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Commentary

What Is the Value of Iron?

“Air isn’t worth very much, unless you’re not getting enough of it.”
– heard in conversation

After writing a multi-part series on this topic, one would think the topic would be discussed to its full extent. However, when the price of factory bundles in the United States leapt to $422.50/GT (AMM, Factory Bundles Index, October 2004), the new question on people’s mind seemed to be, “How high can it go?”

The short answer is that it goes until supply and demand are balanced at that new price.

The longer answer is a lot more long winded, but what is the point of a brief commentary? For the longer explanation, let’s look at the history of iron prices.

As noted in prior articles on this subject, the price of iron, after adjustment for inflation of the U.S. dollar, has fluctuated between a set of limits for over 100 years. A graph of this price history is printed as Figure 1.

As one can see, prices attained a remarkably high level in 1974, the second highest level in a century. A comparison of those prices, from 1974 to current, shows that it is possible, albeit not likely, for prices to go much higher than they are today. The June 1974 price (American Metal Market, three-city composite) rose to over $123/GT. In today’s dollars, that’s over $475/GT! Even more remarkable, in June of 1974, auto bundles attained $173.80/GT. That’s approximately $675/GT in today’s dollars! (These adjustments for inflation use the Consumer Price Index for All Urban Consumers, the
CPI-U, as the indicator of inflation. The ratio of the CPI-U today to its value in June 1974 is 3.88-to-1.)

Following up on this idea of how high the price of iron can go sent me to historical prices of scrap steel during the latter part of the 19th Century and pig iron during the early 20th Century 1, 2, 3. (Obviously, it was not possible to continue the scrap steel price data back so far in time. Prior to tonnage production of steel, there was no organized market in scrap steel.)

The results were quite different from the 20th Century data (see Figure 2). Although also very volatile, the range of prices steadily declined throughout this earlier time period. Apparently through increasingly better technology, the efficiency in making iron improved throughout this era. The decline in prices resulting from technology improvements is all the more remarkable when compared to the enormous technological improvements achieved during the 20th Century, without any similar overall change in the range of iron prices.

Sometime around 1900, the data suggested that we had reached "a point of diminishing returns." Another interpretation of the data, and one that I prefer, is that during the 20th Century, other costs grew and counteracted the enormous savings achieved by technology.

Looking even further back in time, only spot prices could be found in these earlier times (refer to Figure 3). It's doubtful there was an equivalent to Metal Bulletin or American Metal Market back then. Also, any attempt to correct for inflation/deflation seemed futile. So for this older price data, the value of gold is assumed to be a constant, and today's value of approximately $400 per troy ounce is used.

Interestingly, the prices get ever higher and higher as one looks further back. No additional trend was evident until the graph was converted into a log/log scale (as the range of prices and the range of times became so very large). Then with the log/log scale, remarkably, the lower prices aligned (approximately) with the trend line of pig iron prices for the 19th Century! On closer inspection, these lower prices tended to represent iron supplied nearby to manufacture and the higher prices represented iron supplied to 'frontier' regions. Clearly the cost (and possibly risk) of transporting the iron to the frontier was exorbitant, occasionally causing the frontier price to be as much as two orders of magnitude

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1http://www.eh.net/hmit/inflation/
2http://www.nber.org/databases/macrohistory/contents/chapter04.html
The most extraordinary prices found, however, are the ones from ancient times, prior to the discovery of iron smelting. Iron was truly a precious metal then. Four separate royal decrees to fix the price of iron have been found by historians. All of these are in the general region of Mesopotamia, and they set the price at anywhere from four times gold to eight times gold! This was of course meteoric iron, which still commands a remarkably high value by collectors. As soon as furnaces attained temperatures capable of smelting iron, the price plummeted by 100-to-1. Actually, the price decline occurs almost two centuries prior to any known iron smelting, but I suspect that someone was smelting iron (likely in secret to retain value). Their furnaces just have not been found by archaeologists and their iron products have long since rusted away.

Now back to the question at hand, how high can prices go? I can confidently state that scrap steel prices and iron prices aren’t going to set any new record highs. Eight times gold is about $100 million per tonne. But prices are apt to stay at levels well above what would have been expected only two years ago, and they will likely stay at these new higher levels until new iron-making capacity can be built. Enough new capacity will be needed to match the exceptional economic growth we’re seeing in South and East Asia, especially in China, and more recently in India. Most likely, it will require a few years to build this capacity. So unless something happens to slow demand, we should expect relatively high prices to continue through 2005, 2006, 2007 and possibly beyond.

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**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.
By A. R. Elliot
Midrex Technologies, Inc.

Introduction

Midrex refers to in-situ reforming as the reforming that occurs on metallized surfaces of the DRI material in the shaft furnace where the reducing gas enters. This paper addresses the trends and achievements of existing MIDREX® Direct Reduction Plants in the use of in-situ reforming, as well as the limitations placed by thermodynamics and energy availability on the amount of in-situ reforming that can be reasonably achieved.

Since the early 1990s, MIDREX® Plants have been using oxygen to increase production. SIDOR was the first company to introduce air (preheated), and later oxygen, to the reducing gas going to the Shaft Furnace Bustle. Their expectations were high at the time that the energy input from oxygen injection could be translated into a significant increase in the amount of reductant gas being generated through in-situ reforming (increasing production about 40%). Reality did not match those expectations.

Around the same time, in parallel, OEMK (in Russia) was coating their pellets to reduce the high stickiness of their raw material. OEMK’s objective was to decrease the reactivity of the DRI that they exported by reducing it at high temperatures in their MIDREX® Shaft Furnaces. OEMK relied on the high temperature gas coming from the MIDREX® Reformer to achieve high bed temperatures and did not use oxygen.

Acindar was the first MIDREX Plant to install both pellet coating and oxygen injection systems in 1994, and now, in 2004, over 19 MIDREX Modules operate using Oxygen Injection to increase their production capacity. At this point we have a good idea of what can be achieved using oxygen injection in its various forms.

In-situ Reforming

In-situ reforming proceeds according to the following reactions: (see Figure 1).

\[
\text{CH}_4 + \text{CO}_2 \rightarrow 2 \text{CO} + 2 \text{H}_2
\]

and

\[
\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3 \text{H}_2
\]

Both of these reactions are endothermic (absorb heat), and they reduce the temperature of the gases (and solids) in the rest of the bed in the Shaft Furnace, compared to the temperature of the reducing gas that is entering the Furnace.
The more in-situ reforming that occurs, the more the temperature will drop, because reforming is endothermic. Figure 2 shows two cases, one where the temperature drop and reforming is greater ($\Delta T_1$), and another where the temperature drop and reforming is smaller ($\Delta T_2$). In both cases the resulting bed temperature achieved is shown to be the same.

These reforming reactions are also carried out in the MIDREX Reformer where catalyst is used to accelerate the speed of the reactions. In the MIDREX Reformer, in addition to preheating the reactants ($\text{CH}_4$, $\text{H}_2\text{O}$, $\text{CO}_2$) in heat recovery equipment to temperatures in the range of 400 – 580 °C prior to reforming, a significant amount of heat is transferred through the reformer tubes to heat the resultant gas after reforming (reformed gas) to normal exit temperatures which exceed 900 °C. Heat is also transferred through the reformer tube walls to satisfy the endothermic reforming reactions that are occurring inside the tubes. Typically about 1/3 of the heat transferred into the tubes is used to increase the temperature of the gas from the inlet to the outlet temperature and about 2/3 is used to satisfy the endothermic heat of the reforming reactions.

In the Shaft Furnace, the iron in the DRI catalyses the reforming reactions. This was learned the hard way in the first MIDREX Plant where initially $\text{CH}_4$ was not added to the Reformed Gas before entering the Shaft Furnace. Since the bed temperatures in the Shaft Furnace were typically lower than the Reformed Gas temperature, the reforming reactions would reverse and methane would be produced. This phenomenon is called methanation, and it is accompanied by a release of heat which sometimes would overheat the bed excessively during startup or upset conditions and produce clustering. This phenomenon was prevented with the addition of methane to the Reformed Gas (which we call Enrichment Natural Gas) to prevent the reversal of the reforming reactions.

If more than enough natural gas to prevent methanation is added to the Reformed Gas, some reforming (in-situ reforming) is carried out. Since then, Midrex has always recommended that MIDREX Plants operate with some excess Enrichment Natural Gas to prevent methanation and favor in-situ reforming. The addition of this Natural Gas will also favor carbon deposition, thereby increasing the carbon content in the DRI.

As the flow of Enrichment Natural Gas is increased, the temperature of the Bustle Gas will drop and the temperature of the bed will also drop, reducing productivity. Because there was not much excess heat available in the Bustle Gas before the advent of pellet coating and oxygen injection, only a minimum amount of in-situ reforming was carried out before the early 1990s. The advent of pellet coating and oxygen injection changed that.

**Oxygen Injection in MIDREX Plants**

To date two types of oxygen injection have been practiced in MIDREX Plants. Initially oxygen was added to the Reformed Gas resulting in the fulloxidation of $\text{H}_2$, $\text{CO}$ and $\text{CH}_4$, to $\text{CO}_2$ and $\text{H}_2\text{O}$, with maximum temperature rise. Alternatively, Midrex favored the addition of oxygen shrouded by methane into the Reformed Gas, as initially practiced by Acindar. The advantage of this second method is that while some full oxidation of the $\text{CH}_4$ to $\text{CO}_2$ and $\text{H}_2\text{O}$ occurs, some partial oxidation to CO and $\text{H}_2$ also occurs, and the temperature rise of the Bustle Gas (Reducing Gas) is not as great.

In both cases, the excess temperature in the Bustle Gas caused by the oxygen injection is consumed by carrying out in-situ reforming reactions over the DRI catalyst once the Bustle Gas enters the Shaft Furnace (recall Fig. 2). For equal amounts of oxygen and natural gas additions to the Reformed Gas in either case, the main difference will be the temperature of the Bustle Gas entering the Shaft Furnace, with the higher temperature Bustle gas reforming more, but with roughly the same end result regarding temperature and gas quality once the in-situ reforming reactions have occurred in the Shaft Furnace. The main difference, therefore, is the higher Bustle Gas temperature in the first alternative with the potentially dangerous consequences of clustering and/or excess fines generation.

For this reason, Midrex has developed OXY+®, to favor partial oxidation over full oxidation so as to reduce the Bustle Gas temperature further, while still maintaining the excellent gas quality for Direct Reduction. The first OXY+ installation (at OEMK in Russia) will combine OXY+ with Center Injection to maximize the benefits of the additional reducing gas in the Shaft Furnace. This installation is due to start up in the first half of 2005.

**Process Variations and In-situ Reforming**

Midrex has experience with the following process variations:

- **Standard MIDREX Process** – to produce HBI (e.g., Amsteel, Comsigua, Essar, Venprecar)
- **Steam reformer-based MIDREX Process** – to produce HBI (e.g., OPCO in Venezuela)
- **Reformerless process** – to produce DRI (e.g., Saldanha in South Africa)
- **Standard MIDREX Process** – to produce DRI (all other MIDREX Plants)
In the Standard MIDREX Process to produce HBI (see Figure 3), approximately 95% of the reducing gas is produced via the MIDREX Reformer, and 5% via in-situ reforming. The temperature drop from Bustle Gas temperature to bed temperature is approximately 60°C.

In the steam reformer-based HBI Plant of OPCO (see Figure 4), 98% of the reducing gas is produced via reformers (~26% via each of the three steam reformers that existed in the plant before it was converted to the MIDREX Process in 1990, and ~20% via the MIDREX Reformer that was added in 1996).

At OPCO, where the reducing gas is colder because the reformed gas from the steam reformers is cooled to condense...
excess water and reheated to \(~830\) °C, only \(~2\)% of the reducing gas is produced via in-situ reforming. Temperature drop from Bustle Gas temperature to bed temperature is in the order of 20°C.

In the COREX®-based DR Plant at Saldanha (see Figure 5), there is no reformer, and 100% of the reducing gas is produced via CO₂ removal. As there is no natural gas at the plant site and LPG is expensive, minimum LPG is used at the bustle for in-situ reforming. At Saldanha, heating of the reducing gas from the CO₂ removal to required Bustle Gas temperature is done in two stages, first in an indirect fired heater and then with O₂ injection.

In the standard MIDREX Plant producing DRI that uses oxygen injection (see Figure 6), approximately 90% of the reducing gas is produced via the MIDREX Reformer, and a mixture of...
partial and total oxidation, while the remaining ~10% is produced via in-situ reforming. Temperature drop from Bustle Gas to bed temperature is typically in the order of 100-130 °C.

Figure 7 shows the energy balance for a MIDREX Plant producing HBI, which highlights the energy efficiency of the MIDREX Process, where approximately 69% of the available energy is incorporated into the DRI product. Energy efficiency in a plant producing DRI is higher than in a plant producing HBI.

In summary, all the Shaft Furnace processes in operation today depend on either a reformer or on a CO₂ removal system with a heater to generate the good quality reducing gas that is necessary for efficient reduction of iron ore.

Why is a good quality reducing gas needed?

The “easy” reduction of iron ore, from hematite (Fe₂O₃) to wustite (FeO), where 33% of the oxygen in the ore is removed, is carried out rapidly in the upper 15-20% of the reduction zone. The “difficult” reduction from FeO to Fe occurs slowly in the 80-85% remainder of the reduction zone, and is the factor which limits the production rate.

A good quality reducing gas is needed because:

- The “difficult” reduction from FeO to Fe occurs slowly in the lower 80-85% of the reduction zone.
- The limiting factor is the diffusion of the reducing gases (H₂ and CO) to the FeO/Fe reaction boundary inside the pellet (or lump), the chemical reaction at the reaction boundary proper, and the diffusion of the products of reaction (H₂O and CO₂) towards the outside of the pellet.

- Good quality gas increases the speed at which the pellet is reduced, while poor quality gas reduces the speed of reduction.
- Diffusion is faster and productivity increases with higher bed temperatures.

Typically, the MIDREX Process uses a bustle gas quality of 10.

<table>
<thead>
<tr>
<th>Reductants</th>
<th>Oxidants</th>
</tr>
</thead>
<tbody>
<tr>
<td>(H₂ + CO)</td>
<td>(H₂O + CO₂)</td>
</tr>
</tbody>
</table>

Reductants / Oxidants = 10;

or degree of oxidation = \( \frac{\text{Ox.}}{(\text{Ox.} + \text{Red.})} \) = 0.09

In-situ reforming typically increases the gas quality above 10 (oxidation degree < 0.09) after the in-situ reforming zone.

The quality of the gas entering the “easy” reduction zone is typically ~ 3.0 (oxidation degree ~ 0.25), while the typical quality of top gas is ~ 2.0 (oxidation degree ~0.33). However, it should be stressed that a reducing gas quality of 2.0 or less (oxidation degree of 0.33 or more) thermodynamically cannot reduce the FeO to Fe at normal bed temperatures in the “difficult” reduction zone. In other words, the reducing potential of the Bustle Gas is almost totally used up in the “difficult” reduction zone before it is used in the “easy” reduction of ore from Fe₂O₃ to FeO. A significant reduction in the quality of the Bustle Gas will therefore have a significant effect on the volume of Bustle Gas that must be used to achieve the final reduction from FeO to Fe, which is the step that limits the production of DRI (or HBI). This, in turn, would significantly affect the sizing and efficiencies of all the equipment in the plant (Shaft Furnace, scrubbers, compressors, etc). For this reason, good quality reducing gas is required for efficient operation of the plant.
What limits in-situ reforming?

The amount of in-situ reforming that can be achieved is severely limited by the high bed temperature required to achieve good productivity and/or good HBI quality, on the one hand, and the harmful effects of high reducing gas temperatures on plant operations, on the other. We will now analyze the above statement in more detail.

The ability to produce reducing gas through in-situ reforming is limited in a different manner in the different plants. In Saldanha the situation is quite simple: a lack of natural gas and the high cost of LFG which could be used to generate additional reducing gas through in-situ reforming unattractively at normal DRI price levels. The reducing gas that enters the Shaft Furnace has a gas composition (with minimum addition of LPG) sufficient to minimize the occurrence of the exothermic methanation reaction. As a result, the bed temperature after the in-situ reaction zone is essentially the same as (or slightly higher than) the bustle gas temperature. Therefore, all the reducing gas required for reduction of the iron ore to DRI is supplied by the CO₂ removal system, which strips CO₂ from the top gas recycled from the MIDREX Shaft Furnace and from the make-up top gas coming from the COREX Furnace.

At OPCO, the temperature of the reducing gas is lower than in a regular MIDREX Plant, as the reducing gas temperature is limited by the pre-existing reheaters. Also, as the plant produces HBI, which requires a certain minimum DRI discharge temperature for the production of good quality hot briquettes, and in-situ reforming reduces bed temperature, there is a limit on how much in-situ reforming can be achieved before the bed is cooled too much. Because of the reducing gas temperature limitation on the one side, and the bed temperature limitation on the other side, OPCO is only able to produce approximately 2% of its reducing gas via in-situ reforming.

In a standard MIDREX Plant that produces HBI, the same limitation of minimum bed temperature exists to ensure sufficient temperature for the production of good quality briquettes. As the MIDREX Reformer puts out a high temperature reformed gas, more in-situ reforming can be done (typically generating ~5% of reducing gas), which makes good use of the temperature differential that is available. Some oxygen injection can be practiced in HBI plants but it is limited by the temperature increase that is experienced in the reducing gas. To resist higher reducing gas temperatures without generating excessive sticking, coating of the raw material is required (~1 Kg coating / ton of oxide is used in DRI plants), but this coating will also prevent the formation of good quality briquettes (resistant in drop tests). For this reason, MIDREX Plants producing HBI use little or no coating.

In the standard MIDREX Plant that produces DRI, as there are no briquettes to be formed, coating of the raw material is not a limitation so higher reducing gas temperatures can be tolerated, and on the other hand, lower bed temperatures can also be tolerated. Therefore, it is in plants that produce DRI that in-situ reforming can be maximized, as the temperature differential between the reducing gas temperature and the bed temperature can be maximized.

But even in plants that produce DRI there are limits. The reducing gas temperature is limited on the high side by:

- The tendency of the reduced ore to cluster. Bustle Gas temperatures can be increased to ~1000 °C with the use of coating.
- Potential buildup of dust and fines on the walls of the furnace.
- Risk of clustering after an abrupt shutdown if the DRI material in the furnace cannot be cooled or moved.
- Increased generation of fines at high bustle gas temperatures.

The bed temperature is limited on the low side by:

- The need to achieve high productivity in an existing furnace volume.

Therefore, the ΔT available in plants producing DRI is sufficient for somewhat higher levels of in-situ reforming (~ 10% of the total reforming required), as both higher reducing gas temperature and lower bed temperature than in plants producing HBI are possible. Higher reducing gas temperatures are practiced in plants producing DRI. The lower bed temperatures are theoretically possible but plants do not seek them, in practice. Lower bed temperatures are not practiced in plants producing DRI because, if the bed temperature is reduced to increase the in-situ reforming, the plant productivity will drop. While the in-situ reforming is roughly proportional to the temperature drop (a 10% production of reducing gas requires an approximate 100°C temperature drop), the kinetics of reduction is affected exponentially by the temperature drop. The only theoretical way to compensate the lower bed temperatures (lower reaction velocities) is to increase the volume of the furnace significantly (increasing the residence time significantly), or reduce the production rate significantly, both of which make the operation lower bed temperature uneconomical.

Conclusions

The limited availability for in-situ reforming restricts the amount of in-situ reforming that can be achieved. We have observed the following tendencies regarding in-situ reforming at MIDREX Plants:

- Maximize the bed temperatures in the Shaft Furnace to maximize productivity by increasing the reduction kinetics. This tends to reduce in-situ reforming.
- Back down somewhat from extremely high reducing gas temperatures to reduce fines generation. This also tends to reduce in-situ reforming.
- Increase reducing gas production capacity via:
  - Expansion of the MIDREX® Reformer (recently Sidor, Siderca, and previously others).
  - Preferential use of Partial Oxidation (OXY™) and reduction in the use of total oxidation.
  (The use of equipment to remove CO₂ is not used in MIDREX Plants, as it requires a higher capital cost and a higher operating cost than the MIDREX Reformer)

In summary, the technological tendency in MIDREX Plants is to optimize the use of in-situ reforming to maximize production and product quality, and to increase production (if necessary) through reformer expansions and the use of partial oxidation to increase bed temperatures.
FROM ONE “K” TO ANOTHER

During the early 1980s, recession in the US caused a downturn in the metals industries worldwide, and world steel production stagnated at around 700 Mt/y from 1980 to 1987. Willy Korf’s empire, built on a large amount of debt, began to crumble. By 1983, he was in bankruptcy and forced to sell off parts of his holdings. Among the interested buyers for Midrex was a major Japanese steel company. Kobe Steel had built the MIDREX® Plant in Qatar and was impressed with the technology and in 1984, Kobe purchased Midrex. The intent was not to utilize the technology in its operations, but to earn a profit for its Engineering & Machinery Division from selling plants.

MAKING DRI PORTABLE

In the early 1980s, the State of Sabah in Malaysia began developing an industrial complex on Labuan Island, near Borneo, to make use of extensive natural gas reserves. The complex was to include a methanol plant, power plant, and direct reduction facility. The government contracted with Midrex to build a plant to produce a new product, hot briquetted iron, for sale on the open market. Although some MIDREX Plants sold DRI, it is not the ideal merchant product because of its tendency to reoxidize and the handling problems it causes in meltshops not designed for its use. HBI, however, can be stored and handled like scrap, and melted using existing equipment.

The design of a hot briquetted iron plant presented many challenges, because it was necessary to eliminate the cooling zone, discharge the DRI hot from the shaft furnace, and briquette it. Midrex determined that a conical shaped bottom was the best approach. A flat bottom system with multiple mechanical discharge devices was ruled out because of concerns about high wear of the mechanical parts and frequent downtime due to buildup of material on the bottom of the furnace. High burden pressure at the bottom of the furnace has a tendency to compress the hot, malleable metallic DRI onto the bottom surface. In cases where multiple mechanical discharge devices would be used, there was a concern that failure of a mechanical unit would create a stagnant column of material in the shaft furnace, resulting in overheating and severe cluster formation due to prolonged exposure to the hot gases entering the shaft furnace.

The Sabah Plant started up in late 1984. It was built without a cooling gas inlet device, since cooling was not required. However, Midrex soon discovered that material flow problems were endemic with this design, and an “easy-flow” device, similar to the cooling gas inlet, was added. This worked well, and has become a standard part of MIDREX design.

Another difficulty was breaking the string of briquettes. They are produced in strings two wide, and thus must be broken in two dimensions. The first breaker design incorporated a star arrangement, which was not satisfactory. This was modified to the present hammer mill design.

With the success of the Sabah Gas Plant (now owned by Amsteel Mills), Midrex had developed a new technology.
There are now eight operating MIDREX HBI Modules. The total accumulated production from these facilities is over 70 million tons.

**DRI: AN IDEA WHOSE TIME HAS COME**

By the late 1980s, the recession had ended, and world steel production began increasing. Continued mini-mill growth increased the “scrap intensity of steelmaking.” This pressure on scrap supplies, and higher prices, increased demand for DRI.

In 1987, Midrex experienced a breakthrough with the signing of contracts for three new facilities, OPCO, VENPRECAR, and Essar Steel.

**OPCO**

In 1981, Midrex began discussions with CVG Ferrominera Orinoco of Venezuela about modifying an idled direct reduction facility in Venezuela. A feasibility study confirmed the viability of the project to produce HBI for merchant sale, and a contract was signed with Kobe Steel in December 1987 to execute the project. This was a unique job in several respects. First, it involved the use of existing steam reformers paired with a new MIDREX® Shaft Furnace. Second, the new shaft furnace was the first MEGAMOD® design, capable of one million tons per year. Third, Kobe Steel would lease the plant, modify it, operate it for a number of years, then turn it back to CVG. The plant, dubbed OPCO, started up in 1989.

**VENPRECAR**

Midrex signed a contract with SIVENSA, Venezuela’s largest private steelmaker, to build a 600,000 t/y HBI plant. Start-up of the VENPRECAR Plant (originally known as SIDECAR) was in 1990.

**Essar Steel**

Midrex contracted with Essar Steel of India to relocate two idled MIDREX Plants from Germany to India and convert them to produce HBI. Start-up was in 1990.

Following upon the successful construction and start-up of these three facilities, Midrex entered a time of unprecedented demand for DR plants. This was driven by a number of factors:

- The US economic expansion of the 1990s, the longest in history
- The growth of mini-mills – in the US, EAF production grew 40% from 1985-1996
- The movement of EAF steel producers into higher quality products via innovations such as thin slab casting
- The need for clean charge materials to produce these grades of steel
- Increasing demands on scrap supplies and the resulting price increases – from January 1992 - January 1994, the price of No. 1 HMS rose from $84/ton to $135/ton, shown in Figure 1
As a result of this high DRI demand, there were 18 MIDREX Modules started up from 1992-2000, with a total capacity of nearly 14 million tons per year and an installed value of about $2.1 billion. Each year since 1987, MIDREX Plants have produced over 60 percent of the world’s DRI, shown in Figure 2.

THE MEGAMOD
As early as 1976, Midrex had discussed the idea of a plant to produce one million tons per year. This would have major economic benefits, since the cost of a process plant does not increase linearly with capacity. Thus, larger plants have a lower capital cost per ton of output. The largest MIDREX Plant built prior to 1990 was the ANSDK facility in Egypt, with a rated capacity of 0.716 Mt/y, using a 5.5 m diameter furnace.

During the design of the OPCO Project, it was decided to incorporate a 6.5 m diameter shaft furnace to allow for the production of 0.83 Mt of HBI annually. Although the 6.5 m furnace is capable of producing over one million tons per year with a standard MIDREX Reformer, the original OPCO Plant was limited to 0.83 Mt/y because of the use of existing steam reformers. In 1996, a new “mini” MIDREX® Reformer was added, allowing the plant to produce 1 Mt/y.

Experience with the OPCO furnace was favorable and the design has proven to be very flexible with respect to iron ore use. The plant has produced over its rated capacity when required by market conditions, operating with up to 50 percent lump ore.

Eight MEGAMOD Shaft Furnaces have been built in Venezuela (2), India, Mexico, the United States, Trinidad, South Africa, and Korea.

EXPANDING THE ENVELOPE
In addition to hot briquetting and the MEGAMOD, Midrex continued to develop the technology to improve operating efficiency, reduce maintenance requirements, and improve the economic viability of the process.

Multiple reductant options
Midrex supplied shaft furnaces for two projects using COREX™ Offgas as the reductant - Saldanha Steel in South Africa and Hanbo Steel in Korea.

Lower energy consumption
State-of-the-art MIDREX Plants can incorporate up to five stages of heat recovery. MIDREX Plants consistently achieve the lowest natural gas consumption in the industry.

Flexibility in iron ore use
Midrex continued to investigate suitable iron ores, and design plants to incorporate the widest range of feed materials possible. The Saldanha furnace was designed to accept up to 70 percent lump ore.

Oxide Coating and Oxygen Injection
One of the limiting factors for production in MIDREX Plants is material sticking in the shaft furnace at high temperatures. The use of limestone or other coatings on the iron ore pellets and lump enables an increase in reduction temperature (through the use of oxygen injection to the reducing gas) without sticking.

REBIRTH OF COAL-BASED TECHNOLOGY
In the 1960s, the Midrex Division of Surface Combustion developed the Heat Fast Process for reducing iron ore using coal in a rotary hearth furnace. A two million dollar demonstration plant was built in Cooley, Minnesota, and 9,000 tons of the DRI was tested by the US Bureau of Mines in an experimental blast furnace in Bruceton, Pennsylvania. This was believed to be the best use for the product because its high sulfur content would limit use in electric furnaces. While the technical results of this trial were good, an economic analysis showed that there was no benefit in hot metal cost by using Heat Fast DRI versus the standard charge of 100 percent iron oxide pellets. Surface Combustion then stopped work on the process and concentrated on the gas-based MIDREX Process.

Several times during the next 25 years, especially when natural gas prices increased, Midrex considered resurrecting Heat Fast as a coal-based process.

In 1989, the effort began in earnest and Kobe Steel, Ltd. (KSL) became a development partner. The process was renamed “FASTMET®.” A 150 kg/h process simulator, with a 2.7 meter diameter hearth, was built at the Midrex Technical Center. Over 100 campaigns were conducted from 1992-94. Based on this success, KSL constructed a 8.5 meter diameter, 2.5 t/h demonstration plant at its Kakogawa Works in Japan. The facility started up in 1995 and was the world’s first rotary hearth DR plant to make highly metallized DRI. During the late 1990s, Midrex and KSL embarked on a concerted effort to contract the first commercial FASTMET Plant.

The concluding part of this series will discuss the downturn and subsequent recovery of the world steel industry, the present strong market for MIDREX Plants, and the focus of technical and commercial developments for the future.
30 Year Anniversary Celebration

Midrex Technologies celebrated thirty years of people, places and the MIDREX® Process with an anniversary dinner for its employees in late September. The event took an enjoyable look back at Midrex's rich and colorful history in the industry. As part of the night, special recognition awards were given to the surviving founders of the MIDREX Process and their families. Filled with laughter and fun, the night was a fitting tribute to people that everyday continue to make the company an innovator and success in the iron and steel industry.
AISTech 2004
Nashville, TN

The AISTech 2004 was a success for both its sponsors and exhibitors this year featuring international technologies from the world over. Midrex was represented through both technical presentation and our informational booth.


MIDREX® Hot DRI Plant Planned to Supply MEGASTEEL
Lion Diversified Holdings Signs MOU for 1.54 Mt/y HDRI Plant

Midrex Technologies, Inc. has announced that it has signed a Memorandum of Understanding with Lion Diversified Holdings, Berhad, Kuala Lumpur, Malaysia to enter into a contract for the construction of a 1,540,000 tonnes per year MIDREX® Hot Direct Reduced Iron Plant in Malaysia.

The proposed MIDREX Plant will be located at Lion’s Banting, Selangor, Malaysia Site and will produce Hot Direct Reduced Iron (HDRI) for on-site consumption via Hot Transport at Lion’s three Electric Arc Furnaces at the adjacent MEGASTEEL and Amsteel II steel mills. The Plant will also be capable of producing hot briquetted iron in addition to HDRI.

Midrex projects the finalized contract in Fall of 2004 with commissioning of the plant 4th quarter 2006.

The new plant will use proven MIDREX® Direct Reduction Technology with pre-engineering scheduled to begin immediately. Fueled by Natural Gas, the MIDREX® Process has the lowest greenhouse gas emissions and is also the most energy efficient technology available to convert iron ore to DRI.