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

Designed for Today, Engineered for Tomorrow™
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.
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

<table>
<thead>
<tr>
<th>Plant Size</th>
<th>Million Tons/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prototype</td>
<td>0</td>
</tr>
<tr>
<td>Series 400</td>
<td>0.5</td>
</tr>
<tr>
<td>Series 600</td>
<td>1.0</td>
</tr>
<tr>
<td>MEGAMOD</td>
<td>1.5</td>
</tr>
<tr>
<td>SUPER MEGAMOD</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
</tr>
</tbody>
</table>

**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 FLEXIBILITY**

**FEED MATERIALS**
- Pellets
- Lump Ore

**ENERGY SOURCES**
- Natural Gas
- Coal
- Pet Coke
- Refinery Bottoms
- Coke Oven Gas (COG)
- Gasifier
- Thermal Reactor System™

**REDUCING GAS**
- MIDREX® Reformer
- Steam Reformer
- MIDREX® Shaft Furnace
- Gasifier
- Thermal Reactor System™
- COREX®

**PRODUCT OPTIONS**
- CDRI
- HBI
- CDRI & HBI
- HDRI & CDRI
- HDRI & HBI

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**

<table>
<thead>
<tr>
<th>REACTION</th>
<th>HEAT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3\text{Fe}_2\text{O}_3 + \text{CO}$ $\rightarrow 2\text{Fe}_2\text{O}_4 + \text{CO}_2$</td>
<td>Exothermic</td>
<td>Reduction by CO</td>
</tr>
<tr>
<td>$3\text{Fe}_2\text{O}_3 + \text{H}_2$ $\rightarrow 2\text{Fe}_3\text{O}_4 + \text{H}_2\text{O}$</td>
<td>Exothermic</td>
<td>Reduction by H$_2$</td>
</tr>
<tr>
<td>$\text{Fe}_2\text{O}_4 + \text{CO}$ $\rightarrow 3\text{FeO} + \text{CO}_2$</td>
<td>Endothermic</td>
<td>Reduction by CO</td>
</tr>
<tr>
<td>$\text{Fe}_3\text{O}_4 + \text{H}_2$ $\rightarrow 3\text{FeO} + \text{H}_2\text{O}$</td>
<td>Endothermic</td>
<td>Reduction by H$_2$</td>
</tr>
<tr>
<td>$\text{FeO} + \text{CO}$ $\rightarrow \text{Fe} + \text{CO}_2$</td>
<td>Exothermic</td>
<td>Reduction by CO</td>
</tr>
<tr>
<td>$\text{FeO} + \text{H}_2$ $\rightarrow \text{Fe} + \text{H}_2\text{O}$</td>
<td>Endothermic</td>
<td>Reduction by H$_2$</td>
</tr>
<tr>
<td>$3\text{Fe} + \text{CH}_4$ $\rightarrow \text{Fe}_2\text{C} + 2\text{H}_2$</td>
<td>Endothermic</td>
<td>Carburizing Reaction</td>
</tr>
<tr>
<td>$3\text{Fe} + 2\text{CO}$ $\rightarrow \text{Fe}_2\text{C} + \text{CO}_2$</td>
<td>Exothermic</td>
<td>Carburizing Reaction</td>
</tr>
<tr>
<td>$3\text{Fe} + \text{CO} + \text{H}_2$ $\rightarrow \text{Fe}_2\text{C} + \text{H}_2\text{O}$</td>
<td>Exothermic</td>
<td>Carburizing Reaction</td>
</tr>
</tbody>
</table>
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.

THE OVERALL REDUCTION REACTIONS ARE:

\[
\begin{align*}
\text{Fe}_2\text{O}_3 + 3\text{H}_2 & \rightarrow 2\text{Fe} + 3\text{H}_2\text{O} \\
\text{Fe}_2\text{O}_3 + 3\text{CO} & \rightarrow 2\text{Fe} + 3\text{CO}_2
\end{align*}
\]

Carbon dioxide (CO₂) and water vapor (H₂O) are byproducts of the iron oxide reduction reactions.
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.

### SOURCES OF REDUCING GAS

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.

**MIDREX® Process Energy Source Flexibility**

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>MIDREX® Plant Reference</th>
<th>Reducing Gas Train</th>
<th>Reducing Gas $H_2$/CO</th>
<th>Start-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>More than 60 modules in operation</td>
<td>MIDREX® Reformer</td>
<td>1.5 to 1.7</td>
<td>Since 1969</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>FMO (formerly OPCO)</td>
<td>Steam Reformer, Heater + MIDREX® Reformer</td>
<td>3.2 to 3.9</td>
<td>1990</td>
</tr>
<tr>
<td>COREX® Offgas</td>
<td>ArcelorMittal South Africa</td>
<td>CO$_2$ Removal + Heater</td>
<td>0.3 to 0.4</td>
<td>1999</td>
</tr>
<tr>
<td>COREX® Offgas</td>
<td>JSW Projects Limited</td>
<td>CO$_2$ Removal + Heater</td>
<td>0.5 to 0.6</td>
<td>2014</td>
</tr>
<tr>
<td>Coal Gasifier</td>
<td>JSPL Angul I</td>
<td>CO$_2$ Removal + Heater</td>
<td>2.0</td>
<td>2014</td>
</tr>
</tbody>
</table>
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.

### CHEMICAL CHARACTERISTICS

<table>
<thead>
<tr>
<th></th>
<th>Pellets</th>
<th>Lump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe (%)</td>
<td>67.0</td>
<td>67.0</td>
</tr>
<tr>
<td>SiO₂ + Al₂O₃ (%)</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>S (%)</td>
<td>0.008</td>
<td>0.008</td>
</tr>
<tr>
<td>P (%)</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>TiO₂ (%)</td>
<td>0.15</td>
<td>0.15</td>
</tr>
</tbody>
</table>

### PHYSICAL CHARACTERISTICS

<table>
<thead>
<tr>
<th></th>
<th>Pellets</th>
<th>Lump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Size</td>
<td>6 x 16 mm</td>
<td>10 x 35 mm</td>
</tr>
<tr>
<td>10 x 35 mm (%)</td>
<td>—</td>
<td>85 min.</td>
</tr>
<tr>
<td>9 x 16 mm (%)</td>
<td>95 min.</td>
<td>—</td>
</tr>
<tr>
<td>Minus 5 mm (%)</td>
<td>3 max.</td>
<td>5 max.</td>
</tr>
<tr>
<td>Compression Strength (kg)</td>
<td>250 min.</td>
<td>—</td>
</tr>
<tr>
<td>Less than 50 kg (%)</td>
<td>2 max.</td>
<td>—</td>
</tr>
</tbody>
</table>

### REDUCTION CHARACTERISTICS

<table>
<thead>
<tr>
<th></th>
<th>Pellets</th>
<th>Lump</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIDREX LINDER TEST (760° C)</td>
<td>Metallization (%)</td>
<td>93 min.</td>
</tr>
<tr>
<td>HOT LOAD TEST (815° C)</td>
<td>Tumble Strength (% plus 6.73 mm)</td>
<td>90 min.</td>
</tr>
<tr>
<td></td>
<td>Clustering (% plus 25 mm after 10 rev.)</td>
<td>0</td>
</tr>
</tbody>
</table>
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 SUITTED 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).

HOT TRANSPORT CONVEYOR (Distances < 200m)

HOT TRANSPORT VESSELS (Distances > 100m)

Reference: Jindal Shadeed (Oman)

Reference: Hadeed Mod E (Saudi Arabia)

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.