

DIRECT FROM MIDREX

3RD QUARTER 2016



> CDRI AND HBI PRODUCT

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COMMENTARY

CONTINUING TO BUILD OUR REPUTATION

By KC Woody
VP Sales & Marketing



As many of you may know, recently Midrex had a series of management changes. Our long time President & CEO, Jim McClaskey, will retire next year. He retains his position as CEO and Stephen Montague was named President & Chief Operating Officer. As they say, change is in the air and the Sales and Marketing team here at Midrex is no different. As the article in this issue describes, there are new faces in key positions in the newly restructured Commercial Group. One thing is clear, the group is focused on better serving our current and future Process Licensees.

Warren Buffet once said, "It takes twenty years to build a reputation and five minutes to ruin it. If you think about that you'll do things differently." At Midrex, we have a longstanding reputation of quality plants that have outperformed the competition for more than three decades and produced 60% or more of the world's DRI each year since 1987. If we really think about why, the answer is simple, our Process Licensees. They are the operators who run these plants every day and continue to set standards for productivity and quality in the Direct Reduction industry. We appreciate their hard work and continue to support them strongly. We are not resting on past successes either, but are focused on improving our performance and better serving the Midrex family of Licensees.

Late last year, the Sales and Marketing team was restructured with the goal to provide better service. Rather than separate the Aftermarket (Global Solutions) and Plant Sales teams, Midrex has unified them into one Sales team. As a result, the Sales Manager who works with the potential Licensee for the initial plant sale will remain in regular contact with them to meet the plant's aftermarket needs after the plant is commissioned and joins the Midrex family. This new approach will allow us to strengthen our relationship with our Licensees and insure the best possible support.

Midrex UK, our London based subsidiary, has also joined the Commercial Group. Our team in London is working closely with our Sales team to provide clients with access to Export Credit Agency financing as well as assisting the team to evaluate new business models that will bring our Licensees greater value. Our teammates in India and China continue

to support their market and work closely with their colleagues in Charlotte to bring the best possible service to our current and future licensees.

While Midrex is proud of the work we have done in the past, we look at the challenges facing the steel industry today and realize our Process Licensees are being forced to make difficult changes. We are intensely focused on providing our Licensees and potential Licensees more value and assisting them in succeeding in this changing industry. Midrex is not doing this alone, rather we are working closely with our partners to investigate new products and business models to better support current and future Licensees.

One example of this effort is our in-plant Liaison program. For nearly two years, Midrex has had an in-plant Liaison working with the team at Nu-Iron in Trinidad and Tobago. The liaison is there to support the management team at Nu-Iron to meet and exceed their goals. This program has helped strengthen the communication between Nu-Iron and Midrex and we were proud to be part of the Nu-Iron team setting new plant records for availability and production last year.

Actions speak louder than words. We are confident that the changes to the Commercial Group will provide even better service to our current and future Licensees, enabling them to achieve continued operational excellence. ■



GLOBE TROTTERS WITH A STRONG CLIENT FOCUS:

Midrex Sales & Marketing

By John Kopfle,
Director – Corporate Development



EDITOR'S NOTE:

Periodically, we like to pull back the curtain on the operations of our company to give the industry insight into how we continue to advance the state-of-the-art of direct reduction ironmaking technology. In this issue, we show how the commercial side of Midrex promotes the company's products and services worldwide and tailors our offerings to serve individual client needs.

INTRODUCTION

The Midrex Sales and Marketing group promotes and provides Midrex products and services to the iron and steel industry in general and to specific clients. Functions include marketing, plant sales, Global Solutions, and contracts and licensing. This is a major effort because the group covers the entire world, including North America, the Caribbean, South America, Russia, the Middle East, Africa, India, China, and many places in between. In addition to business savvy, this often requires the ability to navigate the waters of culture, language, and politics. Given Midrex's technology focus, marketing and selling the company's products and services also requires a good knowledge of the basic processes and equipment. Many of the commercial staff have technical backgrounds.

Midrex defines marketing as determining market needs and promoting Midrex products and services to broad audiences. Sales is tasked with identifying specific client needs and tailoring our offerings to satisfy those needs. Unlike some companies, Midrex makes a sharp distinction between the marketing and sales functions. For both, Midrex works closely with its construction licensees – Kobe Steel, Primetals, and Paul Wurth.

MIDREX COMMERCIAL GROUP BY THE NUMBERS IN 2015 AND 2016



2,000,000
MILES TRAVELED

90
CLIENT
MEETINGS

ALGERIA, AUSTRIA, BAHRAIN, CANADA,
CHINA, EGYPT, FRANCE, GERMANY, INDIA,
ITALY, LUXEMBOURG, NIGERIA, OMAN, QATAR,
RUSSIA, SAUDI ARABIA, SOUTH AFRICA,
SPAIN, TRINIDAD, TURKEY, UAE, UK, USA
23 COUNTRIES VISITED

50
CONFERENCES
ATTENDED



HOW DO THE FUNCTIONS OPERATE?

Marketing

No matter how good a company's products are, market analysis and promotion are essential to make the market aware of the benefits of a company's offerings. Today, very few firms can simply wait for customers and take orders. Midrex marketing promotes existing products such as the MIDREX® Natural Gas Process and new ones such as MXCOL®.

There are two general product promotion strategies: demand pull (outside in) and technology push (inside out). Demand pull requires a continual assessment of market needs and the crafting of products and services to meet those needs. Technology push seeks opportunities to sell the company's innovative and unique products. Each strategy can be effective and the most innovative and successful companies use both. Midrex does this by continuously monitoring the market (with the help of our overseas offices and partners) and also by maintaining an active research and development program.

Table I shows the range of the Marketing Department's work.

Table I Marketing Functions

- Stay up-to-date on developments in the direct reduction and steel industries
- Regularly analyze the steel, iron ore, metalics (DRI, HBI, scrap, pig iron) and energy markets
- Perform project feasibility studies as required
- Assist Sales Dept. in qualifying potential clients
- Coordinate Midrex conference and trade show participation
- Prepare market and technical papers and make conference presentations as required
- Manage advertising program
- Coordinate preparation of collateral materials such as brochures and videos
- Manage website
- Produce Direct from Midrex
- Compile information and publish annual World Direct Reduction Statistics
- Maintain and develop relationships with trade press and issue news releases
- Assist Midrex global offices with marketing needs
- Coordinate marketing activities with partners

Sales

After target clients are identified, the Sales Department is responsible for client interactions all the way through contract signing. The first step is to engage the client, gather information, and help them determine if a MIDREX® Plant is feasible in that situation and location. This requires the ability to ask the right questions, a knowledge of the MIDREX Technology (natural gas or coal based), and the skill to do a preliminary economic analysis including capital and operating costs. Table II shows some of the questions that must be answered during this phase of the sale.

Assuming the economics look promising and there are no insurmountable issues, the next step is for the client to do a more detailed analysis with Midrex's help. Midrex's Proposals Group can provide budgetary and firm price proposals. The latter requires the assistance of many groups within Midrex, including Engineering, Procurement, Project Management, Contracts & Licensing, and Legal. It includes a Technical Specification (Tech Spec) that details the equipment and systems required. If the project remains positive after the firm price proposal, the sales manager then begins detailed negotiations with the client. Since no two clients or projects are alike, it is essential to tailor each proposal and contract to that client's specific needs.

In many cases, Midrex works with a project partner (Kobe Steel Iron Unit Group, Primetals, or Paul Wurth) to supply detail engineering and non-proprietary equipment, perform construction, and provide field services. At times, the partner is granted the right to enter into negotiations with the client and sign contracts. When a Midrex partner takes those roles, Midrex works closely with them throughout the sales phase. In addition, the personnel in Midrex's offices in London, Russia, India, and China provide valuable assistance in maintaining client relationships, facilitating meetings, and assessing the legal, social, and political aspects of projects.

MIDREX® CONSTRUCTION LICENSEES



• KOBELCO STEEL LTD.



• PRIMETALS TECHNOLOGIES



• PAUL WURTH S.A.



Table II Questions for Prospective MIDREX Clients

- Who will be the owner of the plant?
- Who will supply the financing?
- Where will the plant be located?
- Is it a greenfield or brownfield site?
- Are natural gas/coal, electricity, and water available at the site?
- What is the expected source of the iron ore?
- Where is the nearest port?
- What is the desired capacity?
- Will the product be used at an adjacent steel mill or exported?
- What is the desired product form (cold DRI, hot DRI, HBI)?
- What is the expected timing of the project?

In the last 10 years, 50% of MIDREX Plants have been sold to repeat customers, so it is essential for the sales group to regularly contact existing clients. This entails a lot of overseas travel.

Financing is a major part of building and operating a **MIDREX Plant**. The sales group assists clients in developing a financing plan through feasibility studies and providing the information banks and investors need to make a decision. Government export credit assistance has become an important part of industrial project financing. This includes government guarantees of commercial bank loans and in some cases, direct lending. This support usually lowers the interest rate of the loan and improves the terms because the loan is backed by the full faith and credit of the government. In some cases, clients are able to access their home country's export credit agency. Midrex's London office provides the possibility of United Kingdom export credit assistance through UKEF. Midrex UK helped Metalloinvest secure such assistance for the LGOK III Project in Russia.

Midrex's Global Solutions Department, which provides aftermarket equipment and services, was profiled in the 2nd quarter 2015 issue of Direct from Midrex. In early 2016, the plant sales managers assumed responsibility for representing Global Solutions to our clients. This was done so that they can offer clients the full range of products and services. The relationships already established with plant management during the plant sales phase help the sales managers sell aftermarket equipment and services as well.

MIDREX PROFILES



CHRISTOPHER RAVENSCROFT MANAGER - GLOBAL MARKETING & COMMUNICATIONS

EDUCATION

BA PR/Journalism, Syracuse University
MBA, McColl School of Business at Queens University of Charlotte

YEARS WITH MIDREX

16

OTHER POSITIONS WITH MIDREX

Manager – Marketing; Public Relations Specialist

Chris manages the day-to-day functions of the Marketing Department and is a recognized face of Midrex around the world. With his long tenure in marketing, he understands the nuances of promoting **MIDREX® Technology**. A critical part of his role is maintaining relationships with Midrex clients and partners, iron and steel industry associations, consultants and media.

QUOTE:

"Even though the modern direct reduction ironmaking industry is nearly 50 years old, DRI product application and acceptance is relatively still in its infancy. DRI represents a small fraction of the world's ironmaking today, but DRI production and capacity expansion continue to grow at a rapid pace presenting vast opportunities for the future. As preeminent technology leader, it is our responsibility and mission to help educate and develop this emerging market to ensure that our clients excel and prosper well into the next century."



TODD AMES
DIRECTOR - SALES

EDUCATION

BS in Mechanical Engineering, Virginia Tech
MS in Mechanical Engineering, Rensselaer Polytechnic Institute

YEARS WITH MIDREX

11

OTHER POSITIONS WITH MIDREX

General Manager - Plant Sales MENA;
Sr. Mechanical Engineer; Plant Sales Manager

Todd has deep technical knowledge with undergraduate and graduate degrees in mechanical engineering and two decades experience working as an engineer at Midrex and with other firms. Thus, he has the ideal background for technical sales. He oversees the sales process for plant sales and Global Solutions. Todd is leading efforts to identify and evaluate new business models and products to better satisfy client needs.

QUOTE:

"Midrex is the leader in the direct reduction ironmaking technology field. And as leader, we have a responsibility to help our clients make the best possible decisions and support them throughout the process. For us, signing a contract does not mean the end of a plant sales initiative, but rather it marks the beginning of a life-long partnership."



BRAD CANTRELL
SALES MANAGER (AFRICA FOCUS)

EDUCATION

BS in Systems Engineering,
United States Naval Academy

YEARS WITH MIDREX

2

OTHER EXPERIENCE

US Marine Corps (9 years), rank of Captain

Brad brings good experience to Midrex from his years in the military, which involved hands on team leadership, including planning large scale aircraft training exercises and managing a sizable supply operation. His tasks included aircraft maintenance scheduling and planning, operations, safety, quality, logistics and supply. His world travels and exposure to different cultures during military service prepared him well for the demands of sales at Midrex.

QUOTE:

"A quality company is made up of quality people. Take care of them and they will produce a quality product that serves market needs. My role as sales manager is to engage each client, discover their needs, and offer the equipment and services tailored to their situation. Midrex has remained the leader in the direct reduction industry for so many years because of this way of doing business."



ROBERT MONTGOMERY
SALES MANAGER
(GULF COOPERATION COUNCIL FOCUS)

EDUCATION

BA in English, University of North Carolina at Charlotte

YEARS WITH MIDREX

3

OTHER EXPERIENCE

Senior Marketing specialist
 GM of Sales for VidaRF

Robert brings good experience to Midrex from his 10 plus years in technical sales. At VidaRF, he managed a team of six sales representatives and was responsible for many key accounts.

QUOTE:

"My role as a member of the Midrex Sales Team is to manage the commercial portion of the maintenance and plant upgrade needs of Midrex clients in the Middle East, to effectively communicate the latest advancements in DRI from Midrex to our GCC-based customers and to work with existing and/or new clients on the sale of new DRI plants. The best part of the job for me at Midrex is the people I'm able to work with and learn from every day – both colleagues and customers."



ALEX ZOLOTAREV
SALES MANAGER (CIS FOCUS)

EDUCATION

BS and MS in Aviation/Aeronautical Engineering,
 St. Petersburg Academy of Civil Aviation (Russia)
 BS, Cairn University

YEARS WITH MIDREX

4

OTHER EXPERIENCE

Quality Control Manager and Regional Sales Manager
 for SIT Controls Group (13 years)

Alex's sales background, language skills and knowledge of the CIS region are a tremendous asset for his work.

QUOTE:

"Currently there are five **MIDREX® Plants** operating in Russia and one under construction. With Russia's abundant reserves of iron ore and natural gas, DRI plants there have among the lowest operating costs in the world. I strongly believe it will remain a key market for Midrex in the upcoming years. Another factor is the lack of scrap to feed the country's EAFs. We will continue to focus on our relationships with existing and potential clients throughout the CIS. Those relationships and our knowledge of the market will be critical to our success."



THE VERSATILE* OBM (Ore-Based Metallic): Part 2

How to get what you paid for ... A guide for maintaining the value of DRI.

*(VERSATILE: able to adapt or be adapted to many different functions or activities)



By Christopher Ravenscroft, Robert Hunter and Frank Griscom

EDITOR'S NOTE:

This is the second in a series of articles designed to remove some of the confusion about direct reduced iron [DRI] for the novice and perhaps even expand what the seasoned veteran understands. Part 1 of this series [1Q 2016] began with the basics: what is direct reduction and what is direct reduced iron [DRI]. In Part 2 we will discuss what happens after the DRI is produced, the factors affecting DRI quality and how to maintain the quality [and thus the value] of DRI during handling, storing, transporting and ocean shipping.

INTRODUCTION - THE VALUE OF DRI

Direct Reduced Iron (DRI) is first and foremost a metallic iron raw material for making steel. Simply stated, it is a means for achieving the goals and objectives of the steelmaker using it.

DRI has evolved into various forms over the last 50 years (*Figure 1*). The first DRI plants produced only a cold metallic product (CDRI). As demand for DRI increased, a product with excellent handling and shipping characteristics was needed for the merchant market, which resulted in development of hot briquetted iron (HBI). Over time EAF steelmakers with captive DRI plants (i.e., plants adjacent to or nearby the meltshop) wanted a way to take advantage of the heat contained in DRI immediately following reduction, leading to the introduction of hot DRI (HDRI).

All three DRI product forms are versatile ore-based metallics (OBMs) and have distinctive characteristics that benefit steelmakers. The most effective and efficient use of DRI products will depend on the financial and operational objectives of the user. Much like operation of a meltshop, the use and preference of metallic materials will vary with the complexity of the steelmaking practice and the market in which the steel producer

competes. As a result, there is no one way to use DRI nor a single product form that fits all applications. With that said, the value of DRI is best gauged by what is most important to each steelmaker using the product and how well it meets these expectations; thus the product specification can vary with each user.*

Once produced, the product quality (and hence value to the steelmaker) can be directly impacted by what happens to the product prior to it being melted. DRI products, like other forms of iron, have the potential to degrade over time especially if not properly handled, stored or transported. Steelmakers largely have control over maintaining this quality if they take the right measures. This article will examine these measures required to maintain that value.

**It also must be noted that all direct reduction processes remove only the oxygen from iron oxide, thus the DRI is only as good as the iron ore from which it is made. Therefore, additional items such as acid gangue content will affect product value. Since discussing the "right ore specification" is a separate issue, this article will only focus on what users and buyers of DRI products can do after the product is made in order to best maintain the value of the DRI.*



CDRI



HBI



HDRI



FIGURE 1 *Three Types of DRI Products*

FACTORS AFFECTING DRI PRODUCT VALUE

It is a question probably not asked enough: “Is the product the same quality when it reaches the melting furnaces as when it was produced or purchased?”

DRI products provide value to steelmaking operations by delivering a highly metallized, low residual iron source to the melt shop. The extent of this value depends on maximizing the iron units (yield) by minimizing fines and maintaining product metallization after production.

Each DRI product, no matter how it is made, requires special considerations to maintain its value. Therefore, the yield and the degree of metallization (the percentage of total iron in the metallic form) are key factors in determining DRI value. In addition, there are safety concerns that if not addressed could negatively impact a user’s bottom line. These are factors that apply to all three DRI products; however, the ways to address these issues vary to a degree for each particular DRI product.

Fines Generation

Let’s start with fines (*Figure 2*). This factor should be obvious, as generating fines impacts product yield and productivity downstream. Materials handling equipment selection and system design have a huge impact on how much fines will be generated during handling, as will be discussed later in this article.

For steelmaking purposes, it is important that care is taken to prevent DRI from fragmenting into chips (+3 to -6 mm) or degrading into fines (-3 mm) during handling, transporting and storing to and within the steel mill. Fines generation and spillage can range from 3% to 7% and higher if not treated with care. These losses mean fewer iron units reach the meltshop, which

can have significant financial impact on the steel mill’s bottom line.



FIGURE 2 *Example of DRI fines*

Metallization

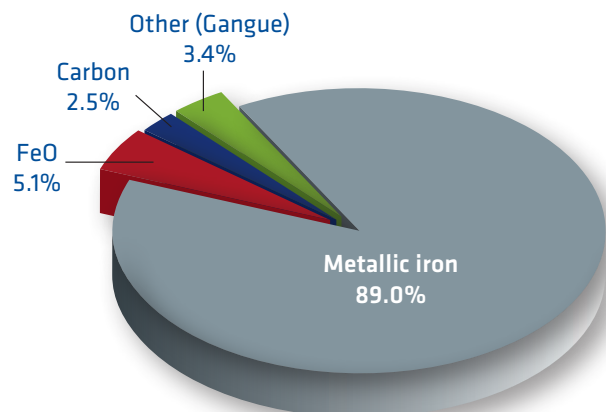
In all DRI products, a small amount of iron oxide (FeO) remains. Metallization is a quantification of the portion of the iron that is metallic. Why is it important? Achieving high metallization is the purpose of direct reduction as it creates metallic iron that is easier and less energy intensive to melt; therefore, higher metallization means value by creating more savings.

When it is stated that DRI has a certain degree of metallization, it means the percentage of metallic iron divided by total amount of iron in the DRI. Total iron is defined as the sum of metallic iron and iron contained as oxide. Metallization is normally expressed as a percentage:

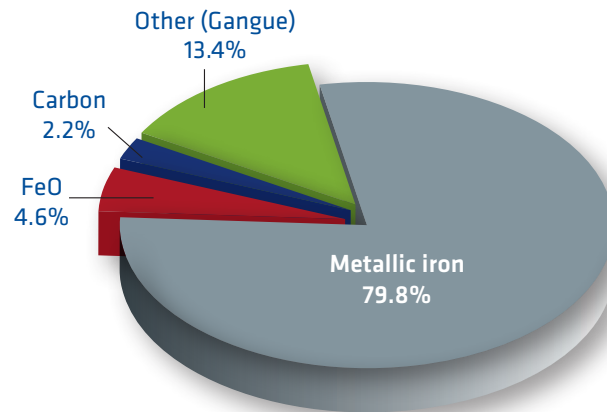
$$\% \text{ Metallization} = \frac{\text{Metallic Iron}}{\text{Total Iron}} \times 100$$

FIGURE 3 *Two examples of DRI at 95% metallization*

Sample A



Sample B



Metallic iron
 FeO
 Carbon
 Other (Gangue)

The addition of 10% gangue in Sample B displaces a portion of each of the other constituents in the product.

The extent to which reduction has been completed is represented by the percentage of metallization. Simply speaking, DRI with 95% metallization (or met) means that 95% of the iron is metallic and thus, the remaining 5% exists as FeO. Depending on operating practice of the meltshop, it may be possible to recover 20-80% of the iron present in DRI as FeO.

Please note that metallization is not the total percentage of everything contained in the DRI, just that of the iron-bearing portion (*Figure 3*). DRI also contains silica and other minerals. In fact, DRI could conceivably have a met of 95% and contain 10% of other minerals.

Metallization is impacted by its reactivity, which is directly influenced by how the DRI is stored and the product form of the DRI (CDRI, HDRI or HBI). In addition, metallization loss varies depending on the particle size of the material. Fines and chips, which have a much higher surface-area-to-volume ratio, are prone to more substantial corrosion and metallization loss, as will be discussed in the next section.

REACTIVITY OF IRON

Any discussion of the value of DRI and what happens during handling, storing, transporting and shipping must include the reactivity of iron. The natural tendency of all iron is to rust; i.e., to combine with oxygen in air (oxidize) and in water (corrode) to form iron oxides.

The tendency of iron to rust is intensified in the case of DRI. After all, DRI is the result of oxygen being chemically removed from iron oxide. A DRI pellet has a sponge-like structure consisting of a network of interconnected pores, which gives it an internal surface area thousands of times greater than a solid iron pellet. This large surface area encourages reactivity with oxygen and water, resulting in oxidation and corrosion. (*Note: We should point out that this is theoretical with HDRI, as the temperature of the product would cause a steam explosion if it were to be in contact with water.*)

The tendency of DRI to oxidize or corrode is called reactivity. All types of DRI are reactive regardless of the production process or product form. Prolonged exposure of DRI to water reduces product metallization due to rusting (the product of corrosion). Given sufficient time, oxygen and water, any iron mass eventually will be entirely converted to rust.

Rusting also generates heat and in bulk scenarios, this heat can cause DRI to ignite if the heat becomes trapped inside a product pile. This in turn could create a potential safety issue, costing additional money. In addition, a fire will no doubt affect both metallization and product yield; however, there is no need to panic as this phenomenon is completely controllable if properly handled. Excessive fines within a DRI pile also can pose a safety hazard, especially if the fines become wet and are buried in the pile.

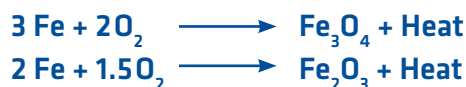


Oxidation and Corrosion

In order to better appreciate the challenges of handling, storing, transporting and shipping DRI products, it is helpful to understand the two most important reactivity reactions – oxidation and corrosion.

Oxidation

Oxidation occurs when hot DRI reacts with oxygen in the air to form either magnetite (Fe_3O_4) or hematite (Fe_2O_3), according to the following reactions:



Oxidation is an exothermic (i.e., heat liberating) reaction and will continue as long as DRI remains hot and sufficient oxygen is present. However, the oxidation reactions form a thin protective layer that modifies the DRI surface structure and substantially affects its porosity, which reduces DRI reactivity.

Research and plant experience have shown that freshly produced DRI reacts quickly with air when first discharged but the reaction decreases rapidly within minutes and continues to slowly decrease as the DRI cools. This reaction is known as natural aging and results in a modest loss of metallization (typically a fraction of one percent). Insufficient heat is generated during natural aging to cause an acceleration of the reaction.

HDRI is already above the ignition temperature ($>200^\circ\text{C}/390^\circ\text{F}$). Therefore, if it is allowed to be in contact with air, it will burn.

Corrosion

Corrosion occurs when CDRI or HBI is wetted and reacts with oxygen in the air to form rust (as previously mentioned, in the case of HDRI, exposure to water would cause a steam explosion due to its elevated temperature).

Rust ($\text{Fe}(\text{OH})_3$) occurs according to the following reactions, which are exothermic:



Two other corrosion reactions may occur under certain circumstances. These reactions are endothermic (i.e., heat consuming):

- If the oxygen is completely consumed after the first corrosion reaction, the $\text{Fe}(\text{OH})_2$ reacts as follows:



- If DRI is submerged in water, the following reaction may occur:



Corrosion is limited to the wetted surface of the DRI and will continue as long as water is present; however, evaporation occurs at $100^\circ\text{C}/212^\circ\text{F}$, so corrosion reactions tend to be temperature-limited. Corrosion is accelerated by contact with salt water because corrosion is an electrochemical reaction. As noted in the equations, hydrogen is also generated when DRI reacts with water.

CDRI is very porous and has a structure reminiscent of the iron oxide pellet from which it was made. As a result it tends to pick up water (as much as 15% of its weight) when exposed to intense wetting. HBI, due to its dense, compacted structure, is much more resistant to water pick up, which typically does not exceed 3% (*Figure 4*).

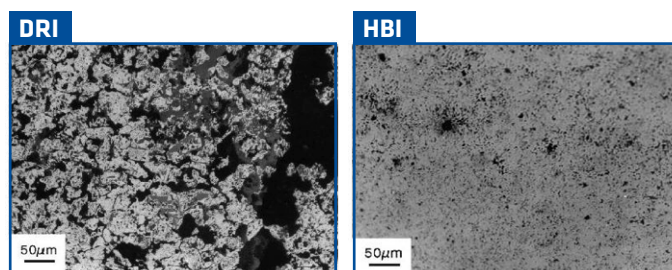


FIGURE 4 Internal structure comparison of DRI and HBI

In order to assess the extent of corrosion that can be expected to occur when storing HBI, a long-term experiment was carried out by BHP Billiton. A 65-ton HBI pile was set up next to the ocean in a salt-laden atmosphere.



The photos in *Figure 5* show the pile when it was first formed, 6 weeks later and 6 months later.



FIGURE 5 HBI corrosion test pile (courtesy of BHP Billiton)

It was found that the majority of metallization loss occurred in a surface layer approximately 0.2 m thick and a transition layer approximately 0.5 m thick with a relatively unaffected core. The test also showed that briquette density influenced the metallization loss of HBI (see *Figure 6*); i.e., the higher the density, the lower the metallization loss. This is understandable since the higher density briquettes have less surface area available for reaction with the atmosphere.

In addition, the metallization loss varies depending on the fraction size of the sample. Fines and chips, which have a much higher surface-area-to-volume ratio, are prone to more substantial corrosion, as shown in *Figure 7*.

A similar test was conducted by Sabah Gas Industries, the predecessor of Antara Steel Mills, on Labuan Island off the north coast of Borneo. A 660-ton pile of HBI was outfitted with thermocouples at six different locations on and in the pile and monitored for six months. At the end of the test period, it was determined that the metallization level decreased by only 0.8% per month despite exposure to tropical weather conditions and a salt-laden atmosphere (see *Table I, next page*).

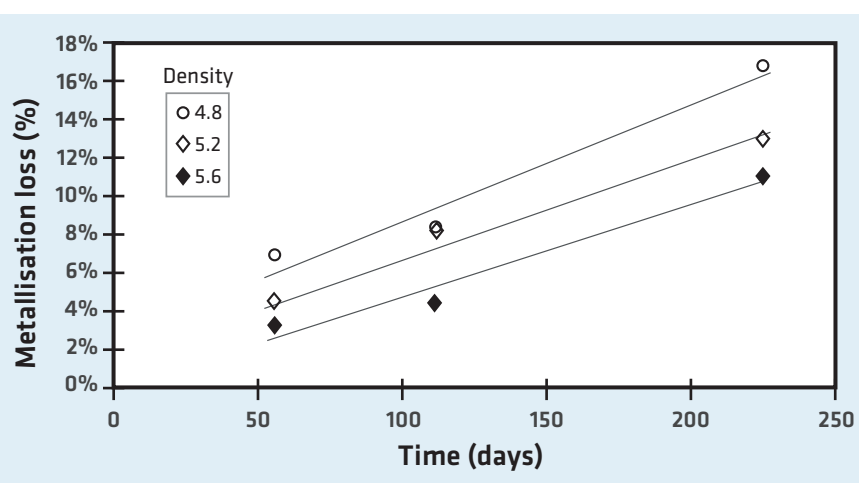


FIGURE 6 Metallization loss over time of various HBI densities (courtesy of BHP Billiton Technology)

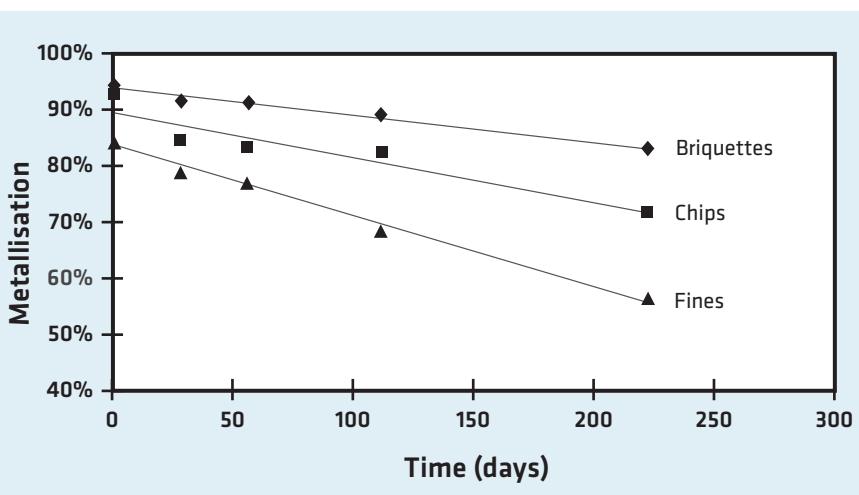


FIGURE 7 Metallization loss over time of HBI, chips and fines (courtesy of BHP Billiton Technology)



DRI Reactivity Stages

Experience has shown that the DRI reactivity mechanism consists of the following stages and is the same for CDRI and HBI:

- **Oxidation** – DRI will slowly oxidize in storage in the same way as scrap. The resulting rust will reduce metallization over time.
- **Steaming** – DRI will absorb water when heavily wetted due to capillary action, or wicking. The exposed surfaces of a DRI pile will release water vapor (steam) due to the heat generated by the corrosion reaction. Piles will continue to steam until the water is evaporated and the material cools to ambient temperature.
- **Hydrogen Generation** – hydrogen gas can evolve when water is present during oxidation and corrosion, which poses a risk of explosion and is detrimental to breathing in enclosed spaces.
- **Auto Ignition** – DRI is not pyrophoric (a material that ignites spontaneously in air at or below 55° C/130° F) but neither is it an inert material. Therefore, DRI piles can reach the ignition point (>200° C/390° F) as a result of excessive fines or hot product in the pile, the presence of excessive water or as a result of prolonged oxidation or corrosion. The auto ignition tendency should be monitored closely because hydrogen can be generated, especially in the presence of saltwater, and without any flame present.

Various techniques have been developed to address the reactivity of DRI products (Figure 8):

- **Natural aging** – an oxide patina develops in first few hours after discharge when DRI is exposed to air. Naturally aged DRI is resistant to dry oxidation up to 50-60° C.
- **Air passivation** – fresh DRI is exposed to a gaseous environment containing a controlled amount of oxygen for 48-72 hours.

660-Ton Test Pile	Fe Total (%)	Fe Met (%)	Met %	Volume %
Original Analysis	93.58	89.43	95.56	100
Final Analysis	91.89	83.13	90.47	100
Analysis by Location:				
Pile Surface	90.80	79.06	87.07	2
Outer Layer (0.2 m)	89.97	78.79	87.57	8
Transition Layer (0.5 m)	89.10	80.64	90.50	23
Pile Core	93.26	88.67	94.99	67

TABLE I SGI 6-month weatherability test results

Ranges of Reactivity of Various Types of Direct Reduced Iron

(note: logarithmic scale)

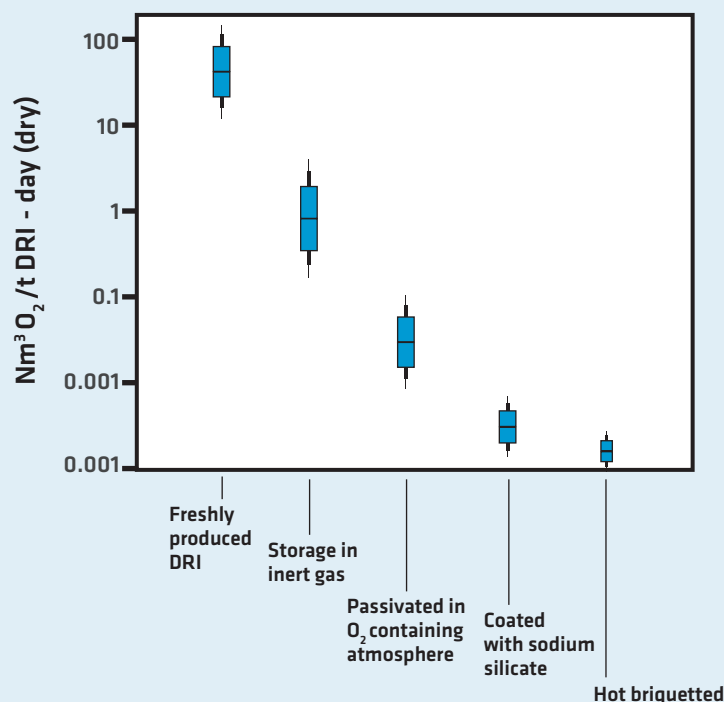


FIGURE 8 Ranges of reactivity of various DRI products

The effect is similar to natural aging.

- **Coatings** – various materials have been tested and used to coat DRI, such as sodium silicate in solution and even wax. Proponents of coatings claim that dust is suppressed in addition to inhibiting DRI oxidation and corrosion.

- **Hot briquetting** – compaction of DRI while it is hot, which increases the density of the DRI thus reducing the specific surface area and porosity, thereby decreasing its reactivity. Proponents of hot briquetting claim that dust and fines generation are reduced in addition to making DRI more resistant to oxidation and corrosion.



HANDLING DRI PRODUCTS

To preserve product quality, care must be taken to varying degrees with each product. As a general rule, users should try to minimize any unnecessary handling of the product. A material handling system should be designed for the minimum number of transfer points required to move material from point A to point B and with the shortest drops. The easiest way to minimize the number of transfer points is to take material along the straightest path possible. However, care should be taken not to compromise metering and feed control in an attempt to eliminate all transfer points. Spillage from overloaded belts may lose more material than breakage through the extra transfer point of a feeder.

A typical DRI handling system associated with a captive DRI plant may include the operations listed in *Figure 9*.

CDRI and HBI

- Conveying/transporting CDRI to storage silos
- Discharging/reclaiming CDRI from storage silos
- Conveying/transporting CDRI or HBI to short-term storage at EAF meltshop
- Reclaiming CDRI or HBI from short-term storage
- Conveying/transporting CDRI or HBI to EAF
- Charging CDRI or HBI to EAF

HDRI

- Discharging HDRI from reduction furnace to pneumatic transport system, insulated hot transport conveyor or insulated hot transport vessels
- Transporting/conveying HDRI from reduction furnace to EAF meltshop
- Charging HDRI to EAF from pneumatic system, insulated conveyor or transport vessels
- Direct gravity feeding HDRI from reduction furnace to EAF meltshop (if equipped)

FIGURE 9 *Characteristics of various DRI handling systems*

A frequently quoted estimate for CDRI breakage due to handling is 0.25% loss per 2-meter drop. This number can be much larger for weaker material, longer drops or poorly designed transitions. Fines and chips generated during handling will oxidize much faster than whole DRI products. A conservative number is 15% loss for -6.35 mm fraction material after exposed (outdoor) storage for a month.

HDRI can be transferred from the DRI plant to the meltshop by hot transport vessels, hot transport conveyors or pneumatic transport, depending on the distance between the DRI plant and the meltshop or by direct gravity feeding in the case of a close-coupled reduction furnace and EAF. Hot transport vessel systems employ ladle-type insulated vessels that are transported on flat-bed trucks and can be maintained at temperature if the meltshop is delayed in accepting the HDRI. Pneumatic transport systems use gas to blow DRI at high velocity through pipes to carry it to the EAF or to a product cooler. The high velocity and resultant turbulence can cause significant breakage and erosion of the HDRI, especially at bends in the pneumatic line. This method can result in fines generation of as much as 8-10%. Hot conveyor systems using enclosed conveyor buckets are less jarring and greatly reduce HDRI fines generation.

STORING DRI PRODUCTS

DRI products are somewhat like fresh fruit. Although they don't have an expiration date they are best consumed when "fresh." As with fruit, this may not always be possible, so the products may need to be placed in storage to preserve their quality, and value.

HDRI is not intended for long-term storage but can retain much of its heat when needed to wait for a charging cycle or to be transported to a different nearby melting furnace. This is a temporary option when using hot transport vessels and not really an option with using pneumatic or conveyor bucket systems.

Outdoor Storage

HBI is normally stored outdoors in exposed piles built on a firm, well drained surface. Bulk piles of HBI tend to dissipate heat rapidly due to its good thermal conductivity characteristics and its shape and form that create voids in the pile. HBI, like scrap can also rust. Rusting has been observed to reduce its metallization by less than one percent per month even in salt-laden, humid air and frequent, heavy rainfall conditions (see *Table I, page 13*).



CDRI can be stored safely in open, well drained piles if it will not be moved until it is used in the meltshop. Rain can only penetrate the stack to a certain depth, typically less than a meter. Although the resulting corrosion will reduce the metallization, as described earlier in this article, the stack should not overheat unless additional material covers the wet area. This will insulate the wet iron and prevent the dissipation of the associated heat, which can cause the pile to overheat and can lead to ignition.

The following precautions should be followed when storing DRI products outdoors:

- Build pile on a firm base, such as concrete, and insure proper drainage to prevent the intrusion of water under the pile. The base should provide protection from moisture in the ground. A sealant layout of tar, bitumen or some other material impervious to water should be laid down before the concrete is poured.
- Avoid excessive fines content in the pile.
- In the case of cold DRI (CDRI), cover the pile to keep DRI dry and to prevent air stacking in the pile.
- Separate any DRI that has been wetted or has a temperature in excess of 65°C/149° F and follow the same precaution as for bins and silos.

A DRI pile will warm up to about 60°C/140° F as steaming occurs (see “DRI Reactivity Stages” earlier in the article) but will cool down again to ambient temperature when the water is evaporated. Normally it is not necessary to take additional action if the pile is steaming as long as the temperature does not exceed 100°C/212° F.

In case of a pile of DRI overheating to temperatures in excess of 100°C/212° F, the material should be removed from the pile and spread out on dry ground in a layer of about 0.5 meters using a track-equipped bulldozer or front end loader, as shown in Figure 10. Another method is to bury the pile under sand or other suitable material to cut off the oxygen supply.

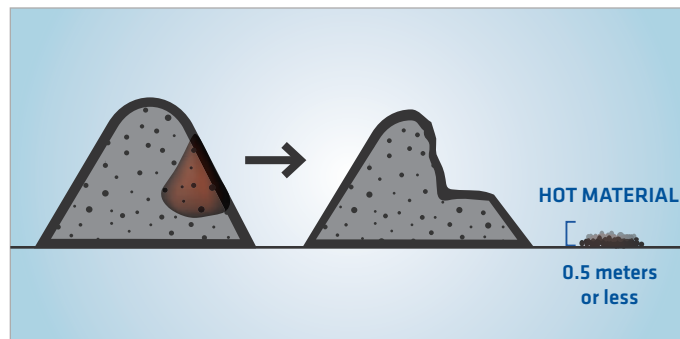


FIGURE 10 Method for controlling hot material in a storage pile

Important note: water should not be sprayed on an overheated DRI pile under normal conditions. However, as a last resort in case of a runaway fire, the pile should be inundated with a strong water stream. Firefighters should be prepared for violent steaming and hydrogen flashing resulting from such action.

THE CAUSE OF PROBLEMS MIGHT BE SOMETHING THAT YOU DON'T SEE.

CDRI needs to be kept dry.

That's well known, but people often only apply it to water falling from the sky (rain). When DRI is stacked on the ground, there is also a good possibility of water “wicking” up from the soil via capillary action and wetting the iron. Except in very arid locations, when CDRI is stored on the ground, it is necessary to provide a water barrier to prevent intrusion of moisture from the ground. In most cases, this is something as simple as tar poured prior to pouring a concrete pad. The tar stops the water, the concrete supports the stack of CDRI.

In addition, DRI needs to be kept away from corrosive chemicals. In the U.S., salt is used in many areas as a means of controlling ice on the roadways. This salt might be stored temporarily at docks and other transportation hubs. A few DRI fires have been caused by stacking the DRI in places where salt had recently been stored.



Storage Bins and Silos

Storage bins and silos are used to protect DRI products when there is a time delay between arrival and when the product can be used or shipped. Badly designed silos can create operational problems and a decrease of product quality. The design of silos should be determined always on the basis of the material flow properties of the bulk solid(s) to be stored. The expenses for testing and silo design are small compared to the costs of lost production, quality problems and retrofits that may be needed because of irregular flow patterns.

The following precautions are recommended when storing DRI products (*Figure 11*):

- Any DRI at a temperature in excess of 65° C/149° F should not be sent to a storage bin or silo. It should be separated from all other material and piled no more than one meter high.
- Bins and silos should be purged with an inert gas from the bottom.
- Top slide gates should be closed except when DRI is being delivered.
- Bottom slide gates should be closed except when DRI is being discharged.
- Inert gas should be introduced into the top of the bin or silo during extended storage periods to insure a slight positive pressure while the top and bottom slide gates are closed
- Periodic gas analyses should be performed to insure that oxygen level is below 3% and hydrogen is not being generated.
- Temperature within the bin or silo should be monitored. If high temperature (65-75° C/149-167° F) is observed, the bin or silo should be sealed and purged from the top until it cools. If the temperature rises to above 90° C/194° F, the DRI should be removed from the bin or silo.

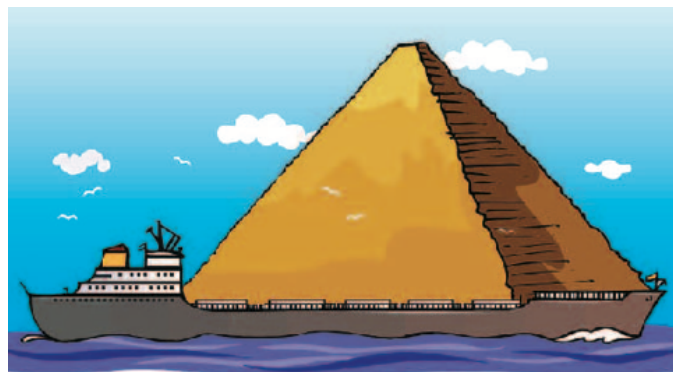
FIGURE 11 Recommended precautions for storage bins and silos

TRANSPORTING AND SHIPPING DRI

There is a considerable body of knowledge pertaining to the physical and chemical characteristics of direct reduction products, which is derived from the collective experience of the industry since the 1970s. This knowledge provides the framework for the wording of a variety of standards and guidelines in use

today. However, there is still a lack of understanding and appreciation of the proper methods and techniques for transporting and shipping these products.

Over the past 45 years, there have been a number of accidents involving direct reduction products. Many of these were the result of human carelessness or negligence when handling, storing and shipping these materials. Most of these accidents could have been avoided if the proper procedures had been followed. In other words, most hazardous situations can be avoided when the hazardous factors are fully identified, understood and controlled.



Shipments of HBI since 1976 are equivalent in ton-kilometers to shipping the Great Pyramid at Giza around the world three times!

Experience with early ocean shipments of CDRI revealed the need for a product that was safer to ship and easier to handle and store. HBI was first introduced commercially by Fior de Venezuela in 1976 and became a globally traded product following start-up of the SGI plant in Malaysia in 1984.

Early tests of HBI showed that it is orders of magnitude more resistant to oxidation than other forms of DRI (*see Figure 8 earlier in the article*). In addition, the heat created by oxidation is more easily conducted through the briquettes; therefore, the heat does not collect within a bulk stack of HBI. The result of these two mechanisms (far lower oxidation rates and much better conduction of heat out of a stack) prevents the overheating and combustion of HBI.

Due to the much lower reactivity and higher thermal conductivity of HBI, the International Maritime Organization (IMO) in its International Solid Bulk Cargo (IMSBC) Code is considerably less restrictive on transporting HBI, or DRI (A), as designated by IMO. Perhaps equally important is that the Protection and Indemnity (P&I) Clubs, which provide insurance underwriting for oceangoing cargoes, consider that the only proven



method of safely carrying non-briquetted DRI is by maintaining the cargo holds in an inert atmosphere throughout the voyage.

From 1970-2015, approximately 1.4 billion tons of DRI have been produced, nearly 300 million of which have been transported and shipped. Prior to the introduction of HBI, CDRI was primarily transported on land by truck and rail and represents more than 52% of all DRI products transported and shipped since 1970.

However, shipping CDRI, or DRI (B), as it is known in the IMSBC Code, is a complicated, detailed and potentially hazardous process. Nu-Iron in Trinidad and Tobago has been able to safely ship by ocean more than 9.0 million tons of CDRI since 2007 by following and improving upon IMO procedures and practices.

The following guidelines should be observed for CDRI and HBI alike when shipping by sea (*Figure 12*):

- Avoid loading during rain.
- Holds must be clean and dry.
- Holds must be of steel and of water-tight construction.
- Holds must not contain steam lines or other heat sources.
- Holds must have water-tight hatch covers that are sealed to avoid the ingress of seawater during the voyage.
- Holds must have adequate ventilization to prevent hydrogen build up.
- Radar and other electronic systems sensitive to dust should be covered during loading and unloading.
- Vessel should be hosed down with fresh water following loading and unloading in order to protect painted steel surfaces from dust.
- Follow International Maritime Organization (IMO) guidelines for the category of DRI product being shipped – DRI A, HBI; DRI B, CDRI; DRI C, DRI A and/or B fines.

FIGURE 12 *Guidelines for shipping CDRI and HBI by Sea*

In the case of CDRI, (IMO classification DRI B), the following additional steps should be followed (*Figure 13*):

- Keep DRI dry at all times.
- Naturally age DRI for at least 72 hours prior to loading.
- Do not load DRI if hotter than 65° C/149° F.
- Inert the holds with nitrogen (must be maintained during the voyage) and seal the holds.
- For transporting by truck and rail, cover DRI to protect from rain and moisture.

FIGURE 13 *Additional guidelines for shipping CDRI*

A NOTE ON SAFETY: ADDING UP THE NUMBERS

Up to this point we have discussed issues in handling, shipping and storage that affect DRI product quality with the understanding that the loss of value means additional costs. Throughout we have noted safety precautions that although they do not improve product quality, none the less, impact financials.

It should be obvious, but workplace safety is a crucial part of any successful or prosperous business, and keeping people safe should be first priority. DRI products can be potentially dangerous under various conditions if not given the proper care. There are no cost savings worth the risks of shortcutting safety procedures when transporting and storing DRI products. Loss of life, injury, or destruction of property is costly on many levels. Direct cost to the company for a major accident include at a minimum: worker compensation claims, indemnity payments, and legal fees. Direct costs for a disabling on the job injury or death can quickly exceed seven figures.

The indirect costs are much more expensive over the long-term. The indirect costs of a lost time accident (LTA) will generally exceed the direct costs by a ratio of 4 to 1 or higher and compound into the millions of dollars in total cost over time. With the true costs of major injury accidents in mind, clearly the best way forward to stay with best industry practices and safety standards to help insure safest possible conditions.

SUMMARY

DRI is a versatile metallic iron for making steel. Its value is best determined by how it contributes to meeting the operational and productivity goals of those who use it. Each steelmaker operates a little differently; therefore, DRI must be not only highly metalized but also of consistent quality and versatile enough to



satisfy the steelmaking process being used. Foremost to steel-makers is that DRI products arrive at the melting furnace in as close as possible to their physical and chemical condition as when they were made. All iron is reactive and will rust. DRI, by definition, is highly prone to react when in contact with air (oxidize) and when in contact with water (corrode). Rust robs DRI of metallization and can lead to dangerous and unsafe situations during storage and ocean shipping if proper procedures are not followed. How the materials are handled, stored, transported and shipped greatly influences the quality – and thus the value – of DRI products.

The good news is that users of DRI products have great control over maintaining the value of the DRI prior to melting by addressing various issues.

Whether you produce CDRI or HDRI to feed an adjacent or nearby meltshop, or purchase HBI or CDRI as a merchant material, it is a significant investment. By taking some well documented precautions and following procedures developed from decades of industry experiences, DRI products can be handled, stored, transported and shipped safely and steelmakers can realize the value of these versatile ore-based metallic iron sources. ■



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 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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CONTACTING MIDREX

General E-mail:
info@midrex.com

Phone: (704) 373-1600
2725 Water Ridge Parkway
Charlotte, NC 28217 USA

General Press/Media Inquiries
Christopher M. Ravenscroft
cravenscroft@midrex.com
Phone: (704) 378-3380