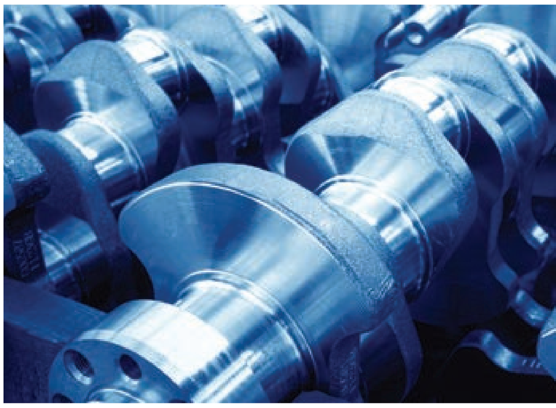


DRI Products & Applications

Providing flexibility for steelmaking

MIDREX

Designed for Today,
Engineered for Tomorrow™

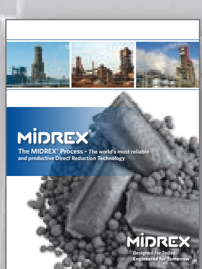
CONTENTS

ENVIRONMENTAL ASSURANCE

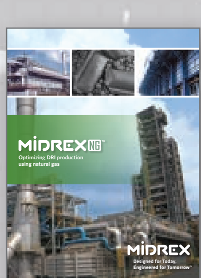
Midrex Technologies, Inc. along with its parent company Kobe Steel, Ltd., recognizes the importance of protecting the environment and conserving natural resources. Through the years we have been proactive in increasing efficiency, productivity, reliability and safety while reducing the environmental impact of our processes.

MIDREX® Plants are designed to minimize water, noise and air pollution.

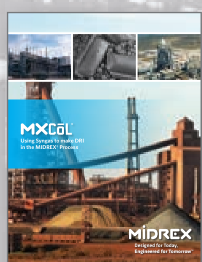
MIDREX® Plants meet applicable World Bank standards and more importantly, Midrex can and will provide DRI Plants designed to meet any local emissions or environmental standards regardless of location.



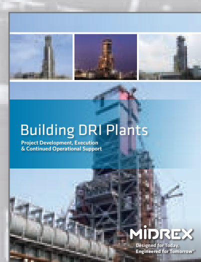
MIDREX® Process



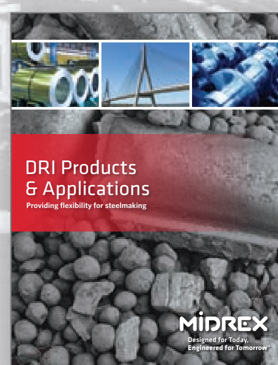
MIDREX NG™



MXCOL®



Building DRI Plants



DRI Products & Applications

DIRECT REDUCED IRON
THE VERSATILE METALLIC

THE NEED FOR METALLICS WILL CONTINUE TO INCREASE AS STEELMAKING GROWS AND EXPANDS GLOBALLY. REGARDLESS OF THE STEELMAKING ROUTE, THERE IS A FORM OF DIRECT REDUCED IRON (DRI) FOR EVERY APPLICATION.

DRI is a premium ore-based metallic (OBM) raw material made by removing chemically-bound oxygen from iron oxide pellets and lump ores without melting. DRI is high in iron content and low in copper and other undesirable metals, tramp elements, and nitrogen content. It is used to make a broad range of steel products...all types of sheets up to and including exposed auto body, extra deep drawing quality, fine wire, special bar quality, forging bar quality, plate and seamless tubes. Its physical and chemical characteristics make it desirable for use in the electric arc furnace (EAF), blast furnace (BF), and basic oxygen furnace (BOF).

HOT ROLLED STEEL COIL

SPECIAL BAR QUALITY STEEL

DEVELOPMENT OF PRODUCT FORMS

The first modern direct reduction plants were built adjacent to the steel mills that consumed their products. As the industry blossomed, technology developed with this new market. In turn, this increased the global market and the demand for the metallic iron.

As users became more familiar with DRI, specific product forms emerged to meet steelmaking needs. These new product forms solved problems such as long term storage and ocean transport and allowed for larger product size and density, which helped to open the BF/BOF market for DRI products. New technologies such as hot transport and hot charging have increased the economic benefit to steelmakers of these versatile virgin iron metallic products.

STEEL BEAMS

FORMS & CHARACTERISTICS OF MIDREX® DRI PRODUCTS

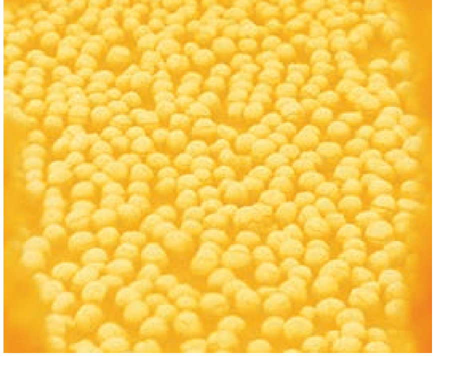
HIGH METALLIC IRON, LOW RESIDUAL CONTENT, ADJUSTABLE CARBON LEVELS AND CONSISTENT CHEMICAL AND PHYSICAL PROPERTIES DEFINE DRI PRODUCED BY THE **MIDREX® PROCESS**.

DRI PRODUCTS

CDRI

HBI

HDRI



Cold DRI (CDRI)

Most MIDREX® Plants built to-date produce CDRI. After reduction, the DRI is cooled in the lower part of the MIDREX® Shaft Furnace to about 50° C. This material is typically used in a nearby EAF and must be kept dry to prevent reoxidation and loss of metalization. CDRI is ideal for continuous charging to the EAF.

Hot Briquetted Iron (HBI)

HBI is the preferred DRI product for the merchant metallics market because it is much denser than CDRI, which reduces the reoxidation rate. This enables HBI to be stored and transported without special precautions under the International Maritime Organization (IMO) code for shipping solid bulk cargoes. It can be used in the EAF, BF, and BOF.

HBI is made by compressing DRI discharged from the MIDREX® Shaft Furnace at ≥ 650° C into pillow-shaped briquettes with a typical size of 30 x 50 x 110 mm and a density ≥ 5 gm/cc. No binder is used to make HBI.

Hot DRI (HDRI)

HDRI can be transported to an adjacent EAF at up to 650° C to take advantage of the sensible heat, which allows the steelmaker to increase productivity and reduce production cost. Midrex offers three methods for HDRI transport: hot transport conveyor, hot transport vessels, and HOTLINK®.

The table on the right shows ranges of chemical and physical characteristics of DRI products typically produced by a MIDREX® Plant. It should be noted that operating parameters are controlled independently by each plant depending on the availability and quality of raw materials and reducing gas. Operation in some cases, will change in response to market cycles or other factors related to steelmaking. For example, some MIDREX® Plants are operated at metallization rates of 92-93% while others produce continuously at 97% metallization to optimize their steelmaking cycles.

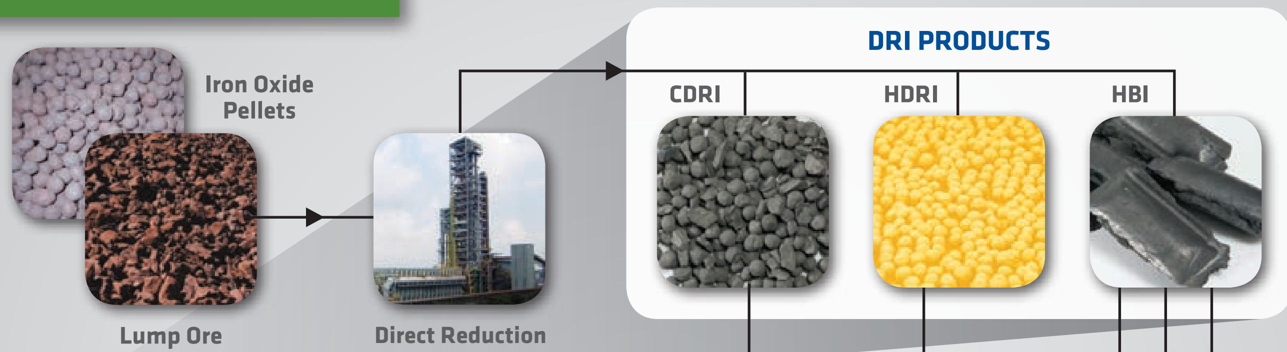
It is worth remembering that while some carbon is necessary in the DRI, increasing the carbon content reduces the total iron present in the DRI. Furthermore, too much carbon can increase tap-to-tap times in the EAF. *(See page 8 for more about carbon in DRI).*

TYPICAL CHARACTERISTICS OF MIDREX® DIRECT REDUCED IRON

	CDRI	HBI	HDRI
Fe Total (%)	90 - 94	90 - 94	90 - 94
Fe Metallic (%)	83 - 90	83 - 90	83 - 90
Metallization (%)	92 - 97	92 - 96	92 - 96
Carbon (%)	1.0 - 4.0	0.5 - 3.0	1.0 - 4.0
P* (%)	0.005 - 0.09	0.005 - 0.09	0.005 - 0.09
S* (%)	0.001 - 0.03	0.001 - 0.03	0.001 - 0.03
Gangue* (%)	2.8 - 6.0	2.8 - 6.0	2.8 - 6.0
Mn, Cu, Ni, Cr, Mo, Sn, Pb, and Zn (%)	trace	trace	trace
Bulk Density (kg/m³)	1,600 - 1,900	2,400 - 2,800	1,600 - 1,900
Bulk Density (lbs/ft³)	100 - 120	150 - 175	100 - 120
Apparent Density (g/cm³)	3.4 - 3.6	5.0 -5.5	3.4 - 3.6
Product Temperature (° C)	50	80	600 - 700
Typical Size (mm)	4 - 20	30 x 50 x 110	4 - 20

**Depends on iron ore source*

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

DRI USE IN THE EAF

THE ELECTRIC ARC FURNACE (EAF) TOGETHER WITH THE MODERN DIRECT REDUCTION INDUSTRY OPENED NEW VISTAS FOR GLOBAL STEELMAKING

EAF steelmaking and DRI have been closely associated for half a century. You might say they have grown up together ... from producing low cost, carbon steel long products to making high quality flat products that meet the most exacting specifications.

Today DRI is still used primarily to make long products, such as reinforcing bars and structural steel where scrap supplies are limited and costly to import; however, the chemical purity of DRI makes it far more valuable. EAF steelmakers have experienced DRI's true value as a scrap supplement that dilutes undesirable contaminants in the charge when the EAF is called upon to make high quality flat products and low nitrogen steels.

VIRGIN IRON SOURCE | Typical levels of residual elements in scrap and DRI/HBI

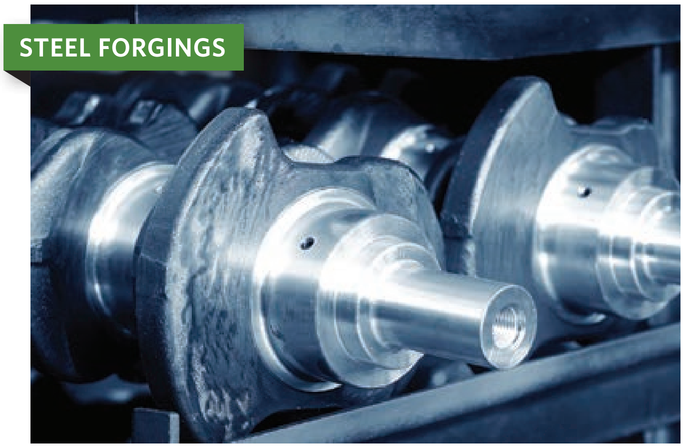
	% of element in scrap / DRI/HBI								
	%Cu	**%Sn**	**%Ni**	**%Cr**	**%Mo**	**%Mn**	**%S**	**%P**	**%Si**
No. 1 Bundles	0.07	0.008	0.03	0.04	0.008	0.03	0.02	0.01	0.005
Shredded	0.22	0.03	0.11	0.18	0.02	0.4	0.04	0.025	0.01
No.1 HMS	0.25	0.025	0.09	0.1	0.03	0.3	0.4	0.02	0.01
No.2 Bundles	0.5	0.1	0.1	0.18	0.03	0.3	0.09	0.03	0.01
No.2 HMS	0.55	0.04	0.2	0.18	0.04	0.3	0.07	0.03	0.01
DRI/HBI	0.002	trace	0.009	0.003	trace	0.06-0.10	0.002-0.007	0.03-0.07*	*

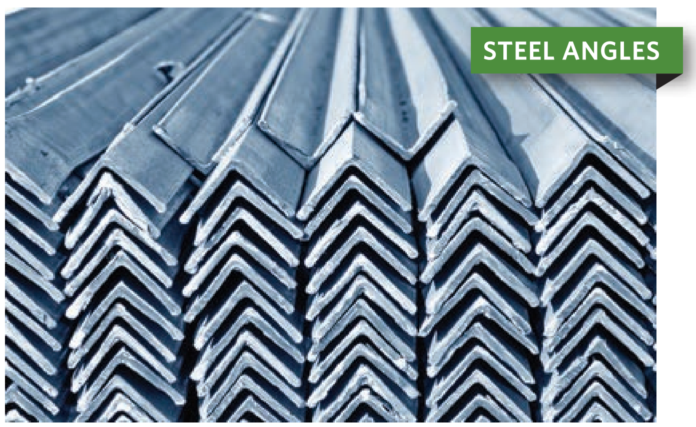
** Both Phosphorus and Silica are contained in the oxide form; they are not in the elemental form.*

DRI is ideally suited for use as either a replacement or a supplement for scrap in the EAF. DRI provides EAF operators the flexibility to tailor their furnace charges to achieve the desired product quality at the lowest cost per ton of liquid steel. This "metallics partnership" not only provides economic and operational flexibility, it brings even the highest steel specifications within the EAF domain.

The benefits of DRI products go beyond their chemical properties. They can be charged either in scrap buckets or continuously fed to an EAF. When batch charged, the density of CDRI and HBI can eliminate the need for a second or third scrap charge, which results in lower energy losses, fewer interruptions in power-on time, improved tap-to-tap time, and increased productivity. Typically CDRI or HBI can be used as up to 30 percent of the batch charge.

Continuous charging systems are used when CDRI, HBI or HDRI make up higher percentages of the total charge. Most commonly, a bucket of scrap is charged initially and then the DRI products are continuously fed. This allows the furnace roof to remain closed and the power to stay on during most of the heat. Maintaining a consistent temperature improves bath heat transfer and speeds up metallurgical reactions.





DRI USE IN THE EAF

MELTING BENEFITS OF HDRI

There are two primary benefits of charging HDRI into an EAF: lower specific electricity consumption and increased productivity. The energy savings occur because less energy input is required to heat the DRI to melting temperature, which results in a shorter overall melting cycle.

The rule-of-thumb is that electricity consumption can be reduced about 20 kWh/t liquid steel for each 100° C increase in DRI charging temperature. Thus, the savings when charging at over 600° C can be 120 kWh/t or more.

An additional benefit of a shorter overall melting cycle is a reduction in electrode and refractory consumption.

The increased productivity from HDRI charging is significant. Use of HDRI reduces the tap-to-tap time, resulting in a productivity increase of up to 20 percent versus charging DRI at ambient temperature.

MELTING BENEFITS OF HDRI IN EAF

- Increases EAF productivity by 15-20% or higher
- Decreases EAF electricity requirements by 120-140 kWh/t liquid steel
- Decreases EAF electrode consumption by at least 0.5-0.6 kg/t liquid steel
- Decreases EAF refractory consumption by at least 1.8-2 kg/t liquid steel

MIDREX HOT CHARGING METHODS

HOTLINK®
(Distances < 40m)

Reference: Jindal Shadeed (Oman)

HOT TRANSPORT CONVEYOR
(Distances < 200m)

Reference: Hadeed Mod E (Saudi Arabia)

HOT TRANSPORT VESSELS
(Distances > 100m)

Reference: Lion DRI (Malaysia)

In a **MIDREX® Hot Discharge Plant**, HDRI can be transferred by one of three methods to an EAF meltshop:

1. **HOTLINK®** for distances of less than 40 meters using gravity transport
2. **Hot Transport Conveyor (HTC)** for distances of less than 200 meters using hot conveyors provided by Aumund
3. **Hot Transport Vessel (HTV)** for distances of more than 100 meters

Commercial results of temperature of up to 650° C have been typical of these systems.

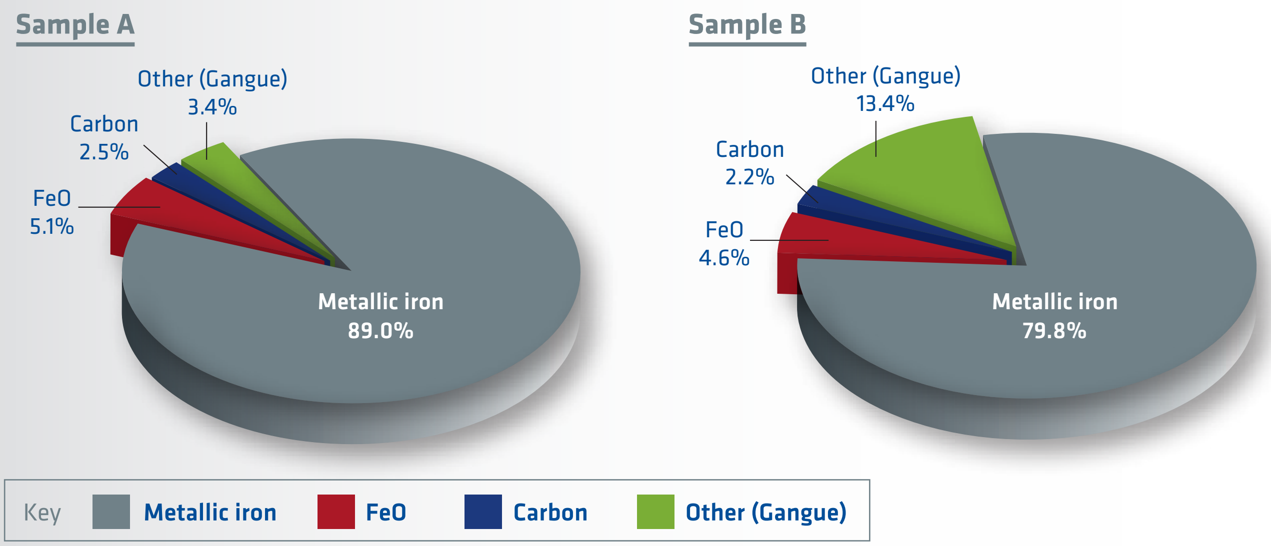
ADJUSTABLE CARBON LEVELS

The carbon levels of DRI produced by MIDREX® Plants can be controlled over a wide range. It is important to be able to adjust these levels as needed especially depending on how the product is being used. In certain cases, more carbon may be desirable to speed up tap-to-tap times; however, high levels can often be counterproductive and actually increase the duration of the tap-to-tap cycles *(see chart at the bottom of this page)*. This can happen when the residual carbon is more than what is needed to optimize the steel cycle time. Any excess carbon (defined as carbon beyond that which is necessary to meet the specific steel requirement of the steel product being produced) must be burned off (decarburized) thus causing a decrease in EAF productivity.

The metallization level of the DRI, the amount of DRI in relation to the quantity and quality of scrap in the charge and whether the DRI is charged hot or cold determine how much carbon is needed in the DRI.

Each EAF is different. The operation and the key drivers of the meltshop operation will determine the most advantageous DRI carbon content. MIDREX® Plants are unique in their ability to control DRI product carbon levels from 0.5-3.0 percent independent of other parameters.

TWO SAMPLES OF DRI AT 95% METALLIZATION



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

THE SPECTRUM OF CARBON IN AN EAF

REQUIRED		USEFUL	DETRIMENTAL
For meeting product specifications	For reducing FeO in unmetallized DRI	Available for oxidation. Can be burned to provide additional heat energy but is limited by: ➨ Decarburization Rate ➨ Available Oxygen ➨ Off Gas Collection ➨ Temperature of DRI	Any carbon higher than specification that remains in melted iron must be decarburized. The extra time consumed causes a decrease in productivity of the EAF.

HBI USE IN THE BF & BOF

THE FASTEST GROWING SEGMENT OF THE HBI MARKET IS BLAST FURNACES AND BASIC OXYGEN FURNACES IN EUROPE, CHINA AND THE US.

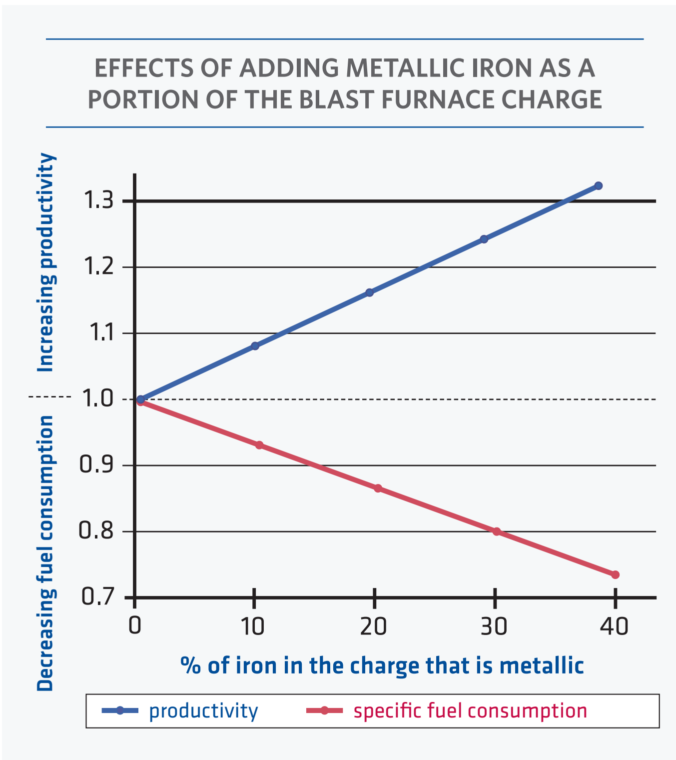
BLAST FURNACE

Due to its physical properties, HBI is the preferred form of DRI for blast furnace use. It can increase hot metal production and lower coke consumption and can be used as up to 30 percent of the BF charge with no significant equipment or process changes.

The addition of HBI increases hot metal production by boosting BF burden metallization...8 percent more production when burden metallization is increased 10 percent or 24 percent more hot metal when metallization is increased to 30 percent.

This is highly desirable when:

- Hot metal availability is insufficient to meet demand
- Hot metal requirements are not matched to blast furnace output
- One blast furnace is offline for maintenance



Using HBI to increase BF burden metallization has an environmental benefit as well. A 10% increase of the burden metallization results in a 7% decrease of the coke rate, which in turn reduces CO_2 emissions.

HBI has been part of normal operation of a commercial blast furnace in the US for nearly 25 years and has been used in other blast furnaces around the world. The voestalpine Group will make HBI on the US Gulf Coast in a **MIDREX® HBI Plant** currently under construction. The HBI is intended primarily for use in the Group's own European blast furnaces; however, some HBI will be available on a merchant basis.

BASIC OXYGEN FURNACE

HBI is the form of DRI best suited for use in the BOF because of its bulk density and physical strength. **It is a preferred alternative to scrap in the initial cold furnace charge because:**

- Residuals levels are lower
- Bulk density is higher
- Mass and heat balances are more accurate
- Steel chemistry is easier to control

Advantages of using HBI include:

- The cooling effect of HBI is approximately 10% greater than the cooling effect of scrap steel.
- There is no increase in slopping relative to using all scrap as the cold charge.
- There is no sculling on the lance.
- HBI can be used for low sulfur steels.
- HBI has lower levels of tramp elements than steel scrap.

HBI may be charged to the BOF from either:

- An overhead bin, or
- The charging box as up to 1/3rd of the cold charge.

PRODUCTION VALUE & FLEXIBILITY

DRI IS THE STEEL INDUSTRY'S MOST FLEXIBLE CHARGE MATERIAL. THROUGH YEARS OF ADVANCES IN PRODUCTION TECHNOLOGY, DRI HAS PROVEN TO BE OF EVEN GREATER VALUE TO STEELMAKERS.

Steady innovation and improvement have allowed for consistent and reliable production, growing the industry to more than 75 million tons annual production in 2013 from less than 1 million in 1970. The most useful technology advances have given greater flexibility to both the producers and the users of DRI products. These innovations have made the product more accessible, more economical to produce and more profitable to use.

MEETING KEY CHALLENGES - INNOVATIONS TO THE DRI INDUSTRY

HOT BRIQUETTING

In the mid-1970s, hot briquetted iron (HBI) was pioneered, allowing producers to more easily and safely transport and store direct reduced iron because the new product was more resistant to reoxidation than CDRI. This opened up new markets to DRI producers. The first plant to produce HBI from a DRI shaft furnace is the **MIDREX® Plant** at Antara Steel in Labuan, Malaysia.

OXIDE COATING

One of the most significant innovations for direct reduction is oxide coating for iron oxide pellets. A thin layer of limestone or cement allows the reducing gas temperature to be significantly increased, resulting in up to 20% more DRI production. The coating can be applied by the pellet supplier or at the DRI plant. Today oxide coating is used by almost every **MIDREX® Plant**.

COMBO PLANTS – MULTIPLE PRODUCT OPTIONS

The invention of the combo plant, which allows production of multiple products simultaneously, has allowed producers to optimize their overall operations. DRI producers can respond quickly to meet market demands by having the capability to make cold DRI, hot DRI, and HBI or any combination of DRI forms simultaneously. A true combo plant is one that should be able to easily vary product without stopping production. The **MIDREX® Shaft Furnace** design and operation enables simultaneous production or a quick change over between products with minimal loss in time, energy and money.

HOT TRANSPORT OPTIONS

The increased productivity from charging hot DRI into the EAF is significant. The key to the modern hot transport technologies is allowing the DRI plant to keep the HDRI at a consistently high temperature whether the EAF is close to the DRI plant or hundreds of meters away. If the DRI furnace is close, MIDREX® Plants have the capability to transport via gravity to the EAF, such as in the installation at Jindal Shadeed in Oman. For greater distances of up to 200m, MIDREX® can use Aumund's sealed hot transport conveyors to deliver high temperature HDRI to the EAF. For distances greater than 200m, or for multiple EAFs, hot transport vessels such as the ones used at LION DRI's MIDREX® Plant in Malaysia are an option. These three options open up HDRI productivity to both brownfield and greenfield sites.

FLEXIBILITY OF PRODUCTION TONNAGE TO ACCOMMODATE MARKET CONDITIONS

DRI plants should have the ability to operate efficiently in any economic market. DRI plants should be capable of meeting - if not exceeding - nameplate capacity in times of high market demand. When downstream operations do not require full production, the operator should also be able to turn down DRI production instead of shutting down the plant. Steady innovation has allowed early plants such as Qatar Steel's MIDREX® Mod 1 to produce double its original rated capacity and has helped Hadeed Mod E, to surpass its design capacity and become the world's first single module to produce more than 2 million tons in a single calendar year.

FLEXIBILITY OF REDUCTANT CHOICES

The availability of plentiful and reasonably priced natural gas has long been a limitation on where high capacity DRI plants could be built. Technologies now available allow a variety of other energy sources to be used for generating reducing gas. A high quality reducing gas can be derived from the export syngas of a COREX® Plant. Coals of any type and ash content can be gasified and coke oven gas can be reformed using a system such as the Thermal Reactor System™ *(see MXCOL® brochure for more information).*

RAW MATERIALS FLEXIBILITY

The MIDREX® Shaft Furnace can operate with any commercially available iron oxide pellets, lump ores, and blends of the two including pellets used in blast furnaces. MIDREX® Plants have successfully processed iron-bearing materials of varying quality from more than 50 sources around the world.

Hadeed Module E
Al Jubail, Saudi Arabia
(Hot Transport Conveyor Combo Plant)

JSPL Angul I
Angul, India
(MXCOL® Coal Gasifier Combo Plant)

ArcelorMittal South Africa
Saldanha Bay, South Africa
(Flexible Reductant Plant)

This operating flexibility allows the plant operator the freedom to determine his raw materials based on cost, availability, and steel mill economics.

ENVIRONMENTAL BENEFITS OF DIRECT REDUCTION IRONMAKING

DRI IS THE BEST WAY FOR THE WORLD'S STEEL INDUSTRY TO DECREASE ITS CARBON FOOTPRINT. EACH YEAR APPROXIMATELY TWO BILLION TONS OF CO_2 ARE PRODUCED WHILE MAKING STEEL. THE GREATEST PORTION, MORE THAN 80%, IS MADE WHILE CONVERTING IRON ORE TO METALLIC IRON.

Blast furnace ironmaking uses a carbon source such as coal or coke to generate metallic iron by removing the oxygen, thus producing CO_2 as a byproduct. Natural gas fueled direct reduction plants make metallic iron by using hydrogen molecules to remove 2/3 of the oxygen atoms and carbon to remove the remainder. Accordingly, the generation of CO_2 is cut by 2/3 relative to standard blast furnace ironmaking.

Since blast furnaces produce about 93% of the world's iron, there clearly is a very large potential for lowering CO_2 emissions by replacing the carbon-intensive ironmaking of blast furnaces with the much lower carbon footprint of natural gas based direct reduction ironmaking.

Coupled with an EAF, a DRI plant is capable of making any variety of steel normally associated with integrated blast furnace/BOF steelmaking. Many organizations have advocated this to help the steel industry reduce its CO_2 emissions; however, it is not feasible that DR/EAFs will completely replace BF/BOF steelmaking. There are simply some locations where BF/BOF is clearly the more economic route.

Another means of lowering the carbon footprint of ironmaking in BF/BOF operations is to pre-reduce a portion of the iron in a DRI furnace prior to charging the iron to a BF. Removing the oxygen (reduction), is the big energy step, and is accomplished using natural gas and then the lesser energy step, melting is done in the BF. This has been demonstrated at many locations over the past decades with as much as 30% of the BF charge being DRI in the form of hot briquetted iron (HBI). HBI is best for use in BF's since the overburden pressure of a large BF may crush unbriquetted DRI. By using HBI, and thus greatly lowering the carbon footprint of a blast furnace, the direct reduction industry can help increase the sustainability of the BF industry.

Finally another way DRI can help lower the carbon footprint of ironmaking is to maximize the coke rate or the amount of iron produced from a given amount of coal. When coke is made for use by a blast furnace, volatiles are driven off the coal and the remaining carbon and ash become the coke. Some of these volatile gases are used to heat the coke ovens. The remaining volatile gases may be, used for a variety of purposes including making DRI. The MIDREX® TRS® makes it possible to convert those gases into a usable syngas to produce additional iron in a MXCOL® DRI Plant.

Regardless of the route used, direct reduction ironmaking presents the steel industry with sustainable possibilities for the steel industry to be more environmentally responsible by lowering its overall carbon footprint.

EVOLUTION OF DRI PRODUCT USE

DRI HAS PROGRESSED IN STEP WITH THE INCREASING MODERNIZATION OF STEELMAKING TECHNOLOGY, EQUIPMENT AND PRACTICES. THE KEY TO SUSTAINABILITY IS FLEXIBILITY...AND DRI IS A PRIME EXAMPLE.

Early DRI plants were built to provide iron units for making basic steel grades in adjacent EAF mills, usually where scrap was not readily available. It often was called "sponge iron" due to the porous structure of the reduced pellets and was cooled prior to discharge from the shaft furnace and stored in covered piles or enclosed bins prior to use in the melting furnace charge.

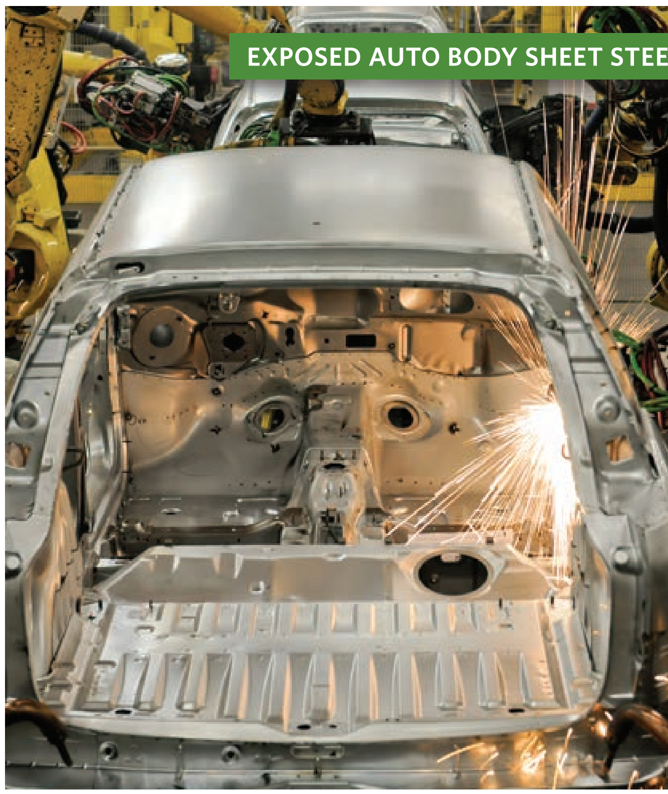
Over the past several decades, DRI production and products have evolved to meet growing steelmaking needs. As EAF steelmaking increases, DRI with its high metallic iron content, adjustable carbon level and consistent chemical and physical characteristics provides EAF steelmakers the broad flexibility to tailor their furnace charges to market conditions as well as giving them the ability to produce higher quality steels than would be possible with scrap alone. Technology advances such as hot charging and larger capacity DRI plants make the DRI/EAF combination even more enticing and economical.

The fastest growing application for DRI products is HBI for use in the blast furnace (BF) and basic oxygen furnace (BOF). The addition of HBI to the BF boosts burden metallization, resulting in increased hot metal production and reduced coke consumption. Therefore, the BF operator can achieve his productivity goals while reducing CO_2 emissions.

In any case or application, the industry is looking for a variety of DRI products, for a growing multitude of uses and users. As world DRI production continues its steady growth, Midrex will continue to innovate, improve and provide reliable technology options for the global steel industry.


STEEL SEAMLESS TUBES


STEEL WIRE & CABLE


EXPOSED AUTO BODY SHEET STEEL

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