DIRECT FROM MIDREX

2ND QUARTER 2006

CONTENTS

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Commentary

Pushing the Technology Envelope

In the last issue of *Direct from Midrex*, our President and CEO, Jim McClaskey, wrote about the tremendous boom in the steel industry, resulting in both exciting and challenging times at Midrex. We have contracted and are executing nine new projects. Despite this flurry of recent activity, we are not resting on our laurels; instead, we are developing strategies and action plans for new technologies and businesses to ensure Midrex's long-term success.

Given the cost and effort required to develop new ironmaking and steelmaking technologies, we need to plan for five, ten, even fifteen years in the future. To this end, we have established a Technology Steering Committee that is evaluating and directing our technology development efforts.

One of the major themes of this most recent wave of projects is hot discharge/hot transport/hot charging of DRI. The benefits of hot charging of DRI to the EAF are increased productivity, lower consumption of electricity and refractories, and reduced greenhouse gas emissions. Almost all the 54 MIDREX® Modules built between 1969 to 2005 produced either cold DRI that was stored and later charged to the EAF, or hot briquetted iron for merchant sale. Only one of these 54 plants was originally constructed to transport hot DRI from the shaft furnace to the meltshop. By contrast, five of the plants now being built will have hot transport capability. These facilities represent three different ways to effect hot transport: vessels, conveyors, and the Midrex HOTLINK® System. These plants reflect an increasing trend of making the direct reduction/EAF steelmaking route more continuous. This can prove challenging, since the MIDREX Process is a continuous technology, whereas EAF steelmaking is done on a batch basis, that is, heat-by-heat.

Since 95 percent of the world's DRI is melted in EAFs, it is essential that we continue to enhance the combination. This will be a major thrust of our technology development efforts over the next several years.

Rob Klawonn
VP Commercial

The first step is to complete the designs of the hot transport plants now being built and successfully start them up. In addition, we are continuing efforts to develop and refine the hot discharge/hot transport/hot charging technologies. Also, we are working on new melting technologies such as KWIKSTEEL™, which is the combination of a MIDREX® Shaft Furnace and a rotary hearth furnace (RHF) melter, as well as coal-based melting of DRI.

These "hot" technologies and the resultant benefits are also applicable to our coal-based RHF processes, including FASTMET®, FASTMELT®, and ITmk3®. Nippon Steel is now hot charging FASTMET DRI to its steelmaking furnaces in Japan.

Interestingly, closer coupling of the iron and steelmaking processes may also provide benefits in raw material use. The development of lower cost, more efficient melting technologies may enable the use of lower-grade iron ores that cannot now be exploited. As high-grade ore reserves are exhausted around the world, there is tremendous interest in finding ironmaking/steelmaking methods that can utilize lower-grade ores and even waste materials. Midrex is investigating a number of these opportunities with clients.

Even as we continue the engineering and purchasing for the projects underway, and begin the start-up procedures, we will maintain our efforts to "push the new technology envelope." Our commitment is to play an important role in ensuring the continued success of the steel industry.

MISSION STATEMENT

Midrex Technologies, Inc. will be a leader in design and integration of solids and gas processes. We will meet or exceed performance expectations, execute projects on time, enhance existing product lines, and provide value-added design, procurement, logistics and field services to our clients. We will develop new business opportunities that will challenge our employees and maintain the economic vitality of our company. Our employees are the key to our success, and we are committed to encouraging them to grow professionally and personally.

The New Iron Age
Direct Reduction's Role in the World Steel Industry

Part Two: Direct Reduction - An Idea Whose Time Has Come

By John T. Kopfle,
Director - Corporate Development
Robert L. Hunter,
Product Applications Engineer
Midrex Technologies, Inc.

Editor's note: Part 1 of this multi-part series examined developments in the world steel industry from 2000-2005

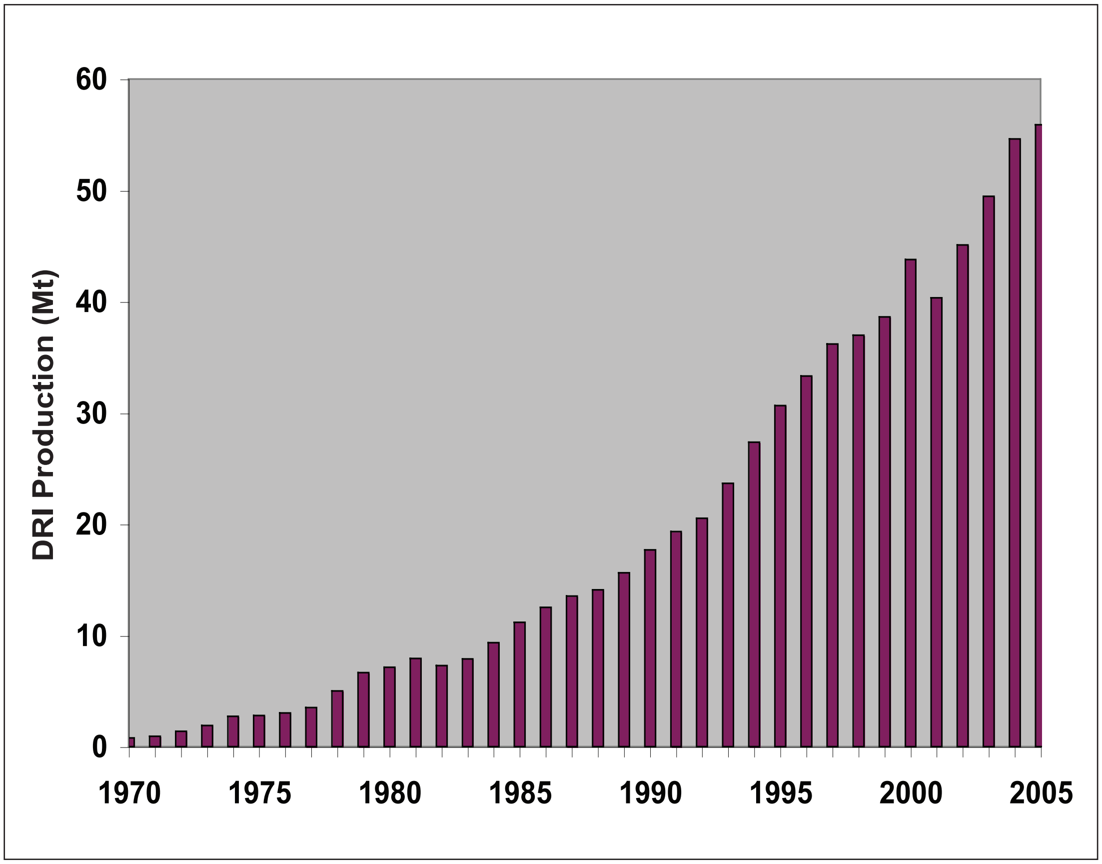

Figure 3 - World DRI Production

DRI DEMAND AND PRODUCTION GROWTH, 1970 - 2005

Given the availability of iron ore in the world and the continued production of scrap, both of which are valuable raw materials, there will always be a mixture of primary (iron ore-based) versus secondary (scrap-based) steelmaking production. For the last 35 years, about 65 percent of the world's steel has been produced from iron ore. Since its development in the 1400s, the blast furnace has provided the major volume of iron made from ore. Beginning in the 1950s and 1960s, direct reduction (i.e., the production of iron from ore without melting) was commercialized and began to play a role in the world iron market. Direct reduced iron (DRI) is produced in pellet and lump forms and is generally used at an adjacent meltshop. Hot briquetted iron (HBI) is a densified form of DRI that is well-suited for transportation and it is usually sold as a merchant product. Both DRI and HBI are mainly used as feedstocks for EAFs, although they are also charged to blast furnaces, BOFs, and foundry furnaces. For purposes of this paper, the terms DRI and HBI are used interchangeably.

Figure 3 shows world DRI production since 1970. Today, 85 percent of DRI is produced by natural gas processes, with the remainder based on coal.

	2000	2005	Increase 2000-2005
Metallics Requirements			
Steel production	847.7	1,126.2	
EAF production	287.4	358.2	
% EAF	33.9%	31.8%	
EAF metallics required	316.1	394.0	77.9
Metallics Sources			
Scrap	253.8	324.5	56.7
Captive DRI	34.2	42.2	
Merchant DRI/HBI	7.6	11.1	
Total DRI	41.8	53.3	11.5
(% of EAF charge)	13.2%	13.5%	
Domestic pig iron	4.2	9.9	5.7
Merchant pig iron	14.6	17.6	3.0
Hot metal	4.0	5.0	1.0

Table II - World EAF Metallics Balance (Million metric tons, except as noted)

World DRI production has increased continually since 1970 with a compound annual growth rate of 13 percent per year. Excluding China, 42 percent of all new ironmaking capacity built in the world since 1995 has been based on direct reduction. DRI has also increased its importance as an EAF feedstock, now comprising about 13.5 percent of the charge worldwide.

REASONS FOR DRI DEMAND GROWTH

Growth in EAF Steelmaking

From 2000-2005, world EAF steel production grew by 71 million metric tons (Mt). Outside China, very few new blast furnaces have been built in recent years. Of the 60 Mt increase in total steel production ex-China from 2000-2005, 77 percent was accounted for by electric furnaces. In the USA, 56 percent of production in 2005 was via the EAF. EAF steelmaking continues to grow because of its capital and operating cost advantages versus the integrated route. In addition, it has less environmental impact and better economies of scale. The general availability of scrap and reasonably priced electricity worldwide has made this growth possible. A large share of future growth in the world steel industry will be via the EAF route. This growth results in increased demand for EAF charge materials, including scrap, DRI, HBI, and pig iron.

Expansion of EAFs into Low Residual Products

EAF steelmakers continue their assault on market segments once dominated by the integrated producers. With the latest generation technology, there are few steel products that cannot be made in EAFs, including wire rod, special quality bar, and hot rolled coil. These products, however, require low metallic residuals (copper, chrome, nickel, molybdenum, tin). It is very difficult to procure sufficient low residual scrap to feed the EAFs; thus, virgin feed materials such as DRI, HBI, and pig iron are required. Mini-mills using thin slab casting require up to 70 percent prime charge materials.

Metallics Supply Limitations

As world steel production increased significantly beginning in 2002, supplies of all iron and steelmaking raw materials were strained. This included iron ore, coal, scrap, pig iron, and DRI. With the growth in EAF steelmaking worldwide, demand for metallic charge materials increased significantly as production capacity reached its limits. Table II reflects the metallics balance for the world. The pig iron here is cold material.

As the table shows, the increase in EAF production required about 78 million tons more metallics charge. Midrex estimates that 57 million tons of this was scrap.

The demand for EAF metallics is supplied by secondary (scrap) and primary (DRI and pig iron) charge materials. There were a number of limitations that restricted increases in supplies of these materials:

Scrap – Since scrap is not a manufactured commodity, there are limitations on growth in supply. The nearly 25 percent increase in demand for EAF feed materials from 2000-2005 put a strain on scrap supplies. Prompt scrap, which is generated as a by-product of manufacturing, is limited by the amount of manufactured goods produced. Obsolete scrap, which is steel that is recovered from items that have reached the end of their utility, is a function of the amount of steel produced in previous years. Since world steel production was essentially flat from 1980-95, the growth rate of the obsolete scrap supply leveled off. As Figure 4 demonstrates on the following page, since EAF steel production accelerated during the last five years, the scrap supply was "pinched" and prices increased significantly.

There are also some indications that the volatility of scrap prices is increasing, especially for the prime (low residual) grades. This uncertainty about where prices are, where they should be, and where they will be next, is one more sign that the demand/supply ratio is somewhat tighter than it was before. Such radical month-to-month changes make planning very difficult, both for buyers and sellers of scrap steel.

Pig iron – Domestic pig iron is a waste product resulting from spillage of hot metal when casting or from some upset condition. Some facilities do produce pig iron for merchant sale and use in EAFs. For large integrated steel mills, however, this is often a marginal business, and when demand is high, these mills prefer to make steel from their hot metal rather than pigging and selling it. There are merchant pig iron operations in Brazil that use charcoal made from Eucalyptus trees. In recent years, there have been economic and environmental factors that limited the possible increase in pig iron supplies.

Given these limitations, demand for DRI increased and use in EAFs increased by almost 12 Mt from 2000-2005. DRI and HBI have now become an essential part of the EAF feed mix for many meltshops. Leading steelmakers, including the Mittal Group, Nucor, and Steel Dynamics, have recognized this and are investing substantial amounts to secure dedicated ironmaking capacity. Nucor has a stated intent of having direct control over one-third of its ferrous raw materials.

DRI PRICES, 2001-2005

Because of the demand increase for EAF metallic charge materials from 2000-2005, prices rose astronomically. Figure 5 shows prices of low-residual EAF charge materials delivered to the midwest USA: DRI/HBI; pig iron; and No. 1 Bundles, a premium scrap grade.

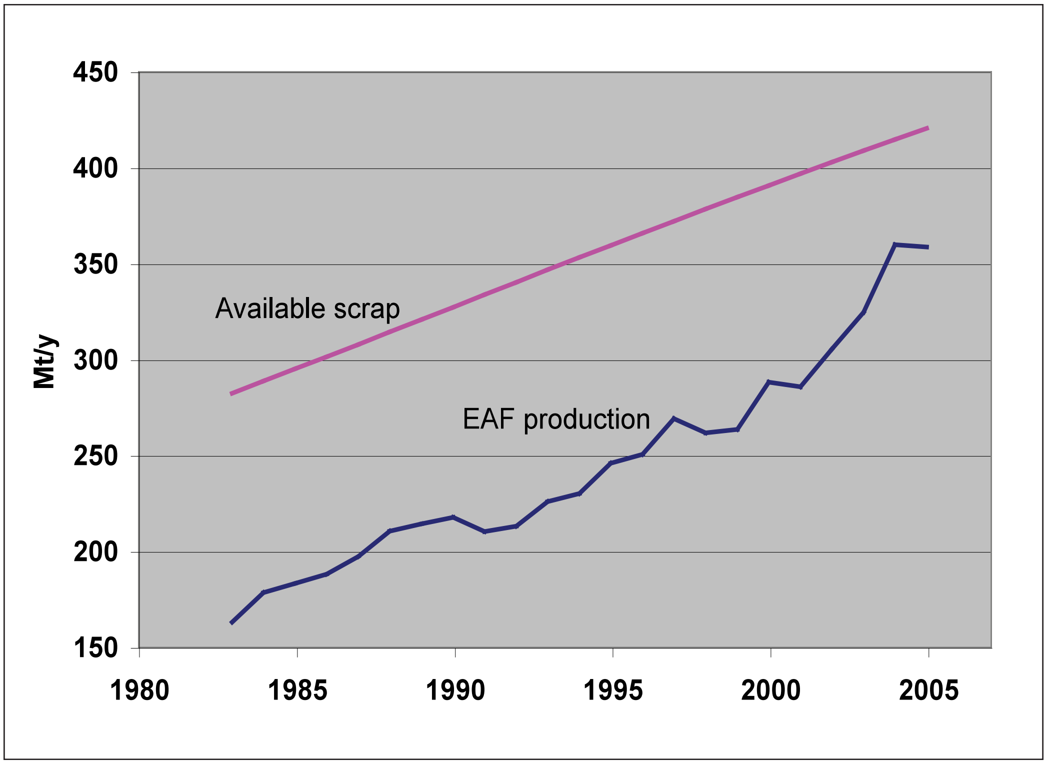

Figure 4 - World EAF Steel Production and Scrap Supply

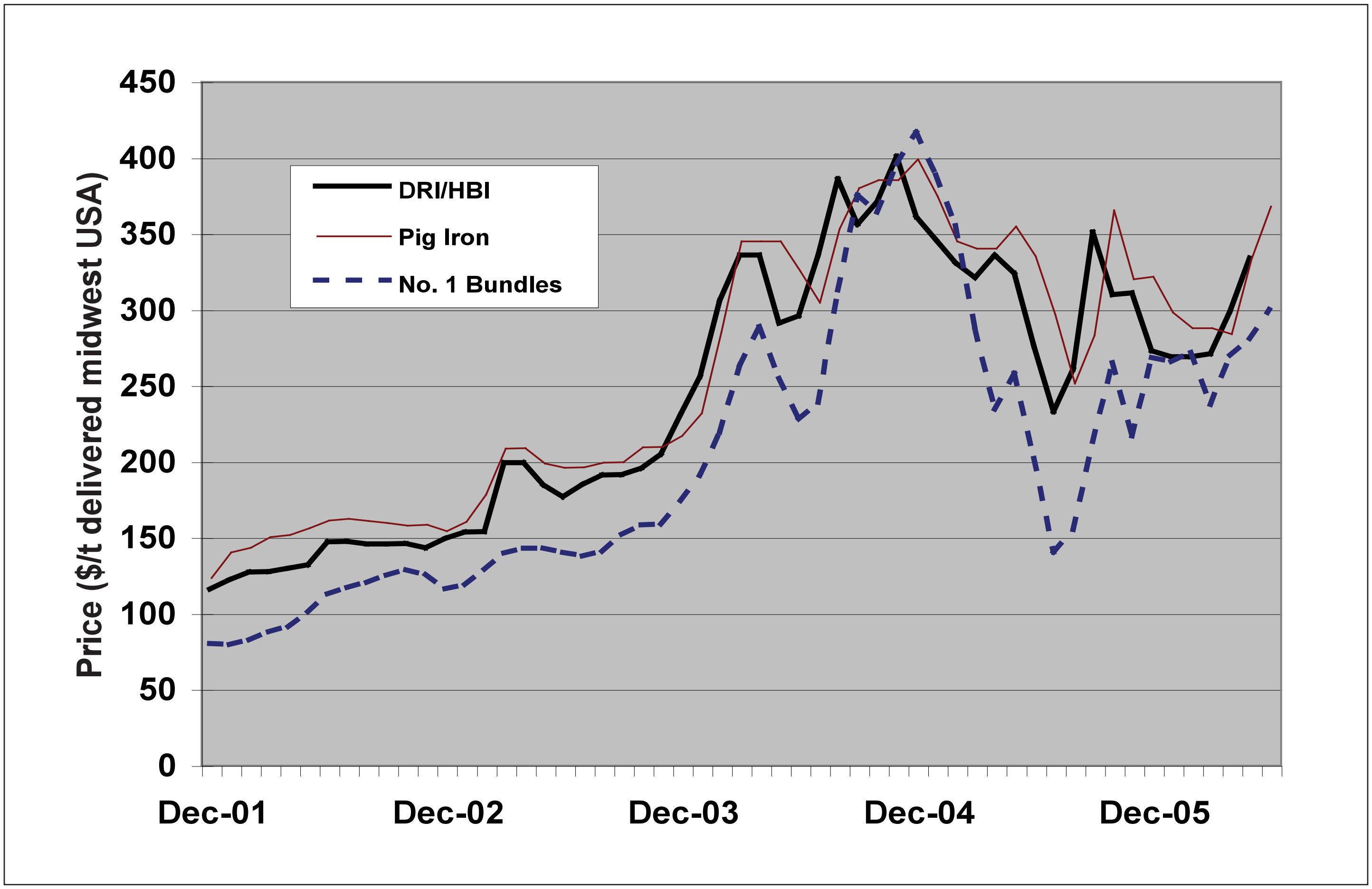

Figure 5 - Premium Metallics Prices

	Conversion Cost ($/t)
DR/EAF	
Middle East Latin America Russia	45 – 55
BF/BOF	
Russia Japan North America Brazil Europe	100 – 140

Table III - Conversion Cost from Iron Ore to Liquid Steel

For USA consumption, DRI/HBI is produced in Trinidad and Venezuela, pig iron in Brazil and Russia, and No. 1 Bundles are collected from USA factories. From November 2001 until November 2004, prices for these three materials increased by a factor of three to four, to all-time highs. Prices have since retreated slightly but still remain very high, relative to historical levels.

The other important consideration is the relative value of these EAF charge materials. Generally, the most important factors for EAF meltshops are the yield to finished steel and the levels of metallic residuals. Since pig iron and No. 1 Bundles have high percentages of metallic iron and low residuals, they are among the highest valued charge materials. Figure 5 shows that DRI and HBI consistently command a price comparable to these two premium feedstocks.

ECONOMICS OF GAS-BASED DIRECT REDUCTION

As discussed previously, there will always be a mixture of iron ore-based and scrap-based steelmaking. Given that, the key issue in determining the best process route for a specific iron ore-based project is the cost of converting iron ore to liquid steel. The benchmark is the cost of blast furnace ironmaking and basic oxygen furnace steelmaking (BF/BOF). With the successful commercialization of gas-based direct reduction paired with the electric furnace (DR/EAF), it is now a viable option to the BF/BOF.

Since in most cases the cost of iron ore is about the same for a blast furnace and a direct reduction plant, the key consideration is the conversion cost from iron ore to metallic iron (hot metal or DRI) and from metallic iron to liquid steel. State-of-the-art BF/BOF and DR/EAF plants are quite energy efficient and their total energy consumptions are comparable. Since other cost factors are also similar, the important variable is the unit cost of energy for reduction, heating, and melting. For the BF/BOF, the primary energy is mostly in the form of coal, used for producing coke and electricity. These steel mills often pay world market prices for this coal – prices that can vary substantially over the cycle. For the DR/EAF route in a gas-rich area, gas comprises nearly all the primary energy used, both directly in the DR plant, and for use in producing electricity. Gas-rich areas include the Middle East (Qatar, Saudi Arabia, Egypt, Libya, and Iran), Latin America (Venezuela and Trinidad), and Russia. The advantage in these locations is that there is excess natural gas available, and its price remains more-or-less constant. In these countries, the price of gas is about $4/Gcal or less. In contrast, the price of coking coal delivered to steel mills in some areas has recently reached levels of $24/Gcal.

Table III lists estimated conversion costs for the two process routes in various locations. This shows that the DR/EAF route has a $45 – 95/t cost advantage versus the BF/BOF.

PROVEN MIDREX TECHNOLOGY

Since 1970, there have been 55 MIDREX Modules (shaft furnaces) constructed in 19 countries. To date, these facilities have produced over 500 Mt of DRI and HBI, with a market value exceeding $50 billion. In addition, Midrex and its partners have contracted and are building an additional 13 Mt of annual capacity that will start up from 2006 – 2008. This record of plant sales, successful start-ups, and continued outstanding performance has resulted in a market share for MIDREX Technology of 60 percent or more each year since 1987.

This stellar record helps clients obtain financing for MDIREX Plants. International banks, export credit agencies, and investors appreciate proven, low-risk MIDREX Technology and the good economics in gas-rich areas.

PROCESS INNOVATION

During the 37 years since installation of the first commercial-scale plant in Portland, OR, Midrex has continued to advance the state-of-the-art in gas-based direct reduction. Improvements have been made in plant capacity, productivity, energy consumption, raw materials and reductant flexibility, as well as product use.

Plant Capacity

The first MIDREX Plant had two shaft furnaces of 3.7 meter diameter, with annual capacity 150,000 t/y each. Over the years, Midrex has built larger and larger modules. The standard MEGAMOD now has a 6.65 – 7 meter diameter furnace and an annual capacity approaching 2 Mt. The capacity of a single module (shaft furnace, reformer, and associated equipment) has increased by a factor of more than ten. Because of the major economy-of-scale of the technology, these larger plants have significantly enhanced economics. Midrex is now considering the use of an 8 meter diameter shaft furnace for some potential projects.

Productivity

The volumetric productivity of the shaft furnace is the best measure of a plant's productivity and is very important for profitable operation. Today, Midrex designs shaft furnaces for a specific production rate of 12 tons per day cubic meter of reduction volume (t/d-m^3). This figure has been achieved largely through the use of higher operating temperatures, which increases reaction kinetics, and internal devices, which facilitate good gas-solids contact. Some MIDREX Plants have achieved sustained productivities of 14 t/d-m^3, the highest in the direct reduction industry. MIDREX Plants routinely exceed rated capacity, and in recent years, the overall capacity utilization has been 120-130 percent. Some MIDREX Plants have achieved as high as 210 percent of capacity on an annual basis.

Energy Consumption

The first MIDREX Plants had a natural gas consumption of over 3 Gcal per ton of DRI. Due to increased heat recovery, some plants now achieve levels of under 2.3 Gcal/t. State-of-the-art MIDREX Plants can incorporate up to four stages of heat recovery.

Raw Materials and Reductant Flexibility

Over the years, MIDREX Plants have operated on over 50 iron oxide sources, including pellets and lump ores, from around the world. Midrex continues to investigate suitable iron ores and design plants to incorporate the widest range of feed materials possible. Several plants have operated on 50 percent or more lump ore for extended periods of time, and plants have been designed for use of 70 percent lump ore.

There is also a great deal of flexibility in sources of reductant. MIDREX Plants can be designed to operate with hydrogen/carbon monoxide ratios of 0.5/1 to 3.5/1. Most MIDREX Plants use standard natural gas processed in a MIDREX® Reformer to create a syngas with a ratio of 1.5/1. The OPCO Plant in Venezuela reforms natural gas using a steam reformer, which generates a syngas with a ratio of 3.5/1. Midrex built a plant at Saldanha Steel in South Africa for the use of COREX® Offgas made from coal, with a ratio of 0.5/1. Midrex is now evaluating the use of syngas from a coal gasification facility.

Product Use

During the 1980s, Midrex pioneered the development of hot briquetting of DRI. Hot briquetted iron is an excellent merchant product that can be transported and handled like scrap, with no special precautions. This development opened up the water-borne merchant market and since 1985, over 80 Mt of HBI has been shipped worldwide.

There is continued interest in close-coupling ironmaking and steelmaking so that hot DRI can be charged to the EAF. This provides both productivity and energy benefits. Midrex and its clients have developed a number of solutions that are being used or are part of plants under construction. These solutions include use of hot transport vessels, conveyors, and the HOTLINK® System. With HOTLINK, the EAF is positioned underneath or to the side of the shaft furnace and hot product is gravity fed.

MIDREX PLANTS CONTRACTED 2004-2006

With the increase in steel and DRI prices from 2001-2004, Midrex experienced a surge of interest from potential clients. The attractive economics of direct reduction in gas-rich regions combined with recent levels of DRI prices resulted in 11 new projects that will start up from 2006 – 2008. These projects, contracted by Midrex Technologies and partners, are shown in Table IV.

Plant	Location	Capacity (Mt/y)	Start-up
Al-Tuwairqi Dammam I	Saudi Arabia	0.50	2006
Essar V	India	1.00	2006
Mobarakeh VI	Iran	0.80	2006
Nu-Iron	Trinidad	1.60	2006
Acindar Expansion	Argentina	0.25	2007
Hadeed E	Saudi Arabia	1.76	2007
LGOK II	Russia	1.40	2007
Lion Group	Malaysia	1.54	2007
QASCO II	Qatar	1.50	2007
Al-Tuwairqi Steel Mills	Pakistan	1.28	2008
Shadeed	Oman	1.50	2008
Total capacity		**13.13**	

Table IV - New MIDREX Projects 2004 - 2005

COAL-BASED DIRECT REDUCTION

Coal-based DRI comprised 15 percent of the world total in 2005. This percentage has increased from less than 10 percent in the 1990s because of the proliferation of small rotary kiln plants in India. DRI is also made from coal in South Africa, China, the USA, and Peru, but production in those countries has not increased in recent years.

Most of the new Indian plants have capacities of 20,000-50,000 t/y and make use of indigenous iron ore and coal. The product is often melted in induction furnaces to make pig iron that is sold to steel mills. Although these types of plants have been successful in India, this is a unique situation and not replicable elsewhere. Because the maximum capacity of a rotary kiln for direct reduction is about 150,000 t/y, this technology is generally not applicable for a steel complex that needs a large quantity of DRI.

Midrex and Kobe Steel are actively marketing and developing rotary hearth furnace-based technologies that use coal. These include FASTMET®, FASTMELT®, and ITmk3®. Kobe Steel has sold three FASTMET Plants in Japan that process iron-bearing wastes and is a partner in a commercial-scale (500,000 t/y) ITmk3 project planned for the USA. These processes have great potential in areas that have high quality coal and access to iron ore or wastes and will be discussed in Part 3 of this series.

Editor's note: The third part of this series will include Midrex's view of the future of direct reduction and initiatives the company is undertaking to continue expanding the business.

Gasification and the MIDREX® Direct Reduction Process

By Robert Cheeley,
Business Development Manager
Midrex Technologies, Inc.

Introduction

The global steel industry is currently expanding at a rapid pace. Much of this expansion is occurring in China, India, and other locations that do not have an abundance of low cost natural gas. This typically precludes the use of natural gas-based direct reduction for making iron. In these locations, the blast furnace is the preferred route for producing iron. However, there are many disadvantages to utilizing a blast furnace, including a high specific capital cost, the need to use expensive coke, limited turndown, and the environmental problems associated with coke ovens and sinter plants.

One option for making iron in these locations is to combine a gasification plant with a MIDREX® Direct Reduction Plant. The coal gasification plant can use a wide range of low cost fuels, such as bituminous and sub-bituminous coal, lignite, pet coke, and petroleum refinery bottoms to generate a synthesis gas or syngas. This syngas can be an acceptable reducing gas source for producing DRI in a MIDREX® Plant.

This article updates a *Direct From Midrex* article published in 1999 and explores the technical issues and economic benefits of combining a gasification plant with a MIDREX Plant.

Photo Courtesy of Nuon Buggenum

Shell Gasification Plant Buggenum, Netherlands

Photo Courtesy of Lurgi

Battery of 40 MK IV Sasol-Lurgi Fixed Bed, Dry Bottom Gasifiers under Construction in South Africa (Circa 1980)

What Is Gasification?

Commercial gasifiers have been in operation for over 50 years. While there are distinct differences between gasifier types, they all operate on the same basic principles. In general, gasification is defined as the partial oxidation of a carbonaceous feed material, which can be a solid, liquid, or gas. The partial oxidation reactions occur at high temperature and usually at high pressure. The gaseous output is called the syngas. The syngas contains mostly H_2 and CO, but also some H_2O, CO_2, N_2, sulfur gases (H_2S and COS), and possibly other byproducts, depending on the gasification technology used.

A wide range of feed materials have been used in gasifiers; however, the most commonly used feedstocks are coal, pet coke, and petroleum refinery bottoms (tars, heavy fuel oils, etc.). All types of coal can be used, including brown coal (lignite), black coal (sub-bituminous and bituminous), and anthracite. Usually, the lowest cost available feedstock is used in the gasifier.

Gasification Technologies and Operations

There are three general types of gasifiers: entrained flow, fixed bed, and fluidized bed. All three types can be used to make an acceptable reducing gas for a MIDREX DR Plant; however, the entrained flow and fixed bed gasification technologies are by far the most commonly used and the rest of this article focuses only on their use.

In an entrained flow gasifier, the carbonaceous feedstock and oxygen are continuously fed co-currently into either the top or bottom of the gasifier. The feedstock and oxygen react at a high temperature to produce the syngas. The reactor temperature is high enough to melt the ash components from the carbonaceous feedstock, which are discharged out the bottom of the gasifier as an inert slag. The dominant entrained flow gasification technology suppliers are Shell, GE (formerly Texaco), and Conoco Phillips.

In a fixed bed gasifier, coal is added to the top of the reactor via a lock hopper and oxygen and steam are continuously fed into the bottom of the reactor. As the coal descends, it is gasified by the counterflowing steam and oxygen. Most fixed bed gasifiers are designed to operate at a temperature below the ash melting point. The solid ash is discharged out the bottom of the gasifier via a lock hopper. The dominant fixed bed gasification technology supplier is Sasol Lurgi. See Table I for relative advantages and disadvantages of each gasifier type.

	Entrained Flow	Fixed Bed
Energy Efficiency	High	Low
Tar-free Syngas	Yes	No
Byproducts in Syngas	No	Yes
Oxygen Consumption	High	Low
Steam Consumption	Low	High
Capital Cost	High	Low

Table I - Relative Advantages and Disadvantages of Gasifier Types

Syngas Characteristic	MIDREX Requirement
Gas Quality*	> 10
Gas Requirement	~ 2.1 net Gcal / t DRI
Temperature	< 900°C
Pressure	> 3 barg
H_2/CO Ratio	All are acceptable, but > 0.5 preferred
Sulfur Content	< 100 ppmv
Particulates Content	< 1000 mg / Nm^3
N_2 + Ar Content	< 5%

*Gas Quality is defined as (% H_2 + % CO) / (% H_2O + % CO_2)

Table II - MIDREX Syngas Requirements

Syngas Cleaning and Conditioning

The syngas produced in the gasifier must be cleaned and conditioned to be used in a MIDREX DR Plant. Downstream of the gasifier, the hot syngas is cooled and scrubbed, which removes the particulates and most of the water vapor. It also generates a large quantity of byproduct steam that can be used elsewhere in the complex.

The majority of the acid gases (H_2S, COS, and CO_2) are removed from the syngas by an amine-type acid gas removal system. The concentrated sulfur gases are further treated to convert them into saleable elemental sulfur. Typically, more than 99.5 percent of all sulfur in the gasifier feedstock is collected as elemental sulfur. The concentrated CO_2 can be sequestered or injected into oil and natural gas fields.

For a project using a fixed bed gasifier, additional unit operations are required to remove the tar, phenols, NH_3, and CN compounds from the syngas. These byproduct compounds can be sold as chemical plant feedstocks.

MIDREX® Direct Reduction Process

The MIDREX DR Process utilizes the syngas produced in the Gasification Plant to produce high quality DRI for melting in an EAF or as feed to a blast furnace. The syngas requirements at the MIDREX Plant battery limits are shown in Table II.

In the MIDREX Plant, the incoming make-up syngas is first depressurized to about 3 barg by a turboexpander. The low pressure make-up syngas is then mixed with recycled top gas to make the required reducing gas. The reducing gas is heated in the Gas Heater to about 800°C. The hot reducing gas enters the MIDREX® Shaft Furnace where it reacts with the iron oxide to produce DRI.

The reduction reactions are shown below:

$$Fe_2O_3 + 3\,H_2 \rightarrow 2\,Fe + 3\,H_2O$$
$$Fe_2O_3 + 3\,CO \rightarrow 2\,Fe + 3\,CO_2$$

The spent reducing gas (top gas) exiting the MIDREX Shaft Furnace is scrubbed and cooled, then recycled. The recycle gas passes through a CO_2 removal system to reduce the CO_2 content to five percent or less. This ensures that the mixed reducing gas (syngas from the gasification plant and recycled top gas from the MIDREX Plant) has a gas quality greater than 10. This is necessary for efficient iron ore reduction to occur inside the MIDREX Shaft Furnace. The CO_2 removal system will also remove the sulfur gases contained in the recycled top gas. See Figure 1 for the Gasification Plant / MIDREX® Plant combination flowsheet and Table III for the Predicted Operating Consumptions for a Gasification Plant / MIDREX® Plant Combination chart.

Integrated Mini-Mill

The gasifier / MIDREX Plant combination is ideally used to provide DRI for an integrated mini-mill. The integrated mini-mill shown on the following page in Figure 2 consists of the air separation unit (oxygen plant), gasification plant, MIDREX Plant, integrated gasification combined cycle (IGCC) electric power plant, and a steel mini-mill. For this complex, the only major raw material inputs are the gasifier feedstock and iron oxide for the MIDREX Plant.

The gasification plant would be sized to produce enough syngas for both the MIDREX Plant and the IGCC power plant. The IGCC power plant would be sized to generate all of the electricity required for the air separation unit, MIDREX Plant, and the steel mini-mill.

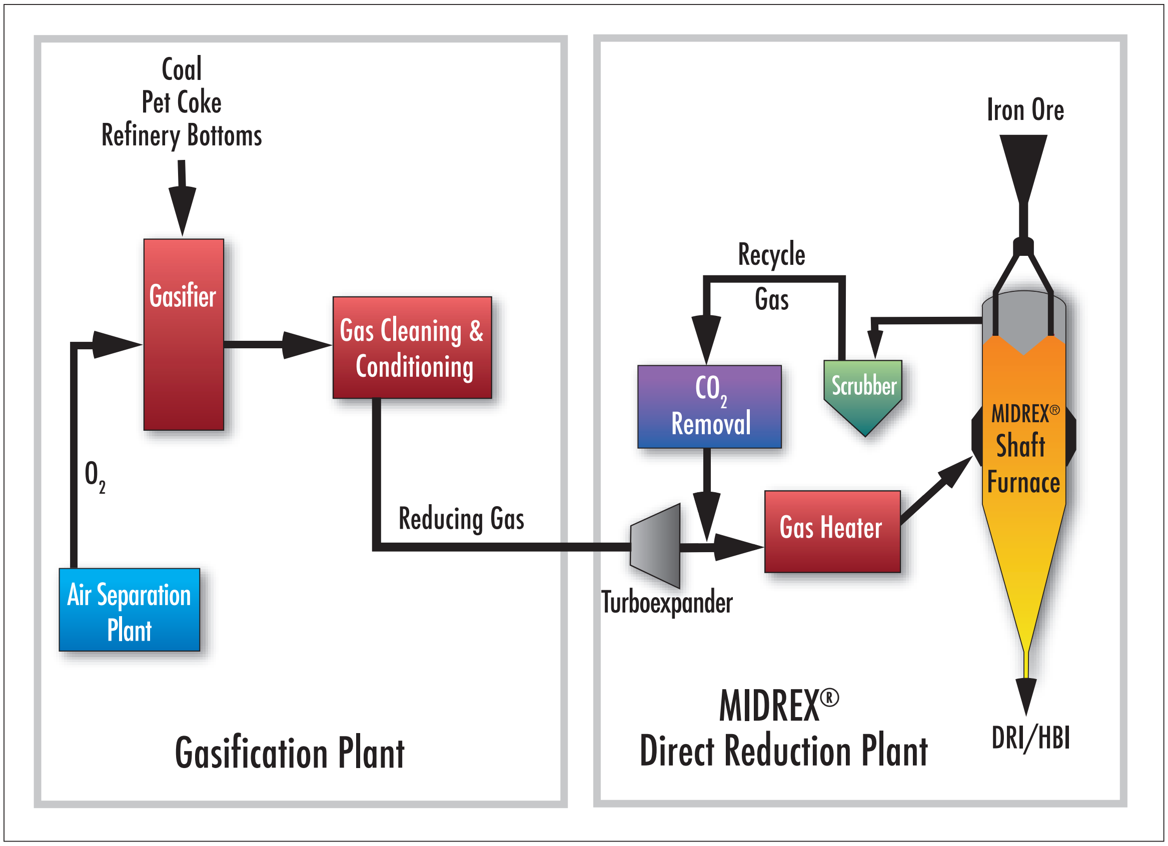

Figure 1- Gasification Plant / MIDREX® Plant Flowsheet

Basis: **MIDREX MEGAMOD® with capacity of 1,600,000 t/y of hot DRI[1]**
Entrained Flow Gasifier

Input	Units	Quantity per t hot DRI[2]
Iron Ore	t	1.45
Gasifier Feedstock	net Gcal	2.25
Limestone	kg	6
Oxygen	t	0.35
Electricity	kW-h	150
Labor	man-hour	0.2
Make-up Water	m^3	1.4
Operations & Maintenance[3]	USD	7.00
Export H.P. Steam[4]	t	0.3

1 The hot DRI product characteristics are: 93% metallization, 2% carbon, and 700°C discharge temperature
2 The quantities are for the combined Gasification Plant and MIDREX DR Plant
3 This is a combination of general operating expenses, general maintenance expenses, and a long-term amortized cost for replacing capital equipment.
4 Superheated steam at 55 bar and 580°C

Table III - Predicted Operating Consumptions for a Gasification Plant / MIDREX® Plant Combination

See the example case of an integrated Mini-Mill in Table IV.

The advantages of the integrated Mini-Mill compared to a conventional blast furnace-based integrated steelworks include:

- Lower specific capital cost
- Lower operating costs
- Ability to use low cost energy sources (pet coke, lignite, bituminous coal, etc.)
- No coke or coke ovens required
- No sinter plant
- Reduced air emissions - since the gasifier operates in a reducing atmosphere, there are virtually no SOx or NOx compounds generated
- Ability to capture high purity CO_2 for sequestering or injecting into oil and gas fields
- Wider turndown possible
- Feedstock sulfur compounds recovered as saleable elemental sulfur

Conclusions

Utilizing a gasifier to generate reducing gases is a technically and commercially viable method for innovative steelmakers to produce DRI in areas where low cost natural gas is not available. The gasifier / MIDREX Plant combination is best suited for the Asian countries, where DRI is needed, but natural gas costs are high. Other possibilities include major iron ore producing areas, such as Brazil, South Africa, and Ukraine. The gasifier / MIDREX Plant combination may also be an option for existing integrated steelmakers in the U.S., Europe, and Japan to replace BF/BOF complexes with cost effective electric steelmaking lines and eliminate the need for environmentally undesirable coke and sinter plants.

In addition, for locations with high electricity costs, the integrated Mini-Mill complex can be an economically viable option. It utilizes low cost coal or petroleum refinery byproducts to produce both reasonably priced DRI and lower cost electricity to allow competitive manufacture of semi-finished steel.

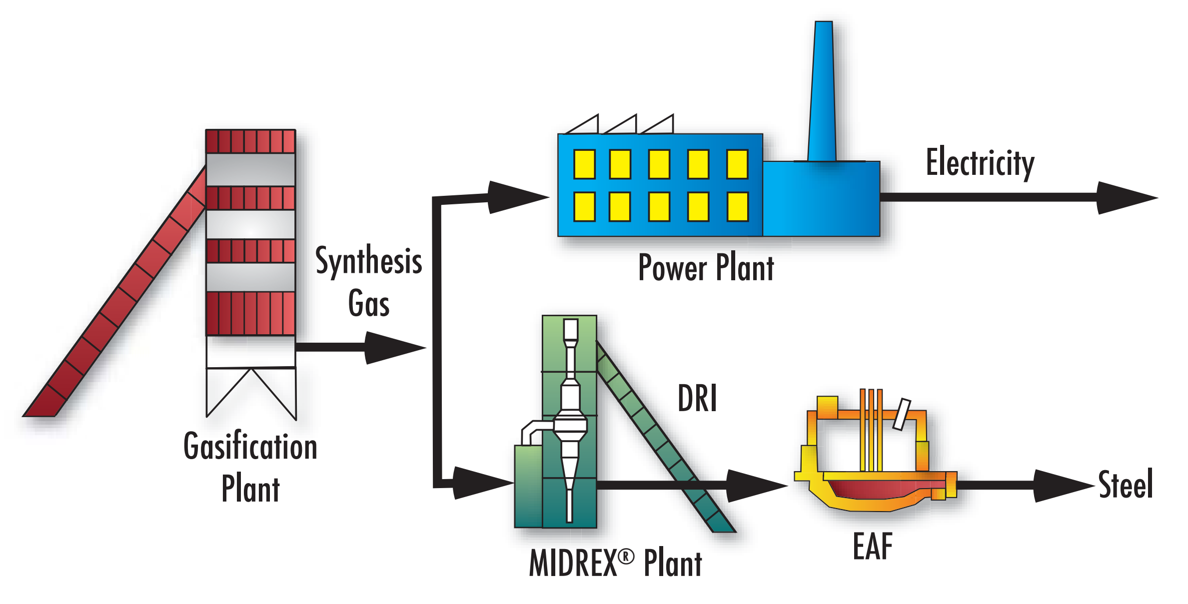

Figure 2 - Integrated Mini-Mill Flowsheet

Basis: **Location: India**
Two MIDREX MEGAMODS (3,200,000 t/y capacity)
Entrained Flow Gasification Plant (5,275 net GJ/h syngas production)
Combined Cycle Electric Power Plant (425 MWe)
Two EAFs (3,000,000 t/y liquid steel capacity)
Two Ladle Furnaces (3,000,000 t/y liquid steel capacity)
Two Slab Casters

Product: 2,920,000 t/y Steel Slabs
Iron Oxide Feed: 70% Indian pellets & 30% Indian lump ore
Gasifier Feedstock: Lignite
Two Air Separation Units (6,000 t/d oxygen capacity)
EAF Feed Mix: 95% DRI and 5% scrap steel
Two Vacuum Degassers (3,000,000 t/y liquid steel capacity)

Input	Units	Quantity per ton of Steel slabs	Cost per unit (USD)	Cost per ton of Steel slabs (USD)
Iron Ore	t	1.64	90	147.60
Scrap Steel	t	0.05	200	10.00
Gasifier Feedstock	net Gcal[1]	4.1	9	36.90
Miscellaneous Operation & Maintenance Costs[2]	USD			57.00
Total Operating Cost	USD			251.50

Notes:
[1] 1 net Gcal = 4.18 net GJ
[2] This is a combination of general operating expenses, general maintenance expenses, and a long-term amortized cost for replacing capital equipment.

Table IV - Example Case for Integrated Mini-Mill

Midrex News & Views

Midrex Hosts Libyan Official

There are three MIDREX® Modules in Libya, two that produce DRI for the adjacent steelworks and one that sells HBI on the merchant market. The plants were supplied by MIDREX licensee, Siemens VAI. With the continuing normalization of relations between the US and Libya, Midrex is exploring opportunities for business with the plant's owner, the Libyan Iron and Steel Company (LISCO). On April 25, Midrex hosted a visit by Ambassador Ali Suleiman Aujali, chief of the Libyan Liaison Office in Washington, D.C. While in Charlotte, Ambassador Aujali met with Midrex officials to discuss business opportunities, participated in a radio show, and spoke at a luncheon sponsored by the World Affairs Council of Charlotte. With the abundance of natural gas in Libya and its strategic location on the Mediterranean Sea, LISCO is ideally suited to take advantage of the present strong market for steel and metallics, including DRI and HBI. Midrex personnel plan a trip to the plant in the near future to discuss opportunities for implementation of the latest MIDREX Technologies and sales of spare parts.

In a related note, on May 15, the United States restored full diplomatic relations with Libya for the first time since 1972. The move followed a decision to remove the country from the list of state sponsors of terrorism, and it reflects increased Libyan cooperation with the US in combating terrorism. Speaking about the restoration of full relations, Ambassador Aujali said it was a "great day."

Pictured are James D. McClaskey, President of Midrex Technologies, Inc.; Firoz Peera, Chairman of the World Affairs Council of Charlotte; and Ambassador Ali Suleiman Aujali, Chief of the Libyan Liaison Office in Washington, D.C.

Christopher M. Ravenscroft: Editor

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