence on briquette quality. Under the right conditions, any DRI can be made into strong compacts or briquettes. However, this small-scale testing allowed us to isolate and quantify the relative effect of those variables individually. While the results obtained on density and tumble index are not to be extrapolated to plant performance, we can see the relative impact of these factors that are known to effect HBI quality- DRI temperature and pressing force- have a more significant impact than carbon.

The key learning from this study was the defi-

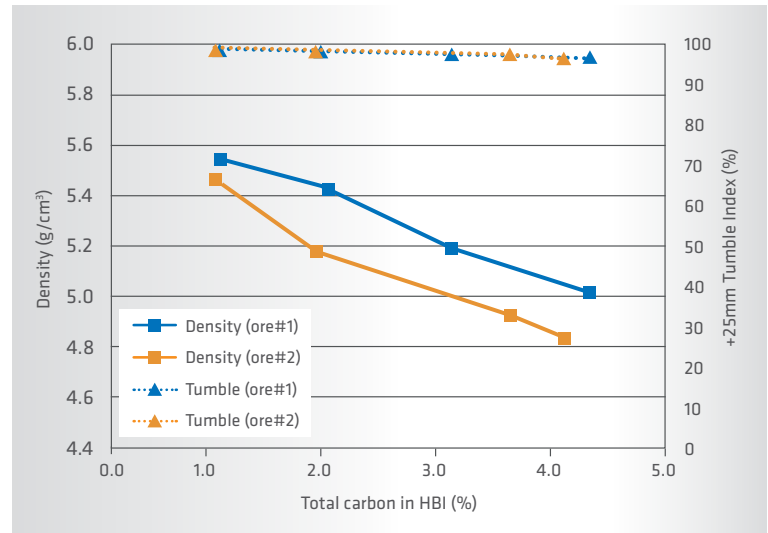


FIGURE 6. Effect of total carbon on compact quality (700°C, 200MPa)

nition of a test protocol (matrix) that can estimate the briquetting performance of a given ore. The results also were benchmarked against known ores used to produce HBI in MIDREX® plants. Therefore, for a small investment, we can make a go/no go decision on whether to proceed to larger scale testing and minimize risks doing so.

HOT BRIQUETTING TESTS

The hot briquetting tests were conducted following a similar approach to hot compaction. First, the DRI was made in the large reduction furnace, where reducing/carburizing gases were preheated, then passed through a fixed bed of DRI. The typical batch size was 400kg. After achieving the desired DRI quality, the retort was emptied carefully, keeping track of the location of the material in the retort. Each layer was analyzed independently (metallization, carbon and cementite). Depending on the desired DRI quality, layers were either mixed within a batch or combined with other batches (made under identical conditions) to minimize the variability of the material.

After carefully homogenizing, the DRI was loaded into a conical transfer vessel, which was then loaded in the furnace and heated under inert atmosphere. The heating profile is critical to maintaining carbon as cementite, rather than dissociating it into iron metal and graphite. The target DRI temperature for all data presented in this article was set to 750°C, which then cooled during transport to the briquetting press. Once the center bed thermocouple reached the desired temperature, the retort was lifted over the Köppern briquetting machine. Proper execution and timing was crucial so the DRI does not lose excessive temperature in the transfer. DRI temperatures at the feed screw were approximately 700°C. Both DRI and HBI temperature were measured



FIGURE 7. Large reduction furnace and HBI coming off the Köppern press

and recorded for each test. The steady-state HBI temperature varied for each test around 680°C.

Compared to a commercial HBI plant, our machine has smaller diameter rolls (0.75m vs. 1.0m typical) and operates at lower speed and lower pressing force. The other key limitation is that the dies are not preheated and do not achieve steady-state during the ~2-minute run. The operation setpoints were selected based on several trials using known / commercial iron ores, with the aim to produce a HBI that has similar properties (such as density) to a MIDREX® HBI Plant where the ore is used. In other words, the pilot-scale briquetter is used to produce HBI realistic to an actual MIDREX® HBI Plant.

The HBI was discharged into a pan. Immediately after the test, the HBI produced in near steady-state was segregated from the beginning and end-of-run material, which is of lower quality. It was spread and allowed to cool in ambient temperature. Initial trials with quenching the HBI did not indicate any significant difference in product quality.

After cooling, the HBI was tested for chemistry (metallization, carbon, and cementite) and used for physical testing. All test runs experienced a minor loss in carbon and a reversion of cementite (Fe_3C) to iron and carbon, despite our best efforts to minimize this loss. This is strictly due to heating and cooling in a large fixed-bed retort. Both

graphs in Figures 8 and 9 show the HBI analysis, not the analysis of the DRI that was used to make it.

Figure 8 shows the effect of carbon on the HBI density for three different commercial iron ore pellets. The density is the average of five briquettes for each test. As expected, density decreases with increasing carbon for a given iron ore.

The effect of total carbon (in HBI) on the HBI strength is plotted in Figure 9. The tumble index is measured using a 1000 mm diameter drum with 500 mm width for 200 revolutions at 25 rpm. In this graph, we elected to show the +6.7mm tumble index, as it is more representative of strength in relation to yield losses.

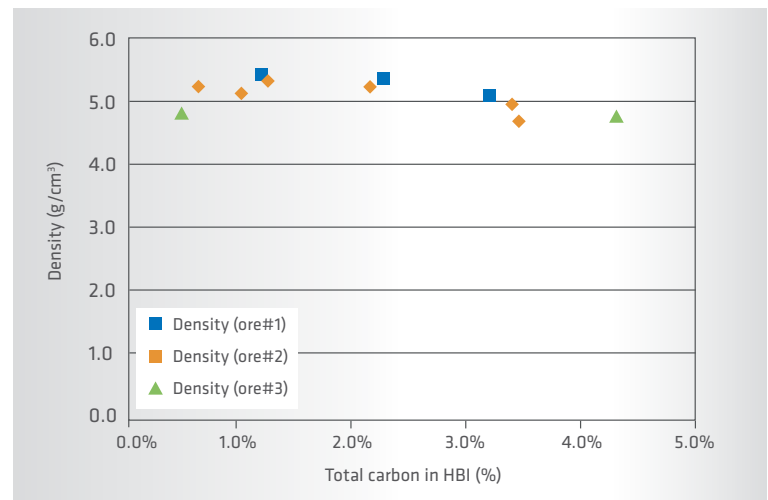


FIGURE 8. Effect of carbon on pilot-scale HBI density for 3 different iron ores



The trend clearly indicates that increasing carbon reduces HBI strength, but this effect is limited in the carbon range of 1% to 5% (with other key briquetting parameters kept nearly constant). Strong HBI can be made even at high carbon, provided that the DRI is briquetted with sufficient temperature.

For these tests, we focused the hot briquetting tests on varying carbon/cementite, using three commercially available iron ore pellets. The trends observed are identical to the hot compaction tests: the presence of carbon does impact the physical properties of the HBI:

- For density, the relationship is linear and according to the mass balance (where the weight of iron is displaced by carbon). While not surprising, this is a good point to prove. Density can be estimated based on the carbon content of the DRI, and there is no additional risk.
- The strength of HBI decreases with increasing carbon (at a given briquetting temperature), but maintains adequate strength over a wide range.

While we cannot extrapolate the results to a commercial plant, we expect this trend to remain. Presently, there are no HBI plants of any process that can independently control carbon and temperature so this testing cannot be replicated at the commercial scale.

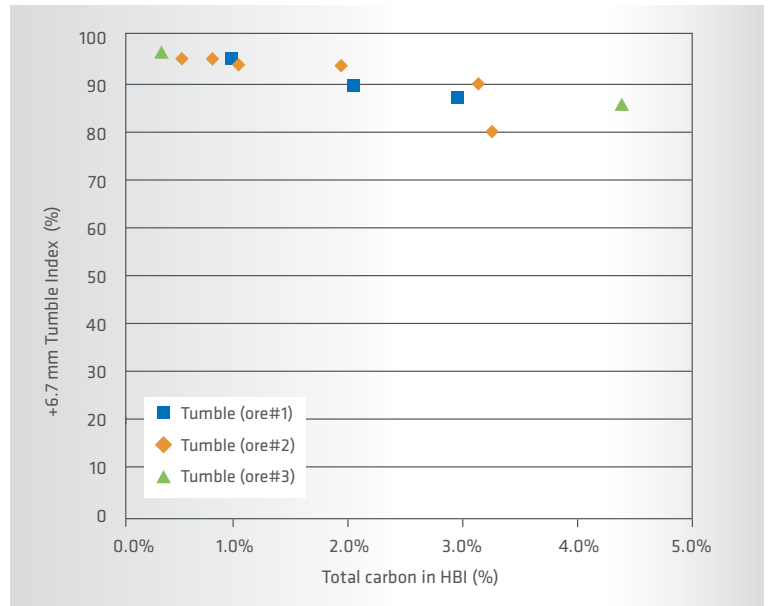


FIGURE 9. Effect of carbon on pilot-scale HBI quality for 3 different iron ores

The first implementation of MIDREX ACT™ is currently under construction. In June 2017, Cleveland-Cliffs, Inc. announced that Toledo, Ohio, will be the location of the company’s first MIDREX® HBI production plant. The plant will have a nominal capacity to produce 1.6 million metric tons of HBI per year and will be able to supply high-quality, customized HBI to the Great Lakes region. The project broke ground for construction on April 11th, 2018, with the estimated production of HBI slated for mid-2020. Carbon in the HBI will be in the range of 1.8% to 3.0% with 95% metallization.



Conceptual rendering of new MIDREX® HBI plant in Toledo, Ohio



OVERALL CONCLUSIONS

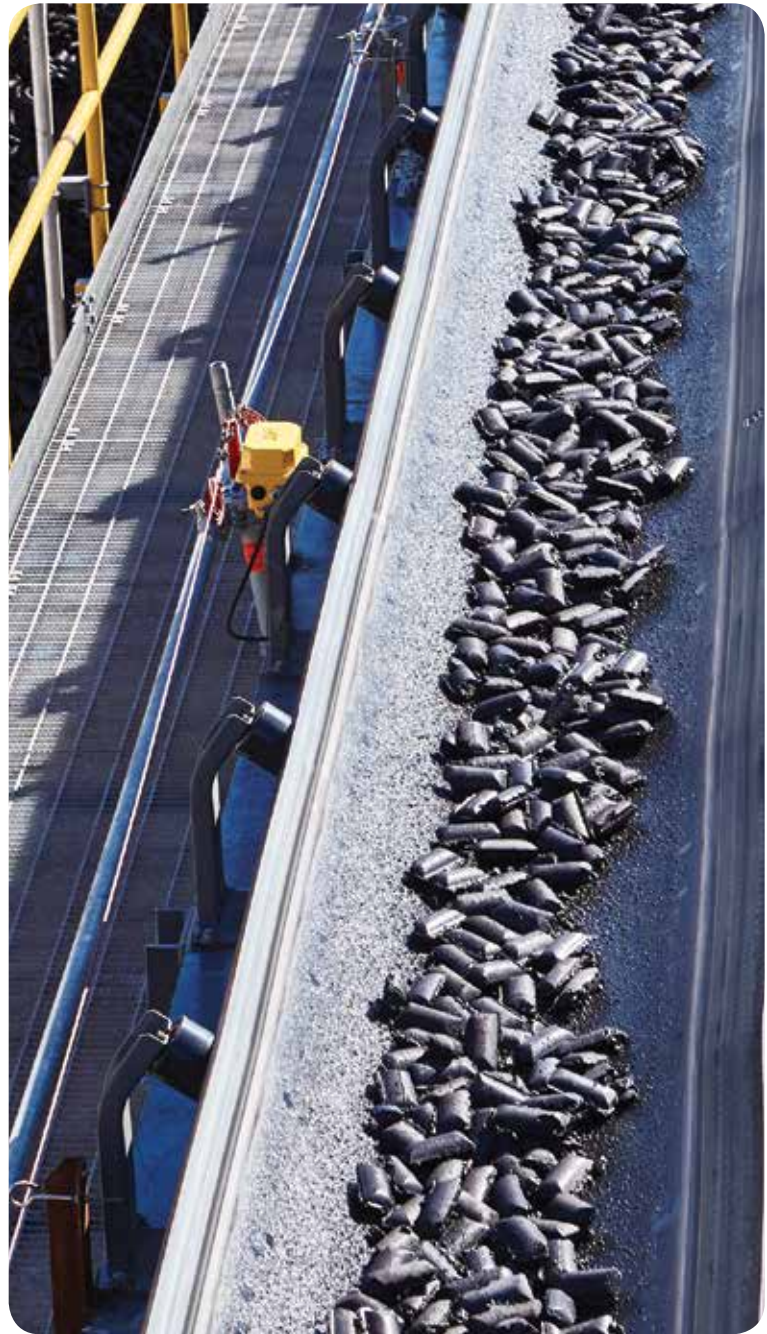
For the nearly five decades that the MIDREX® Process has been in use, product carbon levels have varied based on location and use by plant. These levels have been historically in the range of 0.5% to 3% for CDRI. HDRI and HBI targets were lowered due to the endothermic carburization reactions, coupling product carbon and discharge temperature. MIDREX ACT™ was developed at the Midrex Research and Technology Development Center to provide a means to increase the carbon content of DRI up to 4.5% carbon without temperature loss. Temperature loss is particularly important to producers of HDRI and HBI. For example, HBI producers will benefit greatly from this innovative technology because carbon can be increased to meet specific customers requirement without affecting briquetting temperature. This is critical for making strong briquettes to achieve high yield during transportation and handling.

To minimize scale-up risks, Midrex undertook a series of tests at bench and pilot scale to quantify the impact of carbon/cementite on HBI properties, independently of temperature. The results showed that there is a measurable reduction in both density and strength of the HBI as carbon increases for a given ore. However, the HBI maintains adequate strength over a wide range of carbon (at a given briquetting temperature). Therefore, we expect that HBI produced with MIDREX ACT™ will maintain its transportation advantages, superior yield, and lower reactivity over DRI while providing a value-added product tailored to meet specifications of their end users (such as carbon content). ■

(The author wishes to recognize and thank Andrew Ruthenbeck, Mike Lamb, and the Midrex Research & Development Technology Center staff for their work in conducting the tests and analyzing the data described in this article.)

References:

1. High Carbon Briquettes (HCB) – The future of briquetted DRI. HYL News. December 2016.
2. Ruthenbeck A., Lamb M. and Chevrier, V. Hot Briquetting Trials with variable carbon DRI. AISTech 2018. Philadelphia, PA, USA.



EDITOR'S NOTE:

For more information about MIDREX ACT™, please see the article titled, "INCREASING CARBON FLEXIBILITY IN MIDREX® DRI Products: Adjustable to 4.5%, Excellent Temperature Retention With ACT™," in 3Q2017 Direct From Midrex or download the brochure titled, "MIDREX ACT™- Achieving Higher Carbon in MIDREX® DRI Products," from the Midrex website: www.midrex.com.



DR-GRADE IRON ORE PELLETS – A SUPPLY OVERVIEW



By Chris Barrington, *Secretary General – International Iron Metallurgical Association (IIMA)*

EDITOR'S NOTE: This article is based on presentations made by Chris Barrington at the MIDREX® Plant Operations Seminar, Paris, France, September 2017, and Metal Bulletin DRI & Pellets Conference, Dubai, UAE, April 2018. All mentions of tons are metric.

INTRODUCTION

Iron ore is one of the two essential inputs for producing direct reduced iron (DRI); the other being natural gas or another hydrocarbon fuel that can be reformed to create a reducing gas rich in CO and H₂. Although direct reduction processes can operate with pellets having an iron content of 65% or lower, typical of blast furnace (BF)-grade pellets, the preferred feed for a DR plant has an iron content of 67% or greater.

The principal sources of DR-grade pellets are located in South America, Canada, Sweden, Bahrain and Iran (TABLE I).

Company	Country/Region
Vale	Brazil & Oman/SA & Middle East
LKAB	Sweden/Europe
Rio Tinto Iron Ore (IOC)	Labrador/Canada
ArcelorMittal Mines Canada	Quebec/Canada
Bahrain Steel	Bahrain/Middle East
CMP	Chile/SA
Samarco	Brazil/SA
Iran	Iran/Middle East

TABLE I. Merchant DR-Grade Pellet Suppliers

Other sources of DR-grade pellets include:

- Metalloinvest (Russia)*
- Severstal Resources (Russia)
- FMO (Venezuela)*
- Cleveland-Cliffs, Inc. – Northshore Mining (USA)*
- India (48% from 5 producers) *
- Projected projects:
 - Chippewa Capital Partners (MN, USA)
 - New Millennium Iron (Canada)
 - El Aouj Mining (Mauritania)
 - Wadi Sawawin (Saudi Arabia)

* Supplies DRI plant(s) in home country

IRON ORE MARKET DYNAMICS

Elevated levels of Chinese steel production propped up the global demand for iron ore in 2016, since China accounts for close to two-thirds of the global seaborne iron ore trade. Global iron ore production grew 5% year-on-year in 2016, to a total of 2,106 million tons. Lump ore production increased 26 million tons to make up 15% of global production. Concentrate output was



broadly flat, accounting for 25% of world production. Iron ore production data for 2017 are not yet available but are thought to be not significantly different to those of 2016.

Iron ore exports exceeded 1,500 million tons in 2016, and the seaborne market was more-or-less balanced for 62% Fe material. The tightness in the 62% Fe market, compounded by other pricing factors and financial speculation, contributed to considerable price volatility.

Iron ore prices improved markedly in the second half of 2016, having reached a low in mid-January when 62% Fe prices fell below \$40/ton CFR China for only the second time since the inception of the S&P Global Platts' index in 2008 (the other instance was in December 2015). Prices reached a peak of \$84/ton in early December 2016, averaging \$58/ton for the year, and kept climbing to over \$90/ton in March-April 2017 before dropping back to just under the 2016 average in late June. A late summer rally allowed prices to rebound to just under \$80/ton in September 2017 before retreating to winter lows just under \$60/ton.

However, restocking in February and March 2018 saw prices again pushing \$80/ton, then falling back in late spring to around \$65/ton.

Figure 1 shows an interesting trend developing since June 2017, in that that price valley are more shallow and the peaks a little higher with each succeeding cycle.

The BF pellet premium over sinter feed (CFR China) ranged from a little over \$10/ton in January-February 2016 to about \$35/ton in August 2016 and went on a rampage beginning in May 2017, spiking to about \$60/ton in November 2017 (Figure 2). Although the premium retreated from the highwater mark, it only fell to \$38-45/ton in spring 2018.

The premium for DR-grade pellets in the Atlantic Market hovered between \$9-12/ton from January-December 2017, with 65% Fe prices hovering around d \$45/ton (Figure 3). The new year saw the price of BF-grade pellets (65% Fe) jump to \$58/ton; however the DR-grade premium only increased by \$5-6/ton.

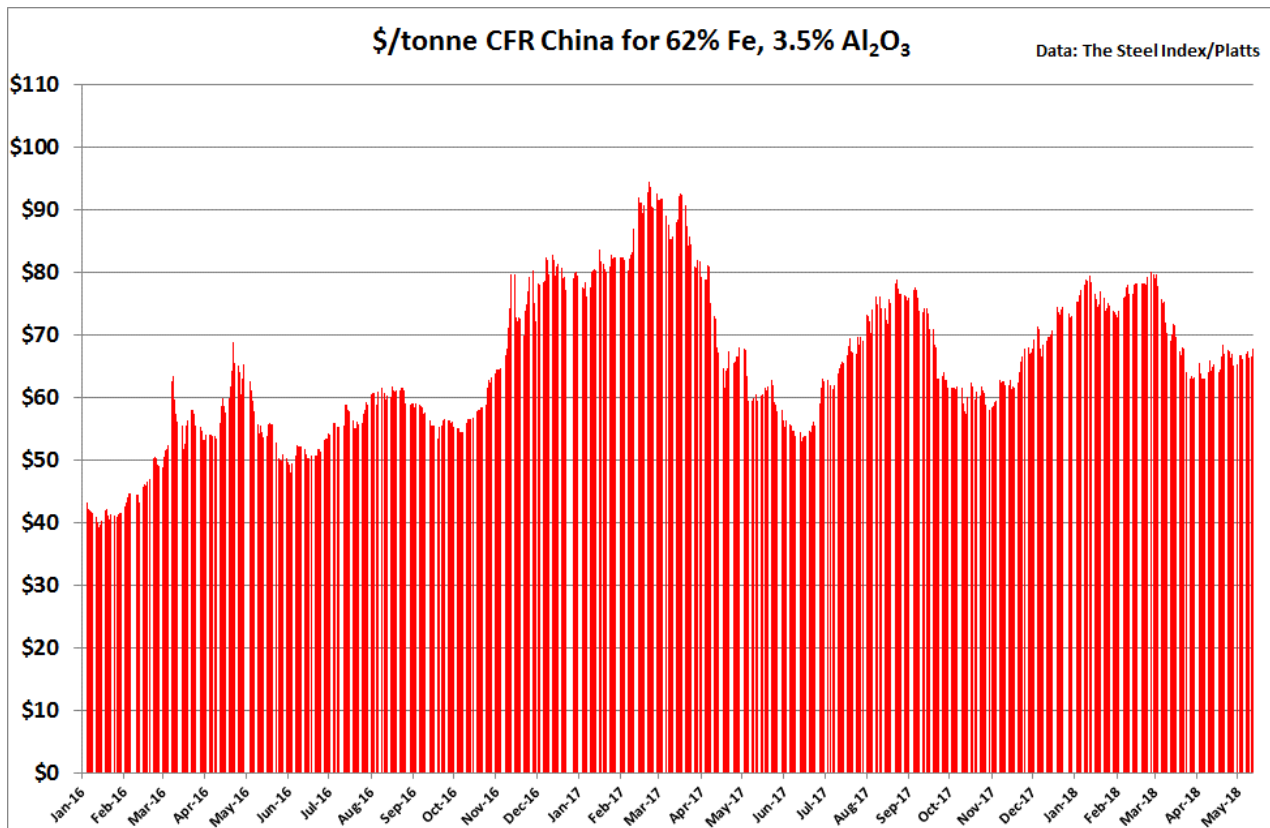


FIGURE 1. Iron ore prices CFR China

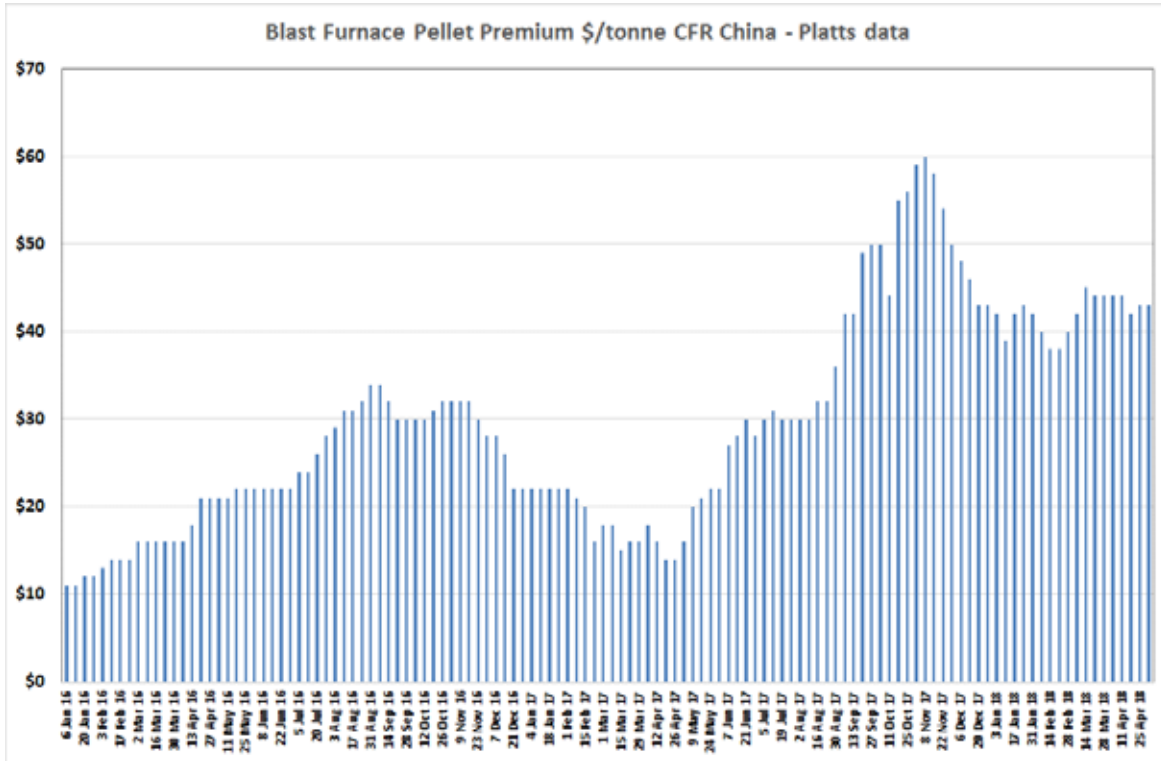


FIGURE 2. Blast furnace pellet premium CFR China

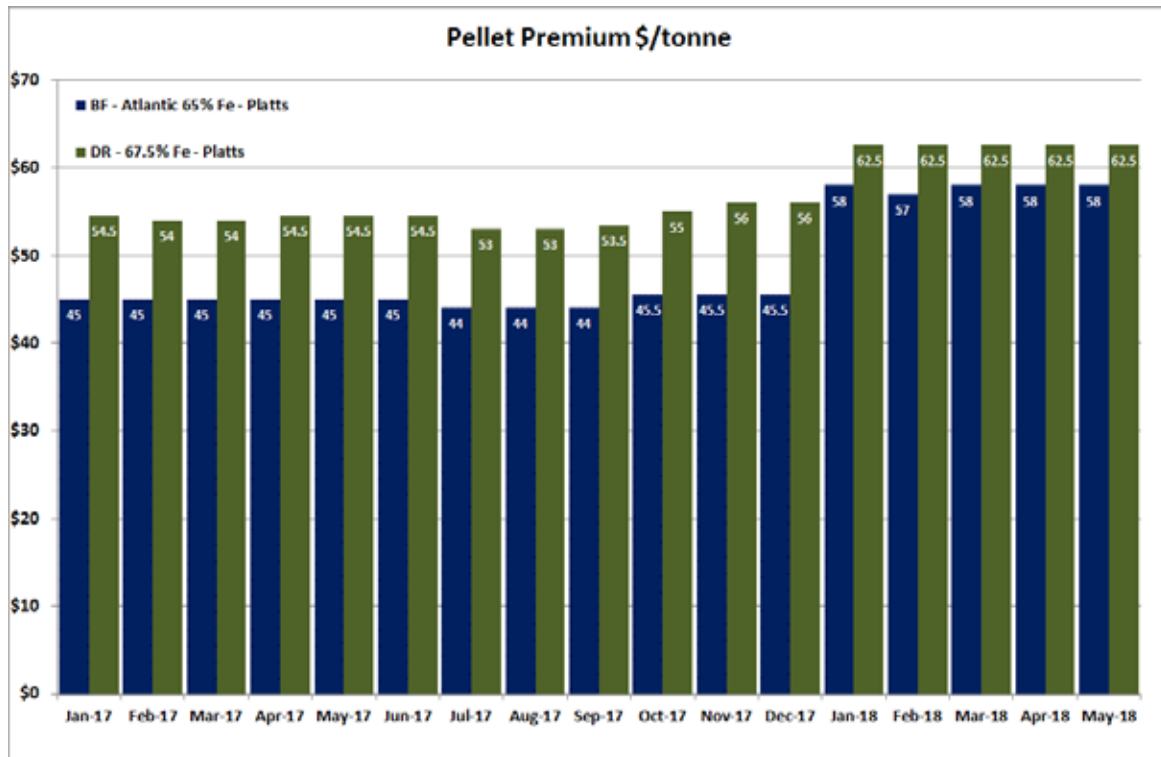


FIGURE 3. DR-grade pellet prices (Atlantic Market)



OUTLOOK FOR DR-GRADE PELLETS

As we saw in TABLE I, DR-grade pellets primarily are produced in four regions of the world: North and South America, Europe and the Middle East (including Iran). However, the presence of DRI plants limits the availability of pellets for merchant trade outside the countries or regions where they are produced (TABLE II).

Brazil – Vale & Samarco

Vale’s operational iron ore pellet capacity is about 41 million tons in Brazil and slightly more than 9 million tons in Oman. Most of its Brazilian capacity is focused on BF-grade pellets while the Oman operation is devoted to DR-grade pellet production, which totaled 9.2 million tons in 2017. Through 1Q2018 2.2 million tons have been produced by the Oman plant.

Vale plans to increase overall pellet production capacity by more than 12 million tons in 2018. Tubarão 2 was restarted in January 2018 and Tubarão 1 was scheduled to start in April 2018. The two Tubarão lines have a combined capacity of approximately 5 million tons. The São Luis plant is scheduled for re-start in 3Q2018, which will add 7 million tons of capacity, mostly BF pellets.

With Samarco still recovering from the tailings dam rupture in November 2015, Vale made almost all Brazilian iron ore shipments in 2017. Sales of DR-grade pellets exceeded 12 million tons and accounted for ± 41% of total pellet sales, which is expected to increase in 2018.

A breakdown of DR-grade pellet exports by Vale in 2017 is shown in Figure 4 (Note: USA total might include some BF pellets; Argentina total excludes 0.7 million tons of BF pellets).

Samarco historically has been the Brazilian iron ore producer most closely identified with DR-grade pellets. Production totaled 24 million tons in 2014 and 24.6 million tons in 2015. The Ponta do Ubu facility has four pelletizing lines with a total annual capacity of 30.5 million tons. However, there was no production in 2016 and 2017 and only a few sales from stock that was not eliminated by the late 2015 flooding.

There are many issues involved in Samarco resuming pellet production including government approvals and granting of environmental and water supply permits and licenses by state authorities, restructuring

Company	Country	DRI Plants
Vale	Oman	Jindal Shadeed
LKAB	Sweden	N/A
Rio Tinto Iron Ore (IOC)	Labrador, Canada	N/A
ArcelorMittal Mines Canada	Quebec, Canada	AM Canada
Bahrain Steel	Bahrain/Middle East	SULB
CMP	Chile	N/A
Samarco	Brazil	N/A
Iran	Iran	Multiple plants

TABLE II. DRI plants in countries where DR-grade pellets are produced

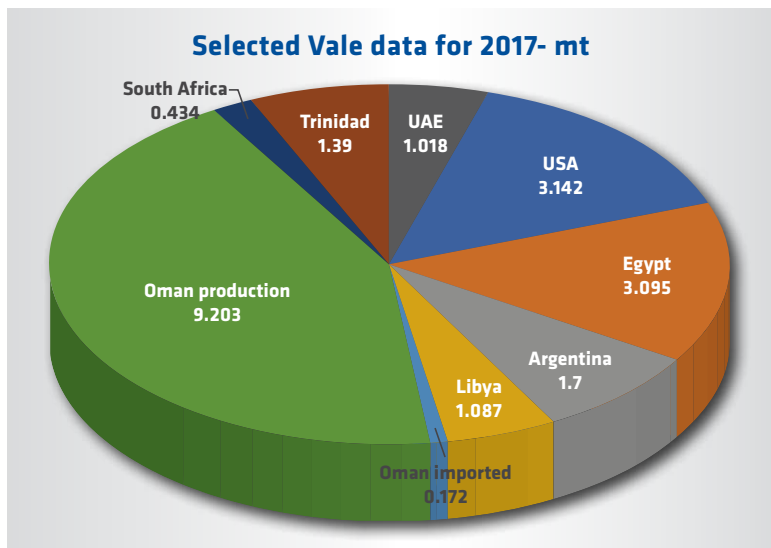


FIGURE 4. Brazilian DR-grade pellet exports by country (Data sources: Vale and trade statistics)



Jindal Shadeed - Sohar, Oman



company debt, economic viability, access to need in-
 frastructure (owned by Vale), local and national public
 opinion and what to do with the tailings.

LKAB

Total iron ore pellet production and sales by the Swed-
 ish company were 24.6 and 22.9 million tons, respec-
 tively, in 2017. This compares with 2016 production and
 sales of 24.0 and 22.7 million tons, respectively. The
 Kiruna operation delivered 14.4 million tons and the
 Malmberget/Svapavaara plants accounted for 8.4 mil-
 lion tons of 2017 sales. Blast furnace pellets made up 55%
 of sales value and DR pellets accounted for 26%.

According to iron ore trade statistics, Sweden ex-
 ported about 7 million tons of DR pellets in 2017, com-
 pared with 6.5 million tons in 2016. The breakdown of
 exports by country in 2017 is shown in *Figure 5*.

The installed pellet capacity of LKAB is about 28
 million t/y, with three lines at Kiruna (BF and DR pel-
 lets), two at Malmberget (BF pellets) and one at Svap-
 pavaara (BF pellets). However, due to environmental
 permits, effective capacity is limited to 26 million t/y.

Kiruna has a combined capacity of more than 10
 million tons and has the flexibility to manage produc-
 tion of BF and DR pellets in response to market condi-
 tions. LKAB uses two lines for DR-grade pellets, KK3
 and KK4, which are equipped to coat the pellets using
 organic binders. DR-pellet capacity could be increased
 by adding coating capability on the KK2 line.

**CANADA – RIO TINTO IRON ORE (IOC)
 AND ARCELORMITTAL MINES CANADA**

The two producers of DR pellets in Canada have a com-
 bined capacity of approximately 22.7 million tons – ±12.5
 at IOC and 10.2 at ArcelorMittal. IOC produced 10.5 mil-
 lion tons in 2017, an increase of more than 10% over 2016.
 IOC’s share of DR-grade pellet sales was ±31% in 2017,
 which exceeded expectations. Prior to a workers’ strike
 in March, 2018 production was forecasted to be 12-12.5
 million tons (each month of lost production equates to
 approximately 1 million tons).

ArcelorMittal Mines Canada produced 10.1 million
 tons of DR-grade pellets in 2017, most of which was used
 in ArcelorMittal’s Canadian DRI plants, as well as its

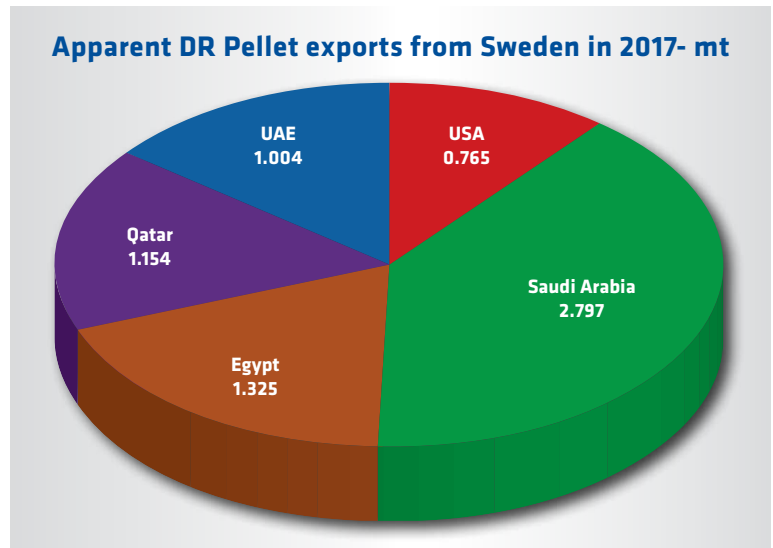


FIGURE 5. Swedish DR-grade pellet exports by country
 (Data sources: LKAB and trade statistics)



Top photo: ArcelorMittal Mines Canada; Bottom photo: AM Hamburg Plant

DRI plant in Hamburg, Germany.

Tagora Mines reportedly has acquired the assets of the former
 Wabush Mines Scully mine and Pointe Noire pellet plant and intends
 to restart operations. However, they are unlikely to produce DR-grade



pellets.

Canadian exports in 2017 are estimated by the author as 3.3 million tons, excluding 0.9 million tons shipped by ArcelorMittal Mines to the company's Hamburg steel mill. A breakdown by country of DR-grade pellet exports from Canada in 2017 is shown in *Figure 6*.

IRAN

Pelletizing capacity in Iran continues to grow. It currently stands at 31 million t/y and is planned to exceed 40 million t/y by first quarter 2018. Pellet production in 2016 was 23.3 million tons.

With DRI production in Iran reaching 16.1 million tons in 2016, pellet demand can be estimated at about 23 million tons. (*Editor's note: Iran produced 20.6 million tons of DRI in 2017*) Therefore, domestic demand, more than covers the entire supply of DR-grade pellets, leaving limited prospect of merchant sales.

CONCLUSION

The supply of DR-grade iron ore pellets always has been tight, but it could become more of a problem with the prolonged disruption of production at Samarco, the addition of HBI capacity to meet growing demand, and the economics of DR-grade pellet production. Some companies building direct reduction plants, such as Cleveland-Cliffs Inc, which has announced plans for a 1.6 million t/y HBI plant using MIDREX' Technology, have their own iron ore resources. Others are considering blending BF and DR-grade pellets or even having a new pellet designed.

One thing is certain, the creativity of DR plant operators, the ingenuity of process suppliers, and the expertise of iron ore pellet producers will find a way to assure that the supply of DRI products keeps pace with the demand. ■

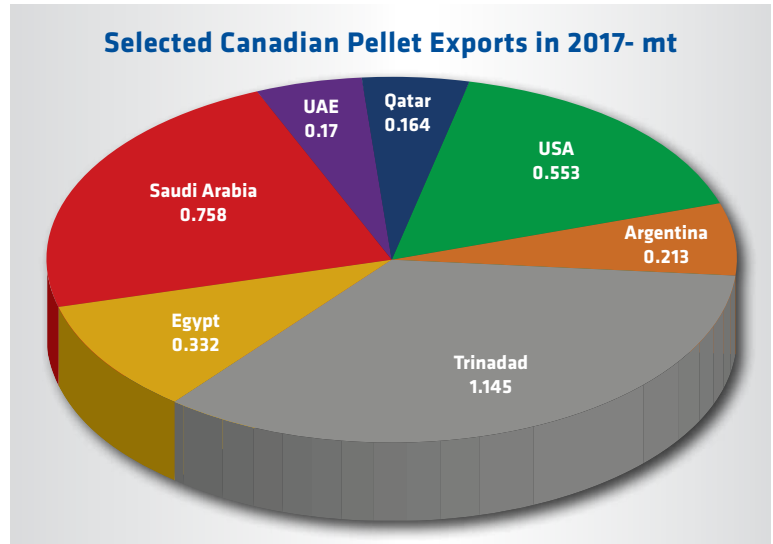
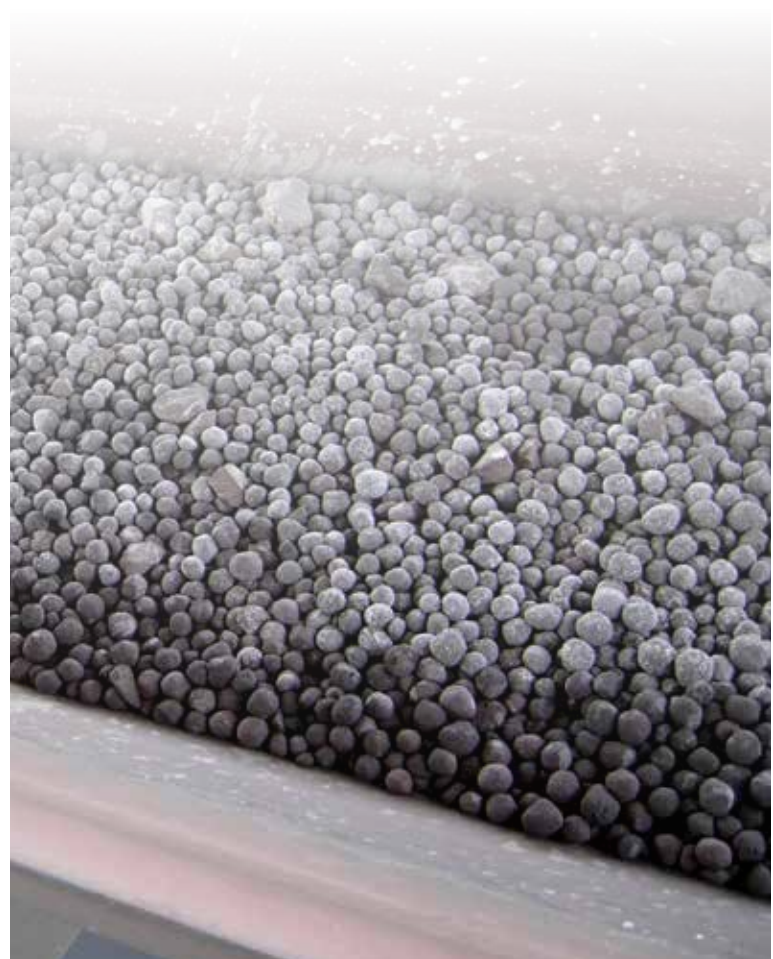


FIGURE 6. Canadian DR-grade pellet exports by country (Data sources: trade statistics)





How Much DRI is 1 Billion Tons?

By Robert Hunter, *Consultant – DRI Economics & Applications*

In June 2018, plants operating with MIDREX® Direct Reduction Technology surpassed the cumulative production total of **one billion metric tons of direct reduced iron (DRI) products**. To reach this production milestone, MIDREX® Direct Reduction Plants have progressed from struggling to produce five tons per hour during the start-up of the first plant at the former Oregon Steel Mills in Portland, Oregon, USA, in 1969, to now making nearly 7,000 tons per hour at locations around the world, 24-7-365.

WHAT WOULD ONE BILLION TONS OF DRI LOOK LIKE?

If it were stacked in a single massive pile, assuming an angle of repose of 33 degrees and a bulk density of 1.8 tons per cubic meter, it would make a stack over 600 meters tall and almost 1.9 km across (*Figure 1*) ... or almost 2,000 feet tall and 1.16 miles across.

★ 1 BILLION TONS OF DRI ★

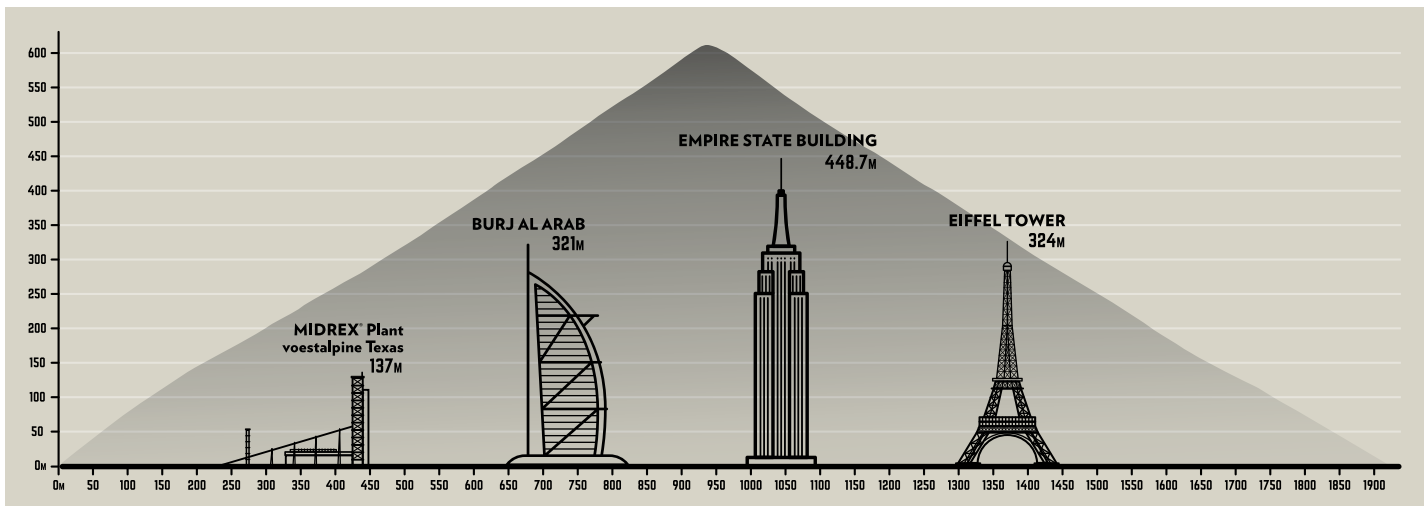


FIGURE 1. How 1 billion tons of DRI “stacks up”

If we assumed all one billion tons were DRI pellets and we laid them in a line with the pellets touching, the line would extend four billion kilometers (about 2.5 billion miles) or 100,000 times around the world or to the moon and back more than 5,000 times. Another way of looking at it is if laid out side-by-side, one pellet deep, one billion tons of DRI would cover 48,000 square kilometers (nearly 19,000 square miles), which is larger than Switzerland. Of course, it would be very difficult to place all those pellets side-by-side in Switzerland – they would all roll into the valleys! So, let’s say instead, larger than the Netherlands.

What could be done with 1 billion tons of DRI? We could make:

- About 900 million kilometers of common #4 rebar, which is enough to go around the world 22,000 times.
- Enough one meter-wide auto body sheet to go around the world 3,500 times.
- 10,000 really big ships, such as a Gerald Ford-Class aircraft carrier and a The Symphony of the Seas cruise liner. At 6,000 passengers per ship, it would take about two-and-a-half years for everyone on earth to go on a one-week cruise.



- The reinforcing bar for the Burj Khalifa (the world's tallest building) in Dubai 23,000 times, 4,700 of the world's longest suspension bridge (Akaishi-Kaikyo in Japan), 2,000 of the world's largest dam (Three Gorges in China), and more than 120,000 of the Eiffel Tower, which was the world's tallest structure from 1887-1930 ... and happens to be built entirely of iron (because steel was too expensive then).
- Last but not least, a billion tons of DRI could supply enough iron to enrich a slice of bread (iron is used as a nutrient in enriched flour) for three meals a day for every human on earth (current population about 7.6 billion) for 250,000 years.

IN HISTORICAL PERSPECTIVE

There is an iron bridge across the Severn River at Coalbrookdale, near Birmingham, in England (*Figure 2*). The fabrication and construction of this bridge is heralded as the initial event leading to the Industrial Age (around 1760 in Great Britain).



FIGURE 2. Iron Bridge over the Severn River

In the early 1700s, world iron production was barely more than 100,000 tons per year ... most of the previous centuries, it had been less than one-third as much. Iron was made then using charcoal as the reductant and fuel. By 1800, world production of iron was about 150,000 tons per year; however, by 1820, it had surpassed 500,000 tons per year. The advent of tonnage steel-making accelerated the growth of ironmaking by the early 1860s to 10 million tons per year, leading to cumulative world ironmaking exceeding 500 million tons probably sometime in the 1880s.

Back to the iron bridge at Coalbrookdale. Abraham Darby leased a blast furnace at Coalbrookdale in 1708. At first, he used charcoal like everyone else. However, he remembered seeing

coke used as fuel for malting ovens when he was a youthful apprentice to a manufacturer of brass mills used to grind malt for brewing beer. The use of coke instead of charcoal greatly decreased the sulfur content of the beer. He successfully applied the same logic to ironmaking and found a much better fuel/reductant.

Blowing in his blast furnace using the new process on January 10, 1709, Darby made enough iron to manufacture 81 tons of iron goods that year. Regrettably, he couldn't find a market for his iron. It took 70 years and the creative mind of his grandson, Abraham Darby III, to find a use for "that much" iron ... he built the famous bridge across the Severn.

The bridge weighed a little less than 385 tons. It took more than two years (1777-79) to cast the iron and erect the bridge. A modern MIDREX® Plant, like the ones being built for Tosyali Algeria in Oran and Algerian Qatari Steel in Bellara, Algeria, can make that much iron in less than an hour and fifteen minutes.

TO 1 BILLION TONS AND BEYOND

It took 38 years for MIDREX® Plants to produce the first 500 million tons of DRI but then only 11 more to achieve the second 500 million tons. By comparison, it took humanity over 3,000 years to produce the first half billion tons of iron, beginning in the centuries before 1,000 BC.

Total output by MIDREX® Plants in 2017 was 56.5 million tons, up more than nine million tons over 2016. The first full year of operation by the voestalpine Texas HBI plant brought MIDREX® Iron production in the USA up by nearly 1.5 million tons and start-up of the LGOK HBI-3 plant in Russia helped increase MIDREX® Iron production there by 1.3 million tons. Large production increases also were seen in Argentina, Canada, Egypt, India, and Iran.



voestalpine Texas HBI Plant



LGOK HBI-3 Plant



MIDREX® Plants were producing DRI products at a rate of nearly 60 million tons/year by the end of 2017, and there is sufficient capacity under construction to boost the production rate to 75 million tons/year by 2020 ... and the acceleration is expected to continue. This means that the second billion tons of DRI products could be produced in less than 13 years.

Legend has it that Don Beggs conceived of the MIDREX® Direct Reduction Process while mowing his lawn in the late 1960s. I wonder if he imagined on that day in Toledo, Ohio, that more than 50 years later his “what if” idea would be heralded as one of the most innovative technologies in iron and steel industry history and his legacy would be a billion tons of DRI used to make millions of tons of steel that have provided the catalyst for emerging economies and the products that are essential for progress and prosperity.

Just think what we can do with the next billion tons of DRI ...



MIDREX

1
BILLION TONS
of MIDREX® DRI

MIDREX
= 1969-2018 =

MIDREX® Plants Reach Production Milestone

1 Billion Tons of DRI Products Since 1969

June 25, 2018

CHARLOTTE, North Carolina, USA – This month, plants operating with MIDREX® Direct Reduction Technology reached the cumulative production total of one billion metric tons of direct reduced iron (DRI) products. To reach the production milestone, MIDREX® Direct Reduction Plants have grown from making less than 1,000 tons during some of the first months of operation in 1969, to currently producing over five million tons every month.

“We are pleased to announce this production milestone,” Midrex President and CEO Steven Montague said, “not only as recognition of the reliability of our technology and the fantastic achievement of those who operate MIDREX® Plants, but also because it comes in a year that saw DRI production grow by 20%.”

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THIRD QUARTER 2018

9.20.18



MIDREX News & Views

Qatar Steel DR2 Recognized for Consistent Exemplary Performance

Qatar Steel Managing Director & General Manager, Mr. Mohammed Nasser Al-Hajri, was presented a congratulatory letter and a commemorative award by Midrex President and CEO Stephen Montague in recognition of the consistently exemplary performance of Qatar Steel’s DR2 plant. *(Photo at right)* Each calendar year, from 2014-2017, the plant achieved the highest cold DRI (CDRI) production by a 6.65-meter diameter MIDREX® MEGAMOD furnace, which was well beyond the original plant rating of 1.5 million tons/year.



Pictured left to right:
K. C. Woody, Vice President – Sales & Marketing, Midrex Technologies, Inc.;
Ahmed Sabt Kalifa, Direct Reduction Manager, Qatar Steel;
Yousef Al-Emadi, Production Division Manager, Qatar Steel;
Robert Montgomery, Key Account Manager, Midrex Technologies, Inc.;
Mohammed Nasser Al-Hajri, Managing Director & General Manager, Qatar Steel;
Stephen Montague, President & Chief Executive Officer, Midrex Technologies, Inc.; and
Khalid Mandani Al-Emadi, Procurement & Warehousing Division Manager, Qatar Steel.



MIDREX News & Views

Midrex RPS Helps SULB DRI Set Daily Production Record

On April 9, 2018, the SULB combination HDRI/CDRI plant ramped up production to its highest hourly rate on record, 208.5 tph, which is more than 111% of rated plant capacity, and achieved its highest daily DRI production since the plant was commissioned in 2013. HDRI was delivered to the SULB melt shop with metallization greater than 95% and carbon content of 1.88%.

Midrex General Manager, Plant Operations & Maintenance David Durnovich credited the outstanding accomplishment to the “SULB DRI and Midrex RPS teams working closely together.” Pascal Genest, SULB CEO, agreed and said, “With reinforced joint efforts of Midrex-SULB, we will see even more significant improvements over the course of this year.”



SULB DRI Hidd, Bahrain

Midrex RPS (Remote Professional Service) is a customer assistance program that assists clients remotely to solve plant issues (“pain points”) or to optimize their plants. By analyzing real time, read only data via a secure connection to the client’s DCS, the Midrex RPS team can provide valuable insight into aspects of plant operations that often are outside the assigned responsibilities of plant personnel.

Midrex RPS is one of several customer-oriented initiatives grouped under **MidrexConnect**, an integrated services platform that focuses on asset information and visualization, operational information and client assistance. Midrex currently monitors plant operations data for Nu-Iron (Point Lisas, Trinidad and Tobago) and ArcelorMittal South Africa (Saldanha Bay, South Africa), as well as SULB (Hidd, Bahrain).

About SULB DR Plant

In 2010, SULB company made a contract with Kobe Steel, Ltd. to supply a dual discharge (hot DRI/cold DRI) **MIDREX MEGA-MOD** Direct Reduced Iron Plant with a rated capacity of 1.5 million tons per year. The DR plant was envisaged to supply HDRI to an adjacent melt shop along with extra CDRI, which could be available for sale in the regional market.

SULB was successfully commissioned without any major start-up issues. The DR plant started commercial production of CDRI on February 3, 2013, and began producing HDRI in August 2013. It operates using 100% Bahrain Steel (formerly GIIC) pellets.



SULB Conveyor



Technology should be...

- designed to fit your needs
- designed to work reliably
- designed to make life easier

DRI Technology **is** designed
by Midrex to work for **you.**

COMING NEXT ISSUE

Hot Briquetted Iron: Steel's Most Versatile Metallic Part 3

John Kopfle: Editor

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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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