MIDREX®

The MIDREX® Process - The world's most reliable and productive Direct Reduction Technology

MIDREX

Designed for Today,
Engineered for Tomorrow™

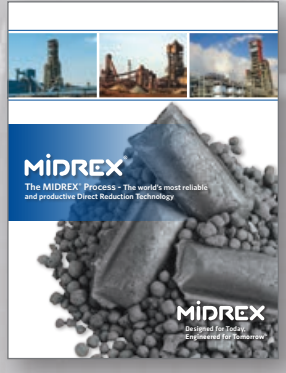
CONTENTS

ENVIRONMENTAL ASSURANCE

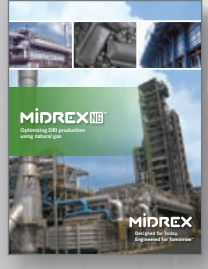
Midrex Technologies, Inc. along with its parent company Kobe Steel, Ltd., recognizes the importance of protecting the environment and conserving natural resources. Through the years we have been proactive in increasing efficiency, productivity, reliability and safety while reducing the environmental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

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

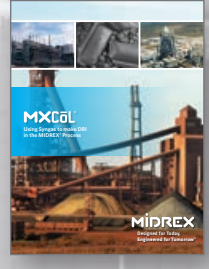
MIDREX® Plants meet applicable World Bank standards and more importantly, Midrex can and will provide DRI Plants designed to meet any local emissions or environmental standards regardless of location.



MIDREX® Process

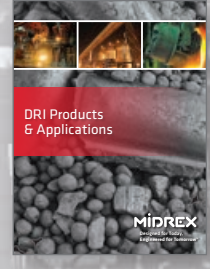


MIDREX NG™



MXCOL®

Building DRI Plants



DRI Products & Applications

The MIDREX® Process

THE GROWTH AND INCREASING SOPHISTICATION OF THE WORLD STEEL INDUSTRY HAS CREATED AN ESCALATING DEMAND FOR HIGHER QUALITY VIRGIN IRON PRODUCTS AND TECHNOLOGY SOLUTIONS TO BEST UTILIZE THE RAW MATERIALS AVAILABLE.

Over the past four decades Midrex Technologies, Inc. has risen to meet the industry's need by supplying and continually innovating the world's most reliable and productive Direct Reduction Technology: The **MIDREX® Process**.

The **MIDREX® Process** is unsurpassed in the Direct Reduction industry in terms of production and process flexibility to meet the constantly evolving nature of steelmakers and ore-based metallics providers.

Adjustable product quality and the flexibility to produce various forms of iron together with some of the best production records industry-wide make **MIDREX® Plants** the most profitable DRI plants in the world to own and operate.

Midrex's primary business is direct reduction ironmaking. We build DRI plants that work day in and day out, year after year to provide value for our clients so that they can make the most of their investment and maximize their profits for years to come.

MIDREX® DIRECT REDUCTION FLEXIBILITY

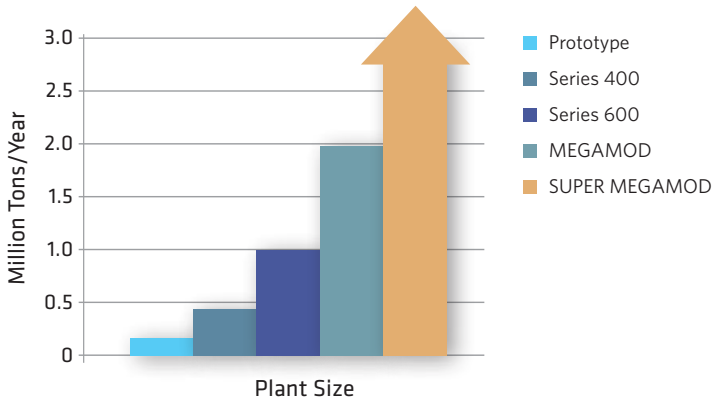
MIDREX® PLANTS ARE DESIGNED TO THE SPECIFIC REQUIREMENTS OF EACH CLIENT BECAUSE THE **MIDREX® PROCESS** ALLOWS FOR THE BROADEST SELECTION OF PROVEN PROCESS OPTIONS.

MIDREX® Direct Reduction Plants are the industry's most productive and reliable direct reduction plants with a proven history using the broadest range of reductant sources and raw materials. The MIDREX® Process provides the most complete product discharge options commercially available with the flexibility to process iron oxide pellets and lump ores of varying quality.

It is the attributes of the MIDREX® Process that give investors and plant owners confidence in the technology and its operation. MIDREX® Plants may be sized to support the Client's needs whether that need is to provide a partial or total charge for EAF(s), for Blast Furnace(s), for Basic Oxygen Furnace(s) or for merchant purposes (sales to other steelworks). Only MIDREX® Plants have proven performance in this regard.

Whether the requirement is for 500,000 tons per year or 2.5 million tons per year and higher, owners know they will receive the same high performance and reliability from the MIDREX® Process and outstanding investment value due to the operational flexibility of the plant.

GROWTH OF MIDREX CAPACITY



Flexibility of MIDREX® Plants

The MIDREX® Process can:

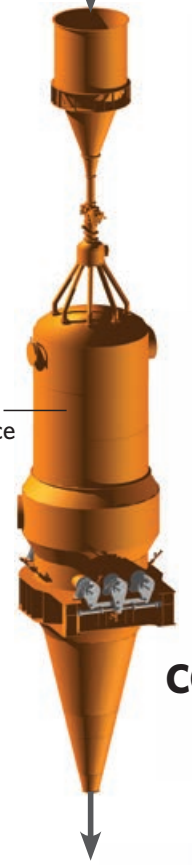
- derive reducing gas from the energy source most readily available and competitively priced
- efficiently reduce local iron oxide pellets and ores of varying quality either separately or in differing combinations
- discharge DRI either cold or hot and in any combination simultaneously to produce cold DRI (CDRI), hot briquetted iron (HBI) and hot DRI (HDRI)

The shaft furnace-based **MIDREX®** **Process** provides an efficient way to reduce iron oxide with the greatest operational flexibility.

MIDREX® DIRECT REDUCTION PROCESS FLEXIBILTY

FEED MATERIALS: Pellets | Lump Ore

ENERGY SOURCES	REDUCING GAS	
Natural Gas	MIDREX® Reformer	MIDREX NG™ Plant
Natural Gas	Steam Reformer	MIDREX NG™ Plant
Coal, Pet Coke, Refinery Bottoms	Gasifier	MXCOL® Plant
Coke Oven Gas (COG)	Thermal Reactor System™	MXCOL® Plant
Coal, Pet Coke	COREX®	COREX® / MXCOL® Plant



PRODUCT OPTIONS: CDRI | HBI | CDRI & HBI | HDRI & CDRI | HDRI & HBI

MIDREX® SHAFT FURNACE

THE HEART OF THE **MIDREX® PROCESS** IS THE **MIDREX® SHAFT FURNACE**. AS A KEY COMPONENT OF THE **MIDREX® DIRECT REDUCTION PROCESS**, THE **MIDREX SHAFT FURNACE** IS THE MOST FLEXIBLE AND VERSATILE REDUCTION VESSEL FOR DRI PRODUCERS.

The MIDREX® Shaft Furnace can use natural gas or a syngas from coal or coke oven gas as its reductant. MIDREX® Plants commonly operate in excess of 8000 hrs per year. In addition, the MIDREX® Shaft Furnace has been proven in using the widest variety of oxide pellets or lump ores to produce CDRI, HDRI and/or HBI.

Operation of the MIDREX® Shaft Furnace is uncomplicated and straight-forward. Iron-bearing material is introduced into the top of a cylindrical, refractory-lined vessel, where it descends by gravity flow and is contacted by upward flowing reducing gas. The reducing gas, which is primarily hydrogen and carbon monoxide, reacts with the iron oxide to reduce (remove the oxygen content) and carburize the material prior to discharge. From there the product can be discharged as CDRI, HDRI, HBI or any combination simultaneously.

MIDREX® SHAFT FURNACE

- Iron Oxide pellets and/or lump are fed to top of furnace and flow downward
- Iron Oxide is heated and converted to DRI by a high temperature reducing gas
- Products can be discharged hot or cold in combinations that include CDRI, HBI or HDRI

REACTIONS WITHIN THE MIDREX® SHAFT FURNACE

REACTION	HEAT	DESCRIPTION
$3Fe_2O_3 + CO \longrightarrow 2Fe_3O_4 + CO_2$	Exothermic	Reduction by CO
$3Fe_2O_3 + H_2 \longrightarrow 2Fe_3O_4 + H_2O$	Exothermic	Reduction by H_2
$Fe_3O_4 + CO \longrightarrow 3FeO + CO_2$	Endothermic	Reduction by CO
$Fe_3O_4 + H_2 \longrightarrow 3FeO + H_2O$	Endothermic	Reduction by H_2
$FeO + CO \longrightarrow Fe + CO_2$	Exothermic	Reduction by CO
$FeO + H_2 \longrightarrow Fe + H_2O$	Endothermic	Reduction by H_2
$3Fe + CH_4 \longrightarrow Fe_3C + 2H_2$	Endothermic	Carburizing Reaction
$3Fe + 2CO \longrightarrow Fe_3C + CO_2$	Exothermic	Carburizing Reaction
$3Fe + CO + H_2 \longrightarrow Fe_3C + H_2O$	Exothermic	Carburizing Reaction

Iron Oxide Charging

Pre-heat

Reduction

Transition

Product Discharge

The MIDREX® Shaft Furnace is designed to:

- Capitalize on the principle of counterflowing gas and solids to maximize reduction efficiency
- Assure uniform solids flow by effectively distributing the furnace burden and avoiding material bridging
- Control the flow of gases between the various furnace zones
- Prevent the reducing gas from coming into contact with air
- Prohibit gas flows from fluidizing the furnace burden
- Maintain a uniform temperature profile across the cross-section of the furnace
- Avoid stoppages of furnace burden flow
- Eliminate the need for water-cooled discharge cone

Midrex has carefully and responsibly scaled up the production capacity of the MIDREX® Shaft Furnace over the last four decades – from an inside diameter of 3.7 meters in the prototype commercial plant in Portland, Oregon to the 7.15 meter furnace diameter of the newest operating MIDREX® Plants.

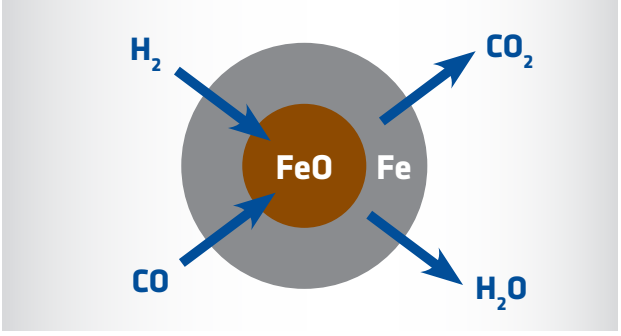
Even though increasing scales of production drive DRI innovation, sometimes the cyclic nature of the steel industry can reduce the requirement for a direct reduction plant's full production capacity. The MIDREX® Shaft Furnace has demonstrated the ability to operate cost-effectively even when operating as low as 30% of design capacity.

Oxide Pellets

THE OVERALL REDUCTION REACTIONS ARE:

$$Fe_2O_3 + 3H_2 \longrightarrow 2Fe + 3H_2O$$

$$Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$$



Carbon dioxide (CO_2) and water vapor (H_2O) are byproducts of the iron oxide reduction reactions.

SOURCES OF REDUCING GAS

VARIOUS FUEL SOURCES CAN BE USED TO CREATE A SUITABLE REDUCING GAS FOR THE **MIDREX® PROCESS**. THESE INCLUDE NATURAL GAS, COAL, COKE OVEN GAS OR PROCESS SYNGAS.

MIDREX® Process Energy Source Flexibility

Energy Source	MIDREX® Plant Reference	Reducing Gas Train	Reducing Gas H_2/CO	Start-up
Natural Gas	More than 60 modules in operation	MIDREX® Reformer	1.5 to 1.7	Since 1969
Natural Gas	FMO (formerly OPCO)	Steam Reformer, Heater + MIDREX® Reformer	3.2 to 3.9	1990
COREX® Offgas	ArcelorMittal South Africa	CO_2 Removal + Heater	0.3 to 0.4	1999
COREX® Offgas	JSW Projects Limited	CO_2 Removal + Heater	0.5 to 0.6	2014
Coal Gasifier	JSPL Angul I	CO_2 Removal + Heater	2.0	2014

Reducing gas, containing mainly hydrogen (H_2) and carbon monoxide (CO), can be generated from a wide variety of energy sources. Natural gas can be reformed in the unique, highly efficient MIDREX® Reformer or in a traditional steam reformer. Coal of any type or ash content can be gasified. Coke oven gas can be reformed using the MIDREX® Thermal Reactor System™ (TRS®). And, the export syngas from a COREX® Hot Metal Plant also makes a high quality reducing gas that can be used in a closely linked MIDREX® Shaft Furnace to produce DRI.

Comsigua MIDREX® Plant, Venezuela
MIDREX NG™

Hadeed Module E MIDREX® Plant, Saudi Arabia
MIDREX NG™

ArcelorMittal South Africa Plant
COREX®/MXCOL®

FMO Planta de Briquetas (formerly OPCO) Venezuela, *Using Steam Reformers*

JSPL Angul I, India
MXCOL® Coal Gasifier

RANGE OF FEED MATERIALS

THE **MIDREX® PROCESS** HAS OPERATED WITH VIRTUALLY ANY BLEND OF PELLETS AND LUMP ORES. **MIDREX® PLANTS** HAVE PROCESSED IRON BEARING MATERIALS OF VARYING QUALITY FROM MORE THAN 50 SOURCES AROUND THE WORLD.

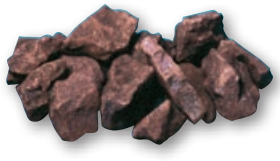
In the early days of direct reduction, there was a clearly discernible difference between iron oxide pellets intended for blast furnace use (BF-grade pellets) and those used to make DRI to feed an EAF. A "DR-grade" pellet typically has higher iron content and less silica, alumina and other gangue constituents than "BF-grade" pellets. DRI products made from DR-grade pellets are more appealing for the EAF user because the meltshop does not have to worry about excessive gangue materials.

Cost, availability and meltshop productivity dictate the type of feed materials used within the DRI plant. **MIDREX® Plants** can be designed to operate successfully using a wide variety of iron oxide pellets and lump ores including pellets used in blast furnaces. In fact, some companies have used the **MIDREX® Process** to reduce BF-grade pellets when they were unable to obtain DR-grade materials in order to maintain steelmaking operations.

Midrex has a comprehensive testing program at its Research and Technology Development Center that evaluates existing feed materials and investigates potential new sources. Midrex also works with the operators of **MIDREX® Plants** to determine the characteristics and composition of iron oxide sources most suitable for their operating conditions. Midrex interfaces with iron oxide suppliers to improve existing products and develop new ones.

FEEDSTOCK OPTIONS

PELLETS



LUMP

TYPICAL CHARACTERISTICS OF DR-GRADE PELLETS AND LUMP USED IN EAF STEELMAKING

	CHEMICAL CHARACTERISTICS	
	Pellets	**Lump**
Fe (%)	67.0	67.0
SiO_2 + Al_2O_3 (%)	3.0	3.0
S (%)	0.008	0.008
P (%)	0.03	0.03
TiO_2 (%)	0.15	0.15
	PHYSICAL CHARACTERISTICS	
	Pellets	**Lump**
Nominal Size	6 x 16 mm	10 x 35 mm
10 x 35 mm (%)	—	85 min.
9 x 16 mm (%)	95 min.	—
Minus 5 mm (%)	3 max.	5 max.
Compression Strength (kg)	250 min.	—
Less than 50 kg (%)	2 max.	—
	REDUCTION CHARACTERISTICS	
	Pellets	**Lump**
MIDREX LINDER TEST (760° C)		
Metallization (%)	93 min.	93 min.
Minus 3.36 mm (%)	2 max.	5 max.
HOT LOAD TEST (815° C)		
Tumble Strength (% plus 6.73 mm)	90 min.	85 min.
Compression Strength (kg)	100 min.	—
Clustering (% plus 25 mm after 10 rev.)	0	0

Lower quality iron ores are often used in MIDREX® Plants depending on the cost of the raw materials and the impact of downstream steelmaking operations. The Midrex Materials Testing Lab can evaluate all types of iron oxide pellets and lump ore to determine suitability for direct reduction ironmaking.

FORMS OF DRI PRODUCTS

DRI IS THE STEEL INDUSTRY'S MOST FLEXIBLE METALLIC CHARGE MATERIAL...AND THE **MIDREX® PROCESS** CAN PRODUCE, DISCHARGE AND TRANSPORT DRI IN THE FORM BEST SUITED TO THE APPLICATION.

PRODUCT FORMS

The first **MIDREX® Plants** produced DRI that was cooled prior to discharge: cold DRI (CDRI). As the benefits of DRI use became more widely known, a product form that was considered safe for ocean shipping by the International Maritime Organization (IMO) was needed. The result was hot briquetted iron (HBI), a DRI product hot discharged from the **MIDREX® Shaft Furnace** into a roller-type press that molds the reduced material into dense pillow-shaped briquettes. Discharging hot DRI (HDRI) as a product from a DRI furnace was the next progressive step for Electric Arc Furnace (EAF) steelmakers to increase efficiency and productivity.

The combination of hot and cold discharge in a single reduction furnace was a logical advancement for the **MIDREX® Process**. Today **MIDREX® Plants** can be switched from one DRI form to another with no disruption of product flow - CDRI to HBI, CDRI to hot DRI (HDRI), or HDRI to HBI. Product can be produced simultaneously in any combination.

DRI PRODUCTS

CDRI

HBI

HDRI

HOT TRANSPORT & CHARGING METHODS

In EAF steelmaking, hot transport/hot charging is an effective means of lowering the cost per ton of liquid steel by reducing power and electrode consumption, as well as increasing EAF productivity – making it possible to downsize the electrical system for a greenfield EAF meltshop.

MIDREX® Shaft Furnaces can be equipped with one of three systems to transfer HDRI to a steelwork's meltshop: **HOTLINK®**, **Hot Transport Conveyor (HTC)** and **Hot Transport Vessel (HTV)**.

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)

INNOVATIVE SOLUTIONS

DESIGNED FOR TODAY, ENGINEERED FOR TOMORROW...

WHATEVER THE TECHNICAL, COMMERCIAL OR GEOGRAPHICAL CHALLENGE, THE **MIDREX® PROCESS** CAN BE CONFIGURED TO DELIVER MAXIMUM VALUE, RECORD-SETTING PRODUCTIVITY, SUSTAINABLE COST STRUCTURE AND UNMATCHED RELIABILITY.

The increasing sophistication and intensely competitive nature of the global steel industry has created the demand for high quality, cost effective metallic inputs - iron products as dynamic as the industry they support.

Midrex has been designing and engineering direct reduction technology for more than four decades. MIDREX® Technology has helped launch national steel industries, contributed to EAF expansion into high end products and continues to close the iron-to-steel production gap.

The MIDREX® Process has become synonymous with performance, reliability and flexibility...the basis of investment value and operating profits for years to come.

MIDREX

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