DIRECT FROM MIDREX

2ND QUARTER 2019

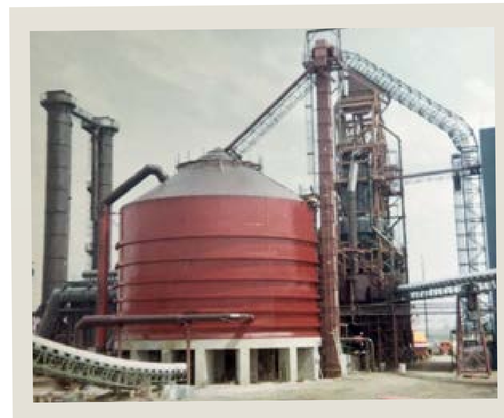
INSIDE THIS ISSUE

COMMENTARY

Building Our Future On 50 Years of Success

Stephen Montague
President & CEO, Midrex Technologies, Inc.

This year marks the 50th anniversary of the first plant based on the MIDREX® Direct Reduction Process. A lot has happened since May 17, 1969, when a small group of engineers of the newly created Midrex Department of Midland-Ross Corporation's Surface Combustion Division held their collective breath and awaited the first direct reduced iron (DRI) to be produced at Oregon Steel Mills (OSM) in Portland, Oregon, USA. Each of the two OSM modules was rated at 150,000 metric tons per year (t/y). Today, single modules that will produce 2.5 million t/y are in operation, and MIDREX Direct Reduction Plants annually produce more than 60% of the world's supply of DRI.

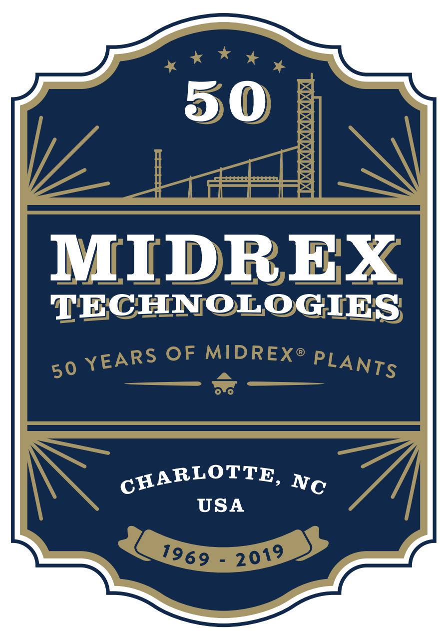


Last year at about this time, the cumulative production of DRI by MIDREX Plants reached 1 billion tons. It took 38 years to produce the first 500 million tons but only 11 to achieve the second 500 million tons. By the end of 2017, MIDREX Plants were operating at nearly 60 million t/y, with sufficient capacity under construction to push production to 75 million t/y by 2020. This means it could take less than 13 years to produce the second billion tons of DRI.

The early Midrex pioneers left us more than the world's most successful technology for the direct reduction of iron oxides. They created a commitment to innovation, excellence, and service that defines who we are today. This commitment is best seen in remarkable technologies, such as Hot Briquetted Iron (HBI), MEGAMOD®-sized plants, and HOTLINK®, which have changed the industry. We are excited by our other game-changing technologies, such as ACT™ and MIDREX H_2™, which make Midrex the most valuable and reliable source of iron for the global steel industry.

This issue of Direct From Midrex goes behind the scenes of the 50-year evolutionary development of MIDREX Direct Reduction Technology, which has continually responded to changing and emerging markets and expanding customer needs. Midrex has regarded each new challenge as an opportunity to better establish our direct reduction technology as the preferred means of preparing iron ores for use in steelmaking. In addition, this issue will report on the 2018 operational achievements of MIDREX Plants throughout the world.

We have come a long way from those tension-filled first days in Portland. The lessons learned along the way have taught us not to be content with success, but to continue striving for excellence. We are about pulling people together to make a difference, whether in the office, for the environment, or in the community. We are a team dedicated to serving others. ■



"It All Started in Portland ..." 50 Years Ago

Donald Beggs
Father of the MIDREX® Direct Reduction Process

By **John Kopfle**, Director – Corporate Development
and **Frank Griscom**, Midrex Marketing Consultant

AUTHORS' NOTE: *The cover of the 3rd quarter 1989 issue of* ***Direct From Midrex*** *was a departure from the normal silver-gray color and a bright red band across the bottom right-hand corner identified it as a special MIDREX® DR Technology issue commemorating 20 years of commercial operation. The first article carried the headline, "It All Started in Portland ..." in recognition of the start-up of the first commercial MIDREX Direct Reduction Plant in May 1969, at Oregon Steel Mills in Portland, Oregon, USA.*

Now, fast-forward 30 years – the ***Direct From Midrex*** *cover design has changed a couple of times and DFM now is published on the Midrex website rather than printed, but the plant in Portland is still celebrated for its role in launching the world's most successful, widely used direct reduction process.*

Midrex teammates celebrated the Portland start-up on May 17, exactly 50 years to the day and hour (see News & Views). We now invite you to join us for a journey through the first 50 years of inspiration, innovations, and improvements that are MIDREX Direct Reduction Technology.

A BETTER MOUSETRAP

American poet, Ralph Waldo Emerson, is credited with the phrase, "Build a better mousetrap, and the world will beat a path to your door."

This may have occurred to Donald Beggs on a Saturday afternoon in the mid-1960s, as he was cutting the grass at his home. Beggs, who managed the research group of Midland-Ross Corporation's Surface Combustion Division in Toledo, Ohio, USA, was intrigued by the idea of reforming natural gas to produce a high-quality synthesis gas that could be used to reduce iron oxide pellets. Surface Combustion was known for its combustion and heat transfer knowledge, its proprietary designs for a near-stoichiometric gas reformer, and a gravity-flow shaft furnace for indurating iron oxide pellets.

Beggs and Jack Scarlett, another member of the Surface Combustion Research Group, developed a process flowsheet and proposed building a pilot plant in Toledo. The plant, with an hourly production capacity of 180-225 kilograms, was built and operated successfully in 1967. The direct reduced iron (DRI) it produced was supplied to Oregon Steel Mills (OSM) in Portland, Oregon, which operated an electric arc furnace (EAF). To the delight of everyone involved, OSM established a new production record using DRI. As a result, OSM contracted Midland-Ross to build a full-scale commercial protype plant in Portland.

The plant, pictured in ***Figure 1***, consisted of two modules, each with a 12-feet diameter (3.7-meters) shaft-type reduction furnace capable of producing 150,000 metric tons per year (t/y) of DRI. Midland-Ross retained ownership of the plant and sold DRI to OSM on a long-term contract. Plant start-up was on May 9, 1969, and regular operations commenced on May 17, 1969.

The Midrex Division was formed that same year to develop the market potential of the MIDREX Direct Reduction Process. A patent for the MIDREX Process was granted to Beggs et. al. on July 24, 1973 ***(Figure 2)***.

THE PATH LESS TRAVELED

Conventional wisdom in 1968 was to use a steam reformer (with a large excess of steam as reactant) to produce reducing gas because it had been used in various industries for half a century. Also, it was believed that stoichiometric reforming (low excess steam) would cause severe catalyst degradation.

Beggs and his group knew that to produce a good quality reducing gas in a steam reformer, the reformed gas would have to be quenched to remove excess steam and then reheated to reduction temperature. Surface Combustion had been using stoichiometric reforming for 20 years and was manufacturing a gas generator that reacted natural gas and air at near stoichiometric ratio to produce a carburizing gas, which was mostly H_2, N_2, and CO with small amounts of CO_2 and H_2O. Therefore, Beggs and his group were confident that a near-stoichiometric ("Midrex stoichiometric") reformer operating at low pressure and capable of reforming CO_2 and H_2O would be successful in a DRI plant and simpler than using steam reforming.

They were correct. The MIDREX Reformer produces a high-quality reducing gas without excess steam that can be fed directly into the reduction furnace without the need for quenching and reheating. The ability to use CO_2 and H_2O to reform CH_4 allows for 2/3 of the top gas from the reduction furnace to be recycled to the reformer, where it is mixed with fresh natural gas to produce a carbon monoxide (CO) and hydrogen (H_2)-rich reducing gas.

Because the Surface Combustion gas generators were simple devices, they were designed without natural gas desulfurization. As a result, the pilot reformer and the first commercial reformer used in the Portland plant were designed to operate with the small amount of sulfur (2-5 ppmv) contained in the natural gas. This sulfur carried into the feed gas and slowed the Boudouard carbon-forming reaction – a practice used today in MIDREX Plants to improve catalyst performance and to prolong catalyst life.

FIGURE 1. *First Commercial MIDREX Plant at Oregon Steel Mills (OSM)*

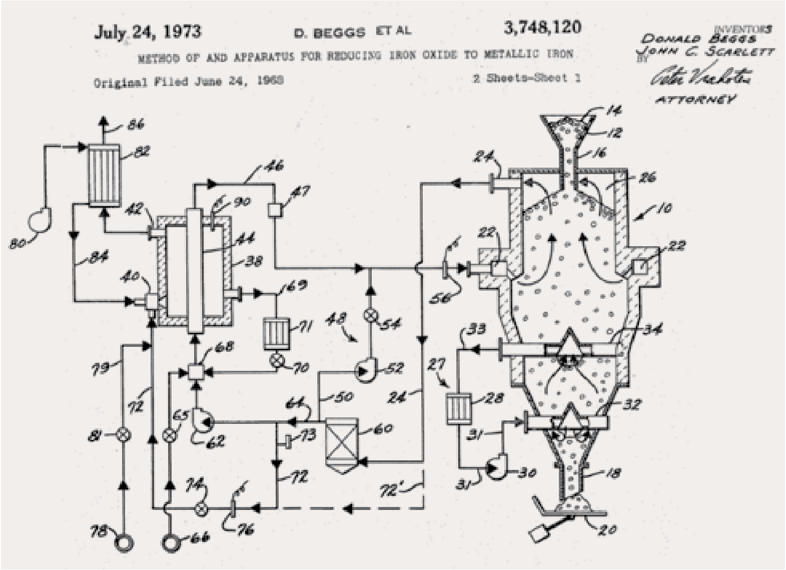


FIGURE 2. *Original MIDREX Process Patent*

Boudouard Reaction

$2CO \leftrightarrow CO_2 + C$

Midrex Stoichiometric Reforming Reactions

$CH_4 + H_2O \leftrightarrow CO + 3H_2$ (H_2O reforming)

$CH_4 + CO_2 \leftrightarrow 2CO + 2H_2$ (CO_2 reforming)

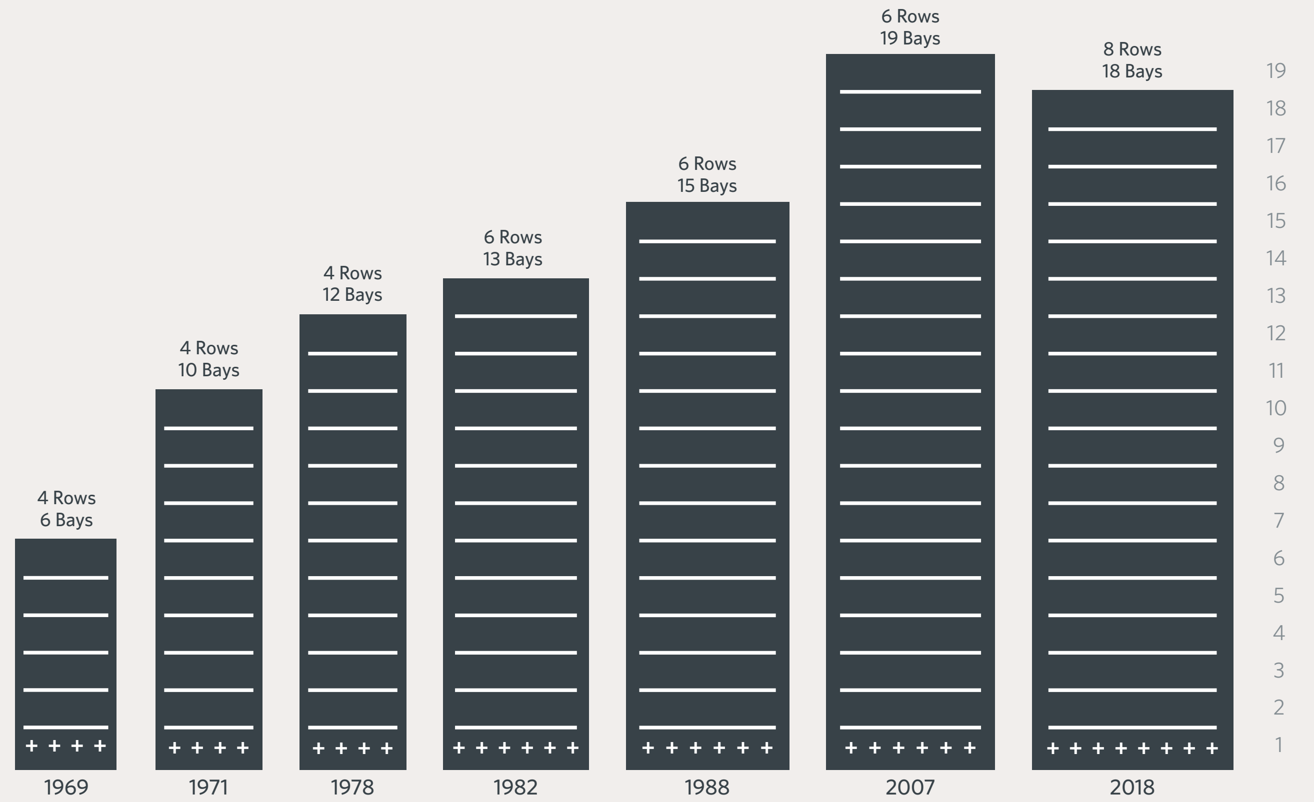


FIGURE 3. *Evolution of MIDREX Reformer Design*

The forward-thinking, modular design of the MIDREX Reformer ***(Figure 3)*** has been instrumental in the annual rated capacity of MIDREX Modules increasing from 150,000 tons in 1969 to 2.5 million tons today*. The simple, mild steel construction of the reformer allows for local fabrication in small, modular units that can be easily transported and erected at the plant site.

The beginnings of modern catalyst design and loading profiles emerged from the pilot-scale reformer constructed in Toledo and were included in the first commercial plant at OSM. Initially, an inert material was used in the inlet section of the reformer tubes (at the bottom), with an active catalyst in the middle and on top. This was done to heat the gas quickly above the range of the carbon-forming reactions. An innovation developed by Surface Combustion was to preheat the process gas before it entered the reformer tubes. This allowed the preheat (lower) section of the reformer tubes to be used for reforming. This discovery became the basis for the catalyst loading philosophies used today in MIDREX Plants, depending on local factors.

As MIDREX Plants increased in numbers and capacities, larger quantities and more sophisticated catalyst materials were required. In the tradition of the Surface Combustion pioneers, Midrex has remained actively engaged in designing and testing the modern, high efficiency catalysts in use today ***(Figure 4)***.

FIGURE 4. *Catalyst types used in MIDREX Plants*

* **AUTHOR'S NOTE:** *MIDREX Plants can include one or more modules. A MIDREX Module includes a shaft furnace, reformer, heat recovery system, and the ancillary systems and equipment to support their operation.*

TAKING THE SHAFT FURNACE TO NEW HEIGHTS

Innovation involves introducing new methods and ideas to something established to create a different (and usually better) way of doing things. There is no better description of what went into designing the reduction furnace for the MIDREX Direct Reduction Process. Midland-Ross was using a shaft-type indurating furnace for iron ore pelletizing in Cooley, Minnesota, USA, in the early 1960s. This furnace shape seemed ideal for what Beggs and his engineers had in mind – to create a process that would produce a higher value iron product than indurated oxide pellets.

Overall Reduction Reactions

$$Fe_2O_3 + 3H_2 \leftrightarrow 2Fe + 3H_2O$$
$$Fe_2O_3 + 3CO \leftrightarrow 2Fe + 3CO_2$$

Development of the MIDREX Shaft Furnace started with the Toledo pilot plant, which included a 1.3-feet (~0.4-meter) inside diameter (ID) reduction vessel. By the time of the Portland commercial plant in 1969, the size of the reduction furnace had increased to 12 feet (~3.7 meters) ID, with a rated capacity of 150,000 t/y. Over the next 20 years, the ID of the MIDREX Shaft Furnace grew progressively to 5.0 meters, then 5.5 meters, then 6.5 meters. Each size increase resulted in higher capacity so that by 1990, the OPCO Plant in Venezuela (now known as FMO) was rated at 1.0 million t/y. OPCO, the first MEGAMOD®, was built to serve the merchant market for HBI.

Today, a single-module MIDREX Plant, equipped with a 7.65-meters ID MIDREX Shaft Furnace, is capable of producing 2.5 million t/y of DRI products (SUPERMEGAMOD™ Furnace). This furnace has been commercialized at Tosyali Algerie Steel and a second one is being built at Algerian Qatari Steel (AQS).

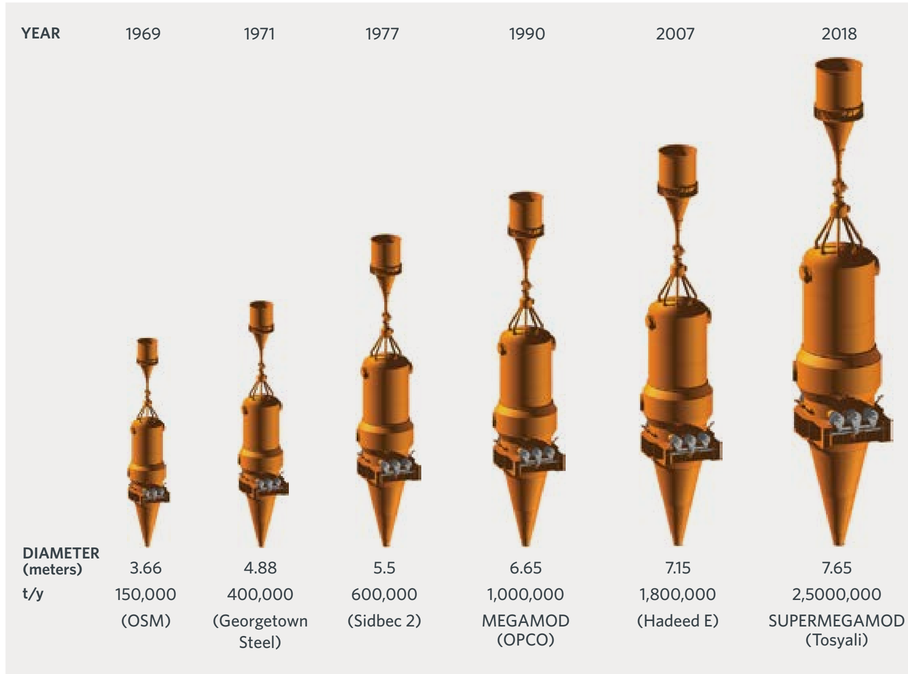


FIGURE 5. *Evolution of MIDREX Shaft Furnace Design*

As the diameter of the reduction furnace expanded, the height also was increased to maintain the desired flow characteristics and the speed of the reactions that occur in the furnace. The shaft furnaces in the Portland plant were 45-46 meters tall. Today, reduction furnaces in the two newest MIDREX Plants (Tosyali and AQS) measure 137.5 meters from DRI discharge feeder to oxide feed hopper ***(Figure 5)***.

ADDING HEAT RECOVERY

With the low cost of natural gas at the time, the Portland plant did not include provisions for recovering heat, and first generation MIDREX Plants were designed to recover only a minimal amount of heat from the flue gas. However, as gas prices increased, the economics of heat recovery became much more favorable, especially with the associated benefits of increased reformer capacity.

During the first decade of the MIDREX Process (1970-80), combustion air preheat was added and increased from 480˚ C to 650˚ C and reformer feed gas preheat was added and increased from 400˚ C to 540˚ C. Top gas preheat was introduced during the first half of the 1990s, with the cumulative effect of reducing natural gas consumption to 2.4 net Gcal/t of DRI.

The heat recovery system in the latest generation MIDREX Plant is comprised of a hot fan and six stages of heat exchangers ***(Figure 6)***. The hot fan pulls flue gas from the reformer through the heat exchangers and releases the spent gas through the stack into the atmosphere. This reduces overall energy consumption significantly and enhances environmental performance. The heat exchangers preheat the following gas

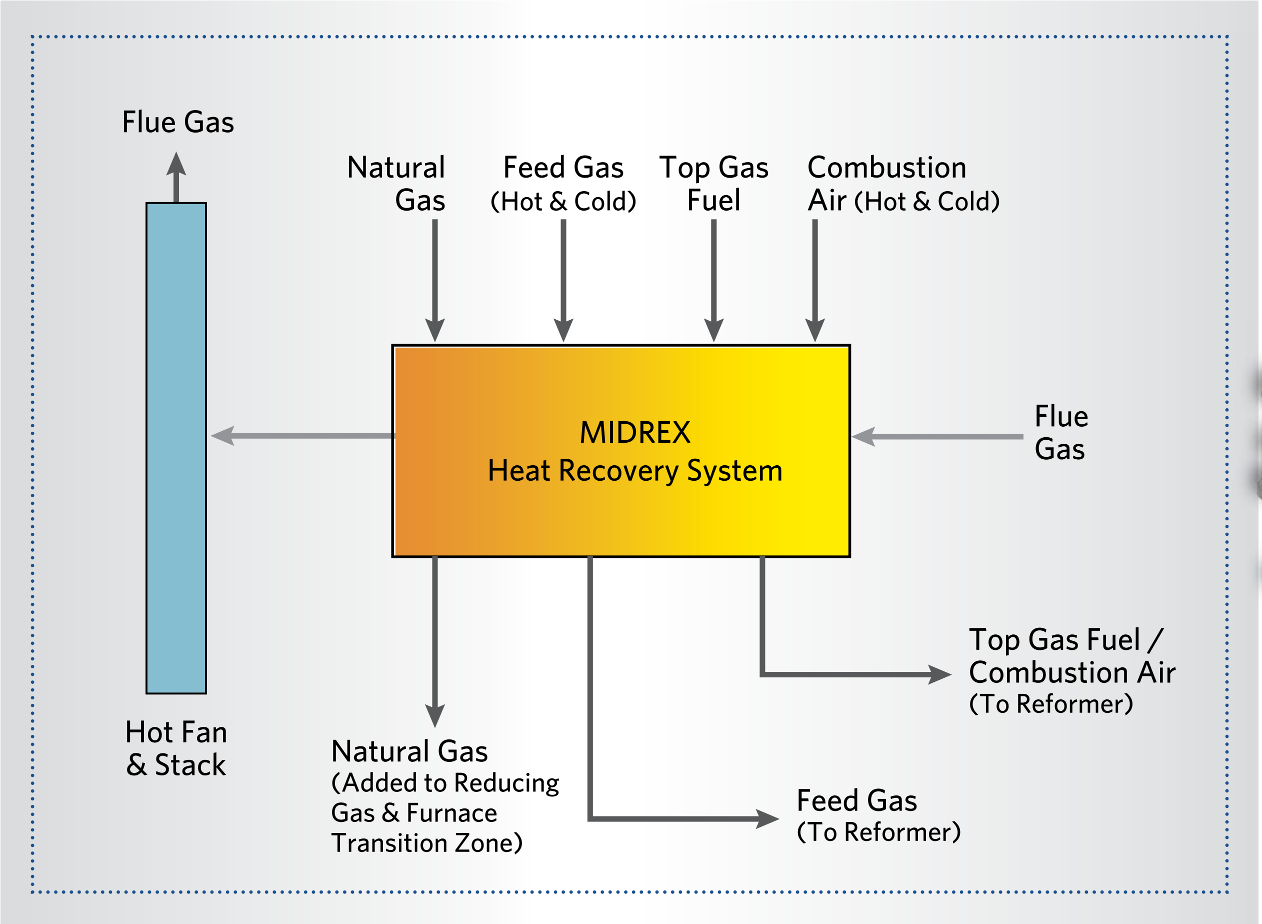


FIGURE 6. *MIDREX Heat Recovery System Diagram*

streams: hot and cold combustion air and top gas fuel (reducing reformer energy consumption), hot and cold feed gas (reducing reformer energy consumption and increasing reforming capacity), and natural gas added to the reducing gas and the shaft furnace (reducing the temperature loss within the shaft furnace and facilitating better utilization of natural gas to deposit carbon on the DRI).

OPTIONS IN ENERGY

Although natural gas is the energy source most often cited in relation to MIDREX Direct Reduction Technology, it was not the first nor is it the only one. Surface Combustion in 1963 developed a process for reducing unfired pellets made from iron ore concentrate and coal fines in a rotary hearth furnace known as Heat Fast. The technical results from the Heat Fast DRI were good but analysis of the economics for producing hot metal showed no benefit versus the conventional blast furnace, and Surface Combustion turned its attention to natural gas-based direct reduction.[1] *(see NOTE on page 13)*

With proof of the MIDREX Process standard flowsheet ***(Figure 7 on next page)*** and the initial commercial successes during the 1970s, Midrex turned its attention to expanding the energy options for making DRI. Flowsheets were created to use with the leading coal gasification technologies of the time (Lurgi and Texaco), as well as options for using coke oven gas. Today, MIDREX Plants are operating with reducing gas produced by coal gasification (JSPL Angul) and with export gas from the COREX® Process (ArcelorMittal South Africa and JSW Toranagallu) in addition to traditional natural gas.

The standard MIDREX NG (Natural Gas) flowsheet includes: a hot discharge furnace, with the flexibility to produce hot DRI (HDRI) and hot briquetted iron (HBI), as well as cold DRI (CDRI), a near-stoichiometric, catalytic reformer; and up to six stages of heat recovery.

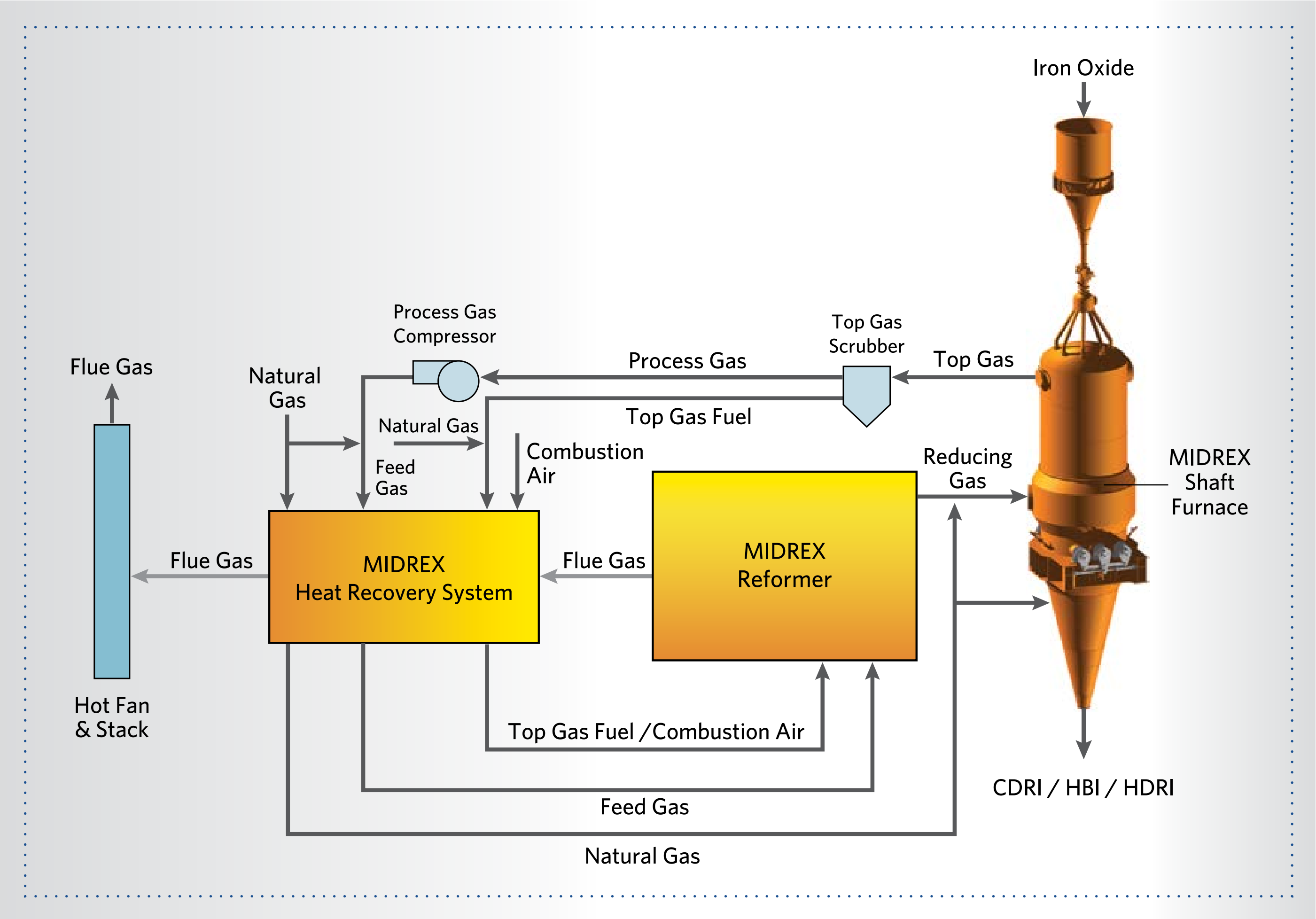


FIGURE 7. *MIDREX Process Standard Flowsheet*

Midrex and Praxair, Inc. built and operated a demonstration plant in 2012-13 to prove the technical feasibility of the Thermal Reactor System (TRS), a means of producing reducing gas from coke oven by-product gas for making DRI.

In 2017, Midrex introduced a flowsheet for substituting hydrogen (H_2) for up to 1/3 of the required natural gas in new or existing MIDREX Plants. For example, 60,000 Nm³/h of H_2 can be substituted for approximately 20,000 Nm³/h of natural gas in a 2.0 million t/y plant.

Midrex also has a flowsheet for using almost pure hydrogen to make DRI in a MIDREX Shaft Furnace. The MIDREX H_2™ flowsheet is similar to the standard MIDREX Process except that the hydrogen input gas is generated external to the process. Thus, there is no reformer and a heater is used to bring the gas to the required temperature. In practice, the reducing gas H_2 content is about 90%, with the balance being CO, CO_2, H_2O, N_2, and CH_4.

NEW OWNER ... NEW HORIZONS

By the late-1970s, MIDREX Plants were operating in North and South America, Europe, and the Middle East. Midrex Corporation was headquartered in Charlotte, North Carolina, USA, and German steel entrepreneur Willy Korf was its owner. Korf's vision for the MIDREX Process was to provide the iron units for electric arc furnace (EAF)-based steel mills sized to local or regional needs. This "mini-mill," as it became known would provide the impetus for industrial development and economic growth. Further to this thinking, Midrex instituted a technology licensing approach in which Midrex would design the plant and license the process technology for local or national owners to operate the plant and use or sell the DRI. Midrex would train the plant personnel and interact with them during the operating life of the plant to develop and integrate technology innovations and improvements. This two-way technology transfer practice was unique to Midrex at the time and has been instrumental in the company's success to date.

Global DRI production increased during the first decade of the MIDREX Process from less than 750,000 tons/year in 1970 to almost 7.5 million tons/year by 1980. The annual production of DRI by MIDREX Plants jumped from little more than 50,000 tons in 1970 to almost 4 million tons by 1980, accounting for more than 50% of worldwide DRI production in 1979.

As Korf had sensed, EAF-based minimills coupled with a DRI plant in natural gas-rich regions would become drivers of economic development. The allure of market-sized steel mills also was gaining traction in established markets, especially the USA. As the amount of "cold charge" (scrap steel vs. blast furnace hot metal) steel production increased, demands for scrap greatly increased and were reflected in the prices.

Midrex responded to the increasing demand for DRI outside of locations where it was being produced by developing a form of DRI that would be strong enough to withstand the rigors of handling and shipping and safe from the risk of severe oxidation during ocean transport. Harking back to its innovative heritage, Midrex designed a hot discharge shaft reduction furnace in 1982 and matched it with a system for molding HDRI into a dense, compacted form known as hot briquetted iron (HBI). The first MIDREX Plant designed to produce HBI was started up on Labuan Island, Malaysia, in 1984 ***(Figure 8)***, and continues to produce and sell HBI throughout the Asian region to this day.

FIGURE 8. *First MIDREX HBI Plant on Labuan Island, Malaysia*

KOBELCO
KOBE STEEL GROUP

KOBE STEEL – OWNER AND PARTNER

As early as the first MIDREX Plant at Qatar Steel Company (QASCO), Kobe Steel Ltd. has been actively involved with the MIDREX Process. Kobe Steel was part of a joint venture with the State of Qatar to build an EAF steel mill coupled with a DRI plant as part of a well-conceived industrialization program to utilize the nation's massive natural gas reserves. Following a successful feasibility study in 1974, Midrex was selected as the DRI technology supplier because of the adaptability of the MIDREX Process to extreme climatic conditions and excellent worldwide plant performance record. The MIDREX Plant was started up in August 1978, as the first DRI facility in the Middle East.

The continued strong performance of MIDREX Plants and the signing of close to a dozen contracts for new plants led KSL to acquire the assets of Midrex Corporation from Korf in August 1983. A KSL spokesman at the time said, "the combining of the DRI expertise of Midrex and Kobe Steel know-how in the area of steel mill construction and operation is expected to prove beneficial to both organizations and their clients."

With the backing of Kobe Steel, Midrex has renewed the commitment to innovation and continuous improvement on which it was founded. The Midrex business model is built on the concept of renewable technology – a self-sustaining cycle that blends science, engineering, marketing, and real-world experience to

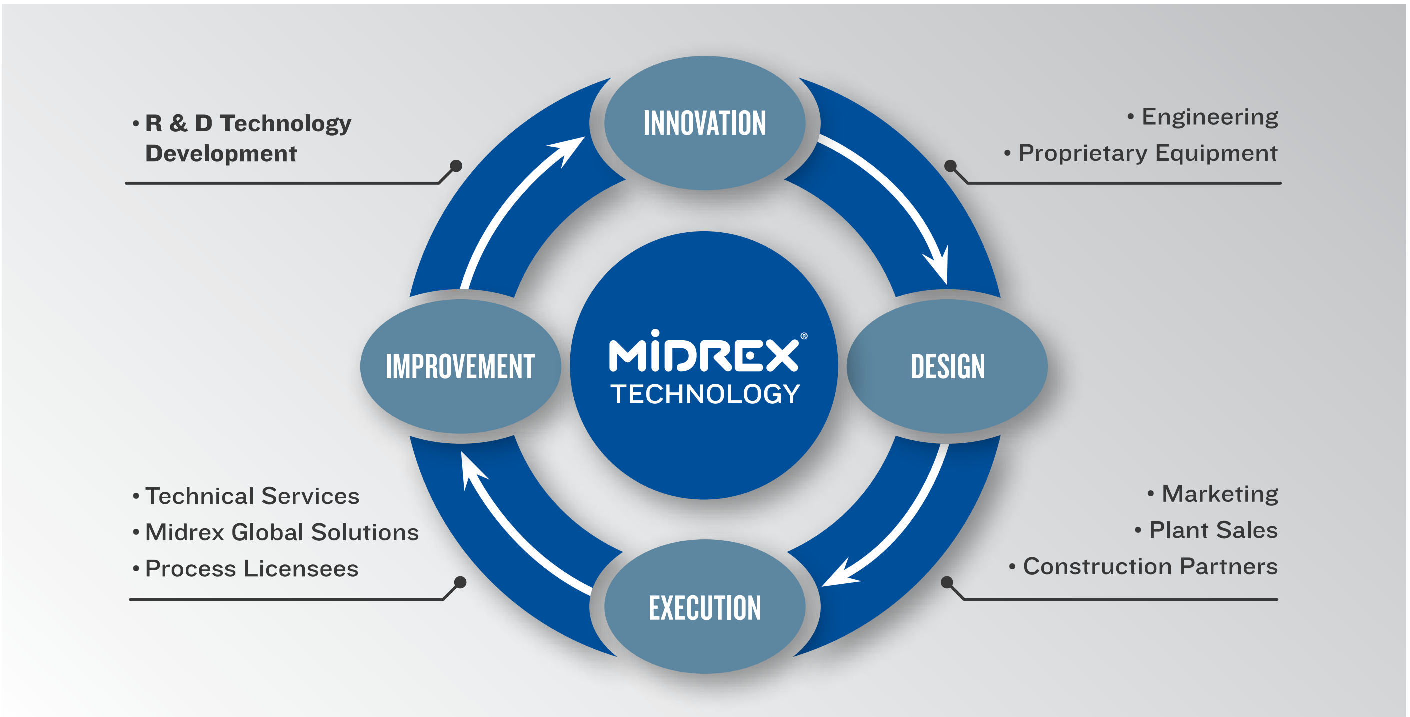


FIGURE 9. ***MIDREX Technology Cycle*** *– R&D develops and analyzes technological knowledge and proves its feasibility; Engineering converts the knowledge into products and services, which Marketing promotes to the marketplace and Plant Sales and Global Solutions present to customers as value-added solutions; Technical Services interacts with established customers (Process Licensees) and feeds back to R&D suggestions and ideas for renewing and expanding the technology knowledge base.*

identify business opportunities and transform them into sustainable solutions ***(Figure 9)***.

In 2015, the Midrex Research & Development Technology Center, located in Pineville, NC, near the Midrex headquarters in Charlotte, NC, was significantly expanded and modernized to better serve the changing demands of the global steel and minerals processing industries. The R&D Technology Center is now the principal facility for ferrous and non-ferrous reduction technology development for both Midrex and Kobe Steel. Capabilities of the R&D Technology Center include: physical testing of raw materials; lab-scale and bench-scale testing and evaluation of catalysts, reductants, iron ores, and DRI; and commercial-scale testing and evaluation of mineral chemistries, minerals preparation, pelletizing, briquetting, and melting.

Since joining the Kobe Steel Group, the installed capacity of MIDREX Plants has increased more than tenfold and MIDREX Plants have produced more than 60% of the world's annual supply of DRI products for more than 30 years ***(Figure 10)***. In June 2018, the cumulative total of DRI products produced by MIDREX Plants exceeded 1 billion tons.

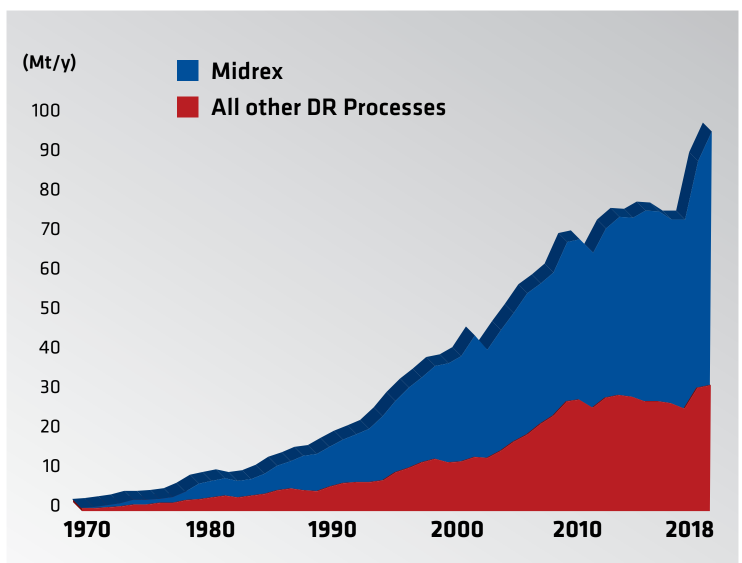


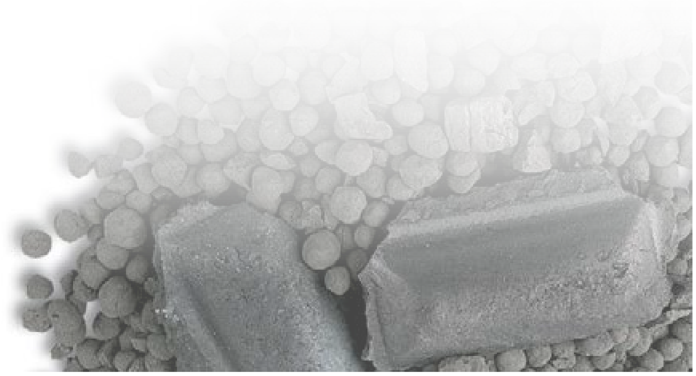
FIGURE 10. *Global DRI Production Since 1970*

DESIGNED FOR TODAY, ENGINEERED FOR TOMORROW®

It has been a long and challenging journey from those early "trial and error" days in Portland to the confidence of starting up the world's most reliable, adaptable, and productive DRI plants. Along the way, Midrex has advanced the state-of-the-art in direct reduction technology with many innovations and improvements and numerous performance achievements (see sidebar). Its advocacy for the benefits of using DRI products, especially when used in combination with scrap in the EAF, is widely credited with developing and expanding the DRI market.

"Designed for Today, Engineered for Tomorrow" is more than a marketing slogan. It represents the basic philosophy that has guided Midrex for 50 successful years – to provide products and services that are responsive to the current wants and needs of iron and steel producers and conducive to innovation and improvement for the future.

Like a fine wine, Midrex produces "no technology before its time"; and when it does, you can be assured that it is relevant, reliable, and results-driven. Midrex enters the next 50 years of the MIDREX Process with the same spirit of innovation and determination that drove the Surface Combustion pioneers. ■



MEMORABLE MOMENTS IN MIDREX HISTORY

MIDREX

1960s

- Donald Beggs, head of Surface Combustion's R&D Group, conceives the idea for the MIDREX Process
- Start-up of first MIDREX Plant – Oregon Steel Mills, Portland, OR, USA

1970s

- Korf Group purchases MIDREX Process and establishes Midrex Corporation in Charlotte, NC, USA
- In-situ reforming
- Heat recovery system
- Flowsheets developed for coal and coke oven gas and high sulfur ores
- Start-up of Hamburger Stahlwerke (now ArcelorMittal Hamburg) – oldest operating MIDREX Plant
- MIDREX Plants produce more than 50% of world's DRI

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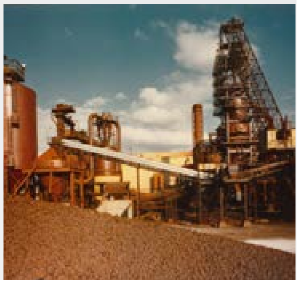


MEMORABLE MOMENTS IN MIDREX HISTORY

1980s

- Kobe Steel Ltd. acquires assets of Midrex Corporation
- Hot discharge furnace designed
- First MIDREX® Plant use of oxide coating – OEMK, Stary Oskol, Russia
- Start-up of first MIDREX Hot Briquetted Iron (HBI) plant – Sabah Gas Industries (now Antara Steel Mills), Labuan Island, Malaysia
- MIDREX Plants produce more than 60% of world's DRI

1990s

- Start-up of first single-module MIDREX Plant (MEGAMOD®) rated for 1 million t/y of HBI – OPCO (now FMO), Puerto Ordaz, Venezuela
- First MIDREX Plant use of oxygen injection – Acindar, Villa Constitucion, Argentina
- First MIDREX Plant to use hot transport/hot charging of DRI – Essar Steel, Hazira, India
- MIDREX Plants produce 10 million tons of DRI in single year
- MIDREX Plants produce 20 million tons of DRI in single year
- Start-up of first MIDREX Plant using coal synthesis gas (from COREX Process) – Saldanha Steel (now ArcelorMittal South Africa), Saldanha Bay, South Africa

2000s

- First use of a hot conveyor for transporting & charging HDRI to an EAF – Hadeed E, Al-Jubail, Saudi Arabia
- First installation of OXY+® partial oxidation system – OEMK, Stary Oskol, Russia
- Start-up of first MIDREX Combination Plants (HDRI/HBI and CDRI on demand) – Hadeed E, Al-Jubail, Saudi Arabia, and Qatar Steel II, Mesaieed, Qatar
- MIDREX Plants produce 30 million tons of DRI in single year
- MIDREX Plants exceed 500 million tons of cumulative DRI production

2010s

- MIDREX Plants exceed 1 billion tons of cumulative DRI production
- Start-up of first Midrex HOTLINK® plant for direct charging of hot DRI (HDRI) into EAF – Jindal Shadeed, Sohar, Oman

Cont'd.

MEMORABLE MOMENTS IN MIDREX HISTORY

MIDREX

2010s

- Start-up of first MIDREX Plant to use coal gasification technology to make reducing gas – Jindal Steel & Power, Angul, India
- Start-up of world's largest HBI plant (2 million t/y) – voestalpine Texas, Corpus Christi, Texas
- Start-up of world's largest single module combination DRI plant, rated at 2.5 million t/y of CDRI/HDRI – Tosyali Algerie, Oran, Algeria
- Midrex and Praxair develop and demonstrate Thermal Reactor System (TRS) for making reducing gas from coke oven gas
- ACT™ (Adjustable Carbon Technology) – increases carbon (up to 4.5%) in new or existing MIDREX Plants without temperature loss
- Flowsheets developed for hydrogen addition to MIDREX NG Plant and hydrogen-based direct reduction (MIDREX H_2)
- 50 years of commercial operation

NOTE:
[1] The work of Surface Combustion to develop Heat Fast was revisited by Midrex and Kobe Steel in the late 1980s and became the basis for development of the FASTMET® Process for recovering iron from iron-bearing waste materials and the ITmk3 Process for producing pig iron-grade iron nuggets. Both processes use pulverized coal or coal fines as the reductant fuel and a rotary hearth furnace as the reduction vessel. Kobe Steel is the exclusive supplier of these technologies.

MIDREX® Direct Reduction Plants

2018 OPERATIONS SUMMARY

MIDREX® Plants produced 64.36 million tons in 2018, ~16.5 percent more than was produced in 2017. The production for 2018 is calculated from the 38.7 million tons confirmed by MIDREX Plants located outside of Iran plus the 25.75 million tons for Iran reported by World Steel Association (WSA). Over 6.2 million tons of HDRI were produced by MIDREX Plants and consumed in nearby steel shops, helping these steel shops reduce their energy consumption per ton produced and increase their productivity.

World DRI production surged by more than 13 million tons to a new record of over 100 million tons. Growth was driven by continued good profitability in both ironmaking and steelmaking and by the start-up of several new plants together with recently commissioned facilities ramping up to capacity. As in recent years, most of the growth occurred in India and Iran. According to WSA data, Iranian output was more than three times greater than it was 10 years ago.

Prices for both long product and flat product steels began the year at relatively high prices but then declined through the course of the year. Long products began the drop earlier but did not fall as far as flats. By the end of the year, flat products were down by as much as $100/t in most world markets.

Delivered prices for DRI, HBI and pig iron reflected the trend of flat products; i.e., healthy margins to begin the year followed by a gradual decrease throughout the year and culminating in constricted profits by year-end.

Meanwhile, iron ore prices vacillated in the range of $65-$75/t for the bellwether grade 62% Fe sinter fines, as delivered to northeast China. High premiums continued for high grade ore due to the tightness of supply caused by a combination of demand growth and supply constraint. The Samarco mine, a major portion of the world capacity of high-grade pellets, remained closed throughout the year.

MIDREX Plants continued to account for 80% of worldwide production of DRI by shaft furnaces. Fifteen plants established new annual production records and at least 14 plants established new monthly production records. Seventeen additional

6.28.19

MIDREX Modules came within 10% of their record annual production, and 17 MIDREX Modules operated in excess of 8,000 hours.

One new MIDREX Module, designed to produce 2.5 million tons of HDRI/CDRI, was started up in November 2018, for Tosyali Algerie located near Oran, Algeria, belonging to the Tosyali Holding Group. Two additional modules were started up this past year in Iran: a 1.5 million t/y CDRI MIDREX Plant belonging to Chadormalu Mining and Industrial Co. at Ardakan, Yazd, in December 2018; and a 1.7 million t/y MIDREX Plant (GISDCO 2) belonging to Golgohar Iron & Steel Development Company at Sirjan, Kerman in June 2018.

MIDREX® Plants have produced a total of 1,045 million tons of DRI/HBI through the end of 2018.

2018 PLANT HIGHLIGHTS

ACINDAR

In its 40th anniversary year of operation, ACINDAR's MIDREX Plant operated at a record average annual production rate in 2018 and 14% more hours than in 2017, despite the typical winter natural gas curtailments. Annual production was over 1 million tons, only 3% short of ACINDAR's annual production record. In 40 years of operation, ACINDAR has produced 30.94 million tons of DRI.


ACINDAR

ANTARA STEEL MILLS

The first MIDREX Plant designed to make HBI exceeded annual rated capacity in 2018 by 15% with over 8,100 hours of operation, which was within 4% of its annual production record set in 2004. Total iron in the HBI product was the highest of all MIDREX Plants, averaging 93.47% for the year. All of the plant's production was shipped to third parties by water.


Antara Steel Mills

ARCELORMITTAL CANADA

In its 45th anniversary year, Module 1 twice set new monthly production records (in March and December). For a second consecutive year, Module 2 set a new annual production record (1.088 million tons and 8,353 hours of operation), surpassing its previous record set in 2017 by 11%. Production from both modules was a record-breaking 1.67 million tons.


ArcelorMittal Canada Module 2

ARCELORMITTAL HAMBURG

In its 48th year of existence, the oldest operating MIDREX Plant at AM Hamburg comfortably exceeded annual rated capacity, averaging over 70 t/h and just under 8,000 hours of operation. With relatively high product quality of 94.33% metallization, AM Hamburg's natural gas consumption was below 2.40 net Gcal/t, and its electric energy consumption (79 kWh/t) was the lowest of any MIDREX Plant.


ArcelorMittal Hamburg

ARCELORMITTAL LAZARO CARDENAS

AMLC produced 17% over its rated capacity of 1.2 million tons in its 21st year of operation. Its cumulative production (31.74 million tons) is the most by a single MIDREX® Module to date.

ARCELORMITTAL POINT LISAS

All three MIDREX Modules in Trinidad and Tobago remained shut down throughout the year.

ARCELORMITTAL SOUTH AFRICA (SALDANHA WORKS)

This COREX® export gas-based MXCOL® Plant operated the whole year but was limited by the availability of gas from the COREX Plant. The MXCOL Plant used an average of 68% South African lump ore for the year.

COMSIGUA

COMSIGUA in Venezuela operated close to full capacity for about 3,000 hours over a 7-month period in the year due to the limited supply of locally produced pellets.

DELTA STEEL

The two MIDREX Modules in Nigeria did not operate in 2018.

DRIC

Each of DRIC's two MIDREX Modules in Dammam, Saudi Arabia, set new annual production records in 2018, through increased hourly production rates. DRI production by the two modules totaled over 1.0 million tons.

ESISCO

Due to the high price of natural gas in Egypt, as well as the competition of foreign steel products, ESISCO did not operate in 2018.

ESSAR STEEL

Essar Steel's six MIDREX Modules operated at less than maximum capacity for the whole year but set a new total DRI production record for the complex of 4.86 million tons. Modules 5 and 6 operated using off-gas from Essar's COREX Plant for ~15% of their energy input. Module 1 was restarted in February after conversion from producing HDRI/HBI to producing CDRI only.

ArcelorMittal Lazaro Cardenas

ArcelorMittal South Africa

Comsigua

Essar Steel

EZDK

With natural gas availability in Egypt becoming more plentiful, production from EZDK's MIDREX Modules increased to over 2.6 million tons, which is ~90% of their maximum capacity. All three modules operated over rated capacity, surpassing the 60 million tons mark. Module 1 also surpassed 25 million tons in its 32 years of operation. Modules 2 and 3 operated over 8,300 and 8,400 hours. Respectively, in 2018. Due to the current pellet shortage, EZDK continued to use 10-20% lump ore throughout the year.

FERROMINERA ORINOCO

Ferrominera Orinoco's MIDREX HBI Plant in Venezuela did not operate the whole year due to limited availability of locally produced oxide pellets.

HADEED

Hadeed Modules A and B exceeded rated capacity for the 34th consecutive year and Module C for the 26th consecutive year. Modules A and B averaged over 8,500 hours of operation in 2018. Module C operated 28% over its rated capacity in 2018, and has produced more than 25 million tons of CDRI since its start-up in 1992. Hadeed E operated at slightly over 235 t/h throughout the year. Hadeed's four MIDREX Modules have produced 90 million tons of DRI to date. Hadeed also owns an HYLIII plant (Module D).

JINDAL SHADEED

After surpassing the 10 million tons mark at the beginning of the year, Jindal Shadeed established a new monthly production record in December by averaging 210 t/h, following a major shut-down for maintenance and improvements and with increased availability of natural gas. The plant's annual production was within 1% of the record it set the previous year. The MIDREX Plant is designed to produce mainly HDRI, with HBI as a secondary product stream. A major portion of the plant's production (88%) was consumed as HDRI by Jindal Shadeed's own steel shop adjacent to the DR plant.

JSPL (ANGUL)

The Jindal Steel and Power Ltd. (JSPL) combination HDRI/CDRI plant in Angul, India, remained shut down the whole year after start-up of JSPL's new blast furnace. This is the first MXCOL plant, using synthesis gas from coal gasifiers to produce HDRI and CDRI for the adjacent steel shop. The plant restarted operations in early 2019.

EZDK

Hadeed Module E

Jindal Shadeed

JSPL (Angul)

JSW STEEL (DOLVI)

The JSW Steel MIDREX Plant in Raigad, India, operated very consistently (8,175 hours) throughout the year, with CDRI production coming within 0.4% of the plant's production record established in 2017. JSW Dolvi set a new monthly production record in March, averaging over 200 t/h, after also breaking the previous monthly production record in January. The plant has averaged over 8,000 hours of annual operation since its start-up in September 1994. The system installed at the end of 2014 to reduce natural gas consumption by adding coke oven gas (COG) from JSW Steel's coke oven batteries to the MIDREX® Shaft Furnace operated throughout the year.

JSW STEEL (TORANAGALLU)

The JSW Steel HDRI/CDRI MIDREX Plant using COREX export gas in Toranagallu, India, set a new annual production record for the fourth straight year as the result of an hourly productivity increase and a record 8,224 hours of operation in the year. JSW also set new monthly production records in January and March 2018.

LEBEDINSKY GOK

The LGOK MIDREX HBI Modules 2 and 3, located in Gubkin, Russia and belonging to the Metalloinvest Group, set new annual production records of 18% and 10% over their rated capacity, with 8,151 and 8,173 hours of operation, respectively. Both modules set new annual production records in October 2018. LGOK HBI-2 has produced over 15 million tons since its start-up in October 2007. LGOK HBI-3 was started up in March 2017, and has ramped up production impressively. LGOK HBI-1 is an HYL plant.

LION DRI

The Lion DRI plant, located near Kuala Lumpur, Malaysia, remained shut down throughout 2018 due to insufficient market demand for locally produced steel products in Malaysia.

LISCO

Production by LISCO's three MIDREX Modules in Misurata, Libya, increased 9% compared to 2017, despite being restricted by natural gas supply and current country turmoil.

NU-IRON

In its 12th year of operation, Nucor's MIDREX Plant in Trinidad and Tobago came within 3% of its annual production record established in 2017 and set a new monthly production record in December 2018. Average DRI metallization for the year was the highest of all MIDREX Plants at 96.0%, with 2.68% carbon in the DRI

JSW Steel (Dolvi)

JSW (Toranagallu)

LGOK HBI-2 and HBI-3

Nu-Iron Trinidad and Tobago

OEMK

Thirty-five years after the start-up of its first MIDREX Module, OEMK produced over 3.2 million tons in 2018, with Module 2 setting a new annual production record after undergoing a revamp in August-September 2017 to increase production. OEMK's four modules averaged 8,429 hours of operation in 2018 and have produced almost 70 million tons since start-up of the first module in December 1983.

QATAR STEEL

In its 11th full year of operation, Qatar Steel's dual product (CDRI and HBI) Module 2 operated 20% over its rated annual capacity of 1.5 million t/y and came within 5% of its annual production record. The entire production from Module 2 was CDRI, with metallization averaging 94.7% for the year. Operating over 8,150 hours in the year, the production of Module 1 was only 4.7% below its record annual production. Qatar Steel has produced more than 44 million tons of DRI to date, 40 years after the start-up of Module 1.

SIDOR

Production by all four of Sidor's MIDREX Modules was just over 200,000 tons in 2018, limited by oxide pellet and natural gas availability in Venezuela. Modules 2B and 2C remained shut down the entire year.

SULB

SULB's 1.5 million tons/year MIDREX Combination Plant (simultaneous production of CDRI and HDRI) in Bahrain set a new annual production record in 2018 at 6% over rated plant capacity and broke monthly production records four times in the year. HDRI sent directly to the steel mill accounted for 70% of the plant's production, with most of the balance exported by ship.

TenarisSiderca

TenarisSiderca operated below maximum capacity and was down for over a month around July due to limited DRI demand by the steel shop and natural gas curtailment during the winter months.

OEMK

Qatar Steel

SULB

TenarisSiderca

TOSYALI ALGÉRIE

Tosyali Holding's new 2.5 million t/y MIDREX Combination Plant (simultaneous production of CDRI and HDRI) located in Bethioua, near Oran, Algeria, began ramping up operations in November 2018. This is the largest capacity, single module MIDREX Plant built to date.

TUWAIRQI STEEL MILLS

The Tuwairqi Steel Mills 1.28 million t/y MIDREX Combination Plant (simultaneous production of CDRI and HDRI) located near Karachi, Pakistan, did not operate in 2018 due to local market conditions.

VENPRECAR

Bricar's HBI production was restricted by the limited availability of oxide pellets in Venezuela.

voestalpine TEXAS

The voestalpine Texas MIDREX Plant located near Corpus Christi, Texas, USA, designed to produce 2.0 million tons of HBI per year, continued to ramp up production in 2018, setting two new monthly production records during the year. The HBI produced was shipped to third parties and to the steel mills of its parent company, voestalpine AG, in Austria.

EDITOR'S NOTE:

At the time of printing, only limited information had been received from MIDREX® Plants in Iran.

Tosyali Algérie

Tuwairqi Steel Mills

Venprecar

voestalpine Texas

MIDREX News & Views

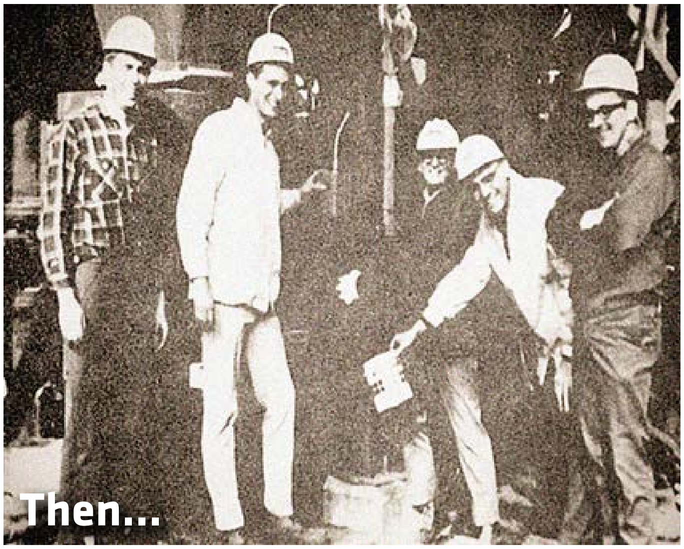
Midrex Celebrates 50th Anniversary of First MIDREX Plant

Midrex employees past and present gathered as one team on May 17th to celebrate the 50th anniversary of the first MIDREX Direct Reduction Plant and to honor three of the engineers who helped develop the technology and put the first plant into operation: Winston L. Tennies, also a past President & CEO of Midrex Technologies, Inc., David C. Meissner, and Bruce G. Kelley.

The initial commercial plant based on the MIDREX Direct Reduction Process began production on May 17, 1969, in Portland, Oregon, USA. By 1979, MIDREX Plants were accounting for 50% of the world's annual supply of direct reduced iron (DRI), which increased to 60% in 1987 and every year since then.

"The early Midrex pioneers set a standard of excellence, which guides and inspires us today," said Stephen C. Montague, current President & CEO of Midrex Technologies, Inc. "We continuously improve the technology to optimize performance of MIDREX Plants, as well as to become more environmentally friendly. We also give back through skills training and employment opportunities where our plants are located," he said.

"Our company is about pulling people together to make a difference, whether in the office, for the environment, or in the community. We are a team dedicated to serving others," said Montague.



Winston Tennies and Bruce Kelley, *pictured on the left;* David Meissner, *pictured on the right*

Winston Tennies, Bruce Kelley, and David Meissner, *pictured left to right*

Lauren Lorraine: **Editor**

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