DIRECT FROM MIDREX

3rd Quarter 1999

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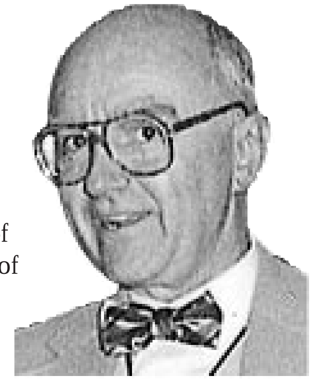
All tons referred to are metric tons (t) or million metric tons (Mt)

In Memoriam...

THE PASSING OF A PIONEER



Charles W. "Sanz" Sanzenbacher

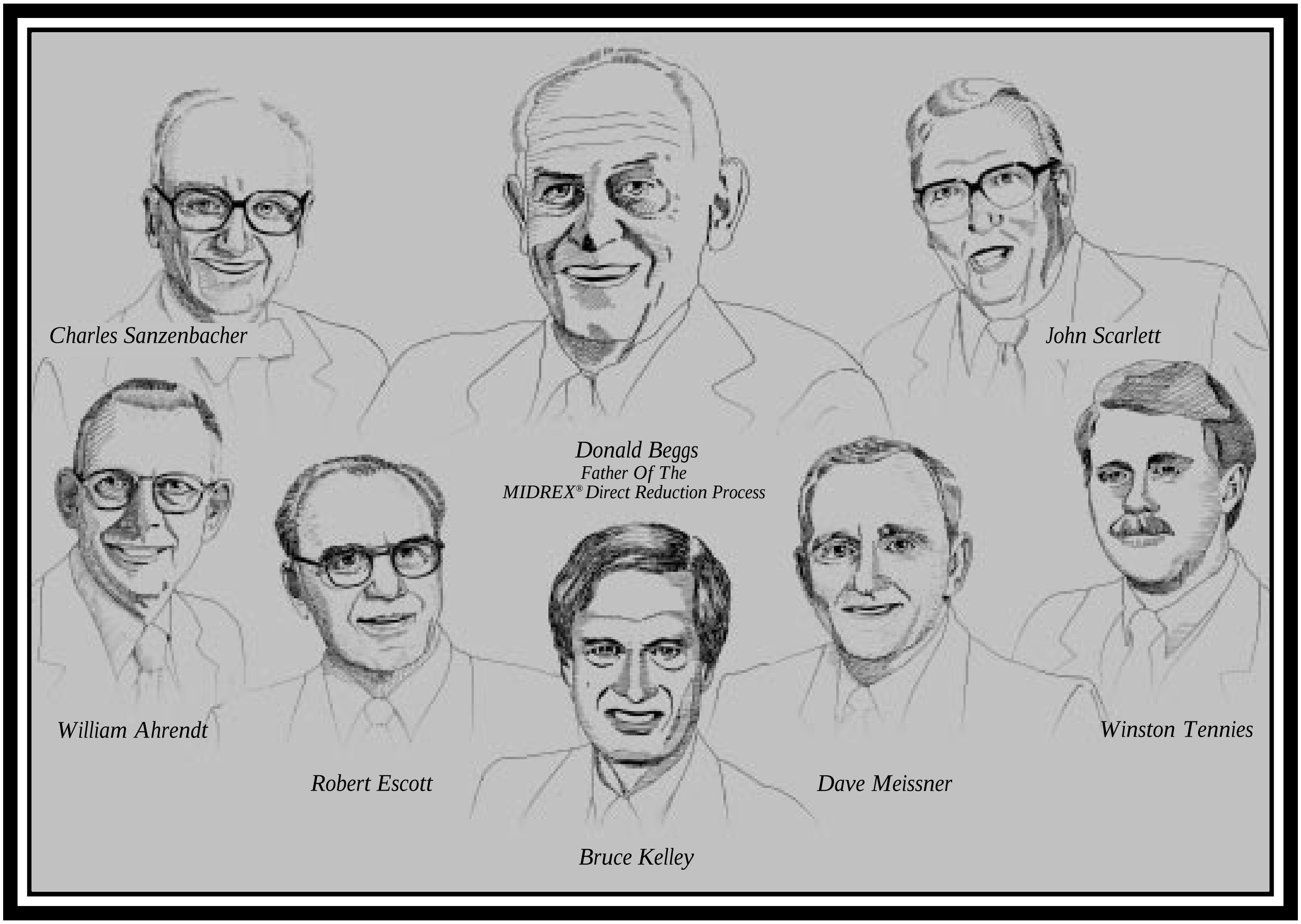
The Midrex family was saddened recently by the passing of Charles W. Sanzenbacher, the retired Vice President of Research and Development for Midrex. On July 11, 1999, Chuck, or "Sanz" as he was known to many of his friends, after a hospitalization of several weeks duration, passed away. After graduating from the Case School of Applied Science (now Case Western Reserve University) with a degree in Chemical Engineering, he served in Europe during World War II as a B-17 bomber navigator with the Eighth US Army Air Corps. In 1948, he began working with Surface Combustion Corp., the predecessor company to Midrex. At Surface he worked in various research and product development functions, and was responsible for developing a line of gas generators to produce inert, carburizing, and reducing gases for the steel and heat treating industries. The hydrogen gas generator he developed is the basis for the design of the MIDREX™ Reformer we use today.

Don Beggs is acknowledged to be the "Father of the MIDREX® Process." While Don was the father, Chuck was his right hand man whom he relied upon for advice on all the process aspects of the development. Once the first MIDREX® Plant went into operation, Chuck became the master process problem solver; and, as would be expected with a first-of-a-kind plant, there were plenty of problems to be solved. Chuck spent much of his time in the early MIDREX Plants learning their problems and developing the solutions that turned the MIDREX Process into the dominant direct reduction technology.

Bow Tie Day. Back, from left: Phil Warnke, Winston Tennies, Carl Sisco, Bruce Kelley, Dave Meissner, Bob Escott, Chuck Sanzenbacher. Front row, from left: Marv Tester, Karen Keller, Jim Beck, Jack Scarlett

MISSION STATEMENT

Midrex Direct Reduction Corporation will lead in the ironmaking technology industry by supplying superior quality services that provide good value for our clients. We will meet or exceed performance expectations, execute projects on time, enhance existing product lines, and develop or acquire new technologies. Our employees are the key to our success, and we are committed to encouraging them to grow professionally and personally.



Above: Portion of the Pioneers of the MIDREX Process plaque on display in the Midrex Corporate Office

During the course of his professional career, Chuck was the inventor of 21 patents and the author of numerous papers on direct reduction. He was active in the leadership of the local section of the American Institute of Chemical Engineers and was a registered professional engineer in the state of Ohio.

Chuck was an exemplary professional engineer with outstanding technical skills and the highest ethical standards. But what really set him apart from everyone else were his human qualities that inspired others to excel. When you did a good job, he always recognized it. When you were having difficulties, he was always there with a pat on the shoulder and a word of encouragement. When you did not perform up to your potential, he was there to provide the inspiration you needed to do better the next time. As a result, he contributed to the personal and professional development of everyone with whom he came in contact.

Chuck had a ready smile and a wonderful sense of humor. He was famous for drawing cartoons to commemorate events and achievements. Over his lifetime, he must have drawn hundreds of cartoons, many featuring Snoopy or other members of the Peanuts gang. Many people in the Midrex family have cartoons they treasure as their remembrance of a significant event in their lives.

One of Chuck's trademarks was his bow tie. He always wore a bow tie because it was safer when working around machinery. This led to the annual tradition of bow tie day when everyone who worked for him would wear a bow tie in his honor. As can be seen in the picture on the left, anyone who forgot to wear a bow tie on the appointed day was provided one made out of crepe paper.

His technical leadership, his sense of humor, his recognition of accomplishment, and his constant encouragement all worked together to develop a very high esprit de corps in the people who worked with him.

Midrex recently hung a plaque recognizing the "pioneers" of the MIDREX Process in our lobby. This plaque contains a characterization of eight people who were instrumental in the development of the MIDREX Process. A copy of this characterization is shown above. As the last of the eight pioneers still working at Midrex, we would like to recognize Chuck as an engineer, a leader, a role model, and most of all a friend. We miss you. Fly high, Chuck.

With love and admiration,

Bruce Dave Win

Bruce Kelley, Vice President–Technology & Engineering
Dave Meissner, Manager–Research & Development
Winston Tennies, President

RIDING THE ROLLER COASTER

Steel and Scrap Cycles

By John Kopfle
Manager-Marketing and Planning
Midrex Direct Reduction Corporation

As in most commodity businesses, the steel market has traditionally been quite cyclical, with steel (and scrap) cycles generally running for 6-10 years. An excellent, although leading, indicator of steel market cycles is the No. 1 Heavy Melting Steel Scrap Composite Price (No. 1 HMS). This is an average of transaction prices in Chicago, Pittsburgh, and Philadelphia, and is the most widely quoted scrap price worldwide. Figure 1 shows the No. 1 HMS for 1979 to the present (all tons used are metric tons).

There have been three cycles (peak-to-peak) during the last 20 years: Cycle 1 lasted 120 months, from March 1979 until February 1989; Cycle 2 lasted 84 months, from February 1989 until January 1996; and Cycle 3 has a duration of 42 months, from January 1996 until the present.

As the data shows, scrap prices can increase or decrease as much as 50 percent in a short period of time. Why is there such a large fluctuation? One reason is that the scrap market is very much a free market, with many buyers and sellers and good information exchange. Also, obsolete scrap has a low intrinsic value. Another factor is the capital intensity of the steel industry. As noted in a recent article:

"Since the steel industry is very capital-intensive, the reactive elasticity of steel prices on deficit or surplus situations in the steel market is very high. A 5% surplus capacity can lead to a 20% price drop and a 5% deficit can lead to the contrary." (1)

Déjà Vu: the Mid-1990s versus the 1980s

Cycle No. 2 did not contain a severe, sustained price drop, and thus is not especially relevant for Cycle No. 3. For purposes of this paper, we will compare and contrast Cycles No. 1 and No. 3. Figures 2 and 3 contains two graphs of the cycles. Figure 2 shows actual prices (in nominal dollars) and Figure 3 shows

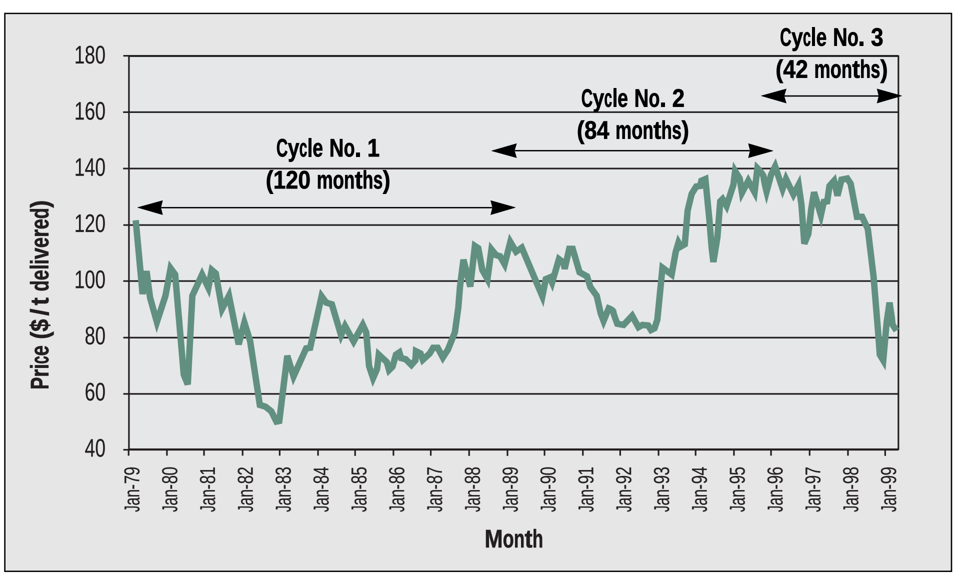


Figure 1 HMS History

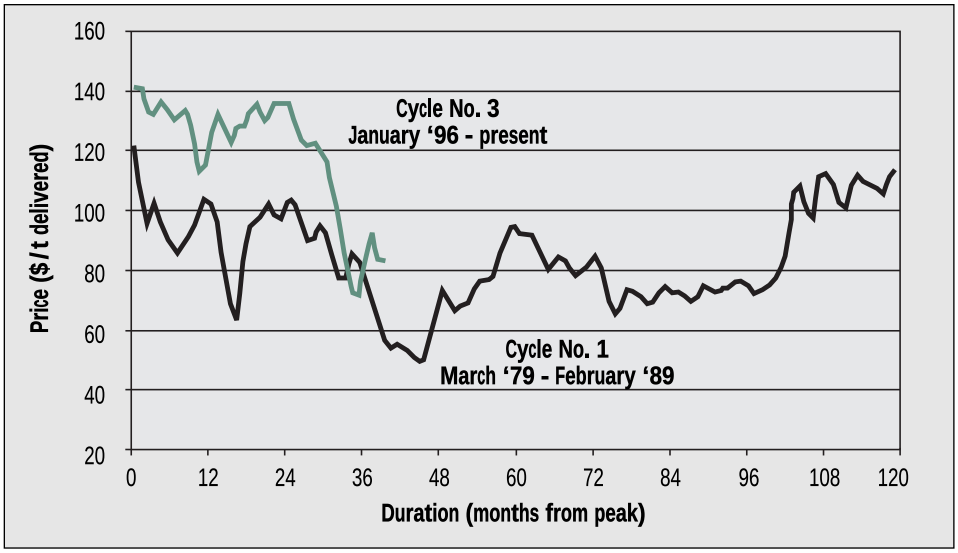


Figure 2 HMS Price Comparison

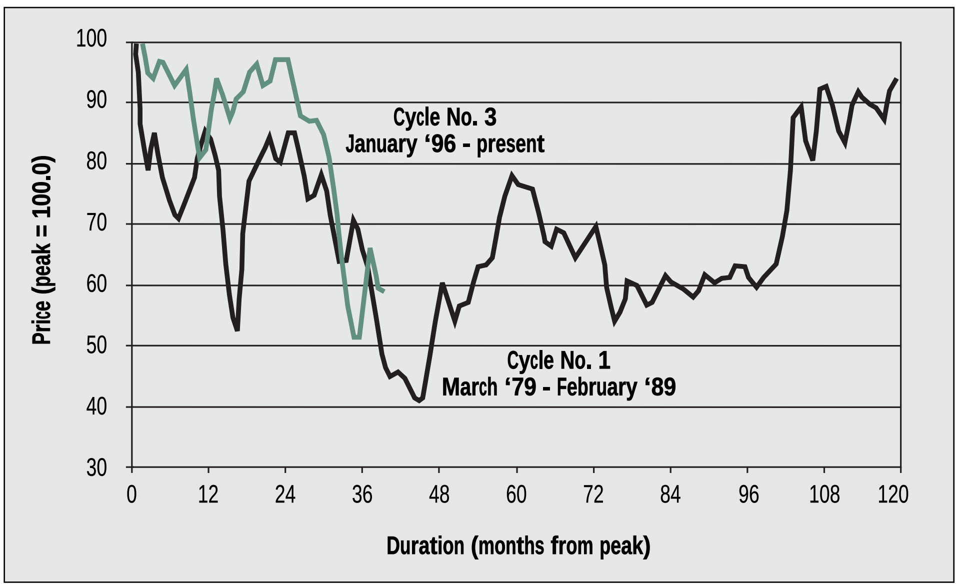


Figure 3 HMS Normalized Comparison

prices normalized, with the initial peak in each cycle set at 100.0.

First, note that the price level of the January 1996 peak was significantly higher, at $140.51/t, versus $121.40/t in March 1979. Also, the price fell in 1982 to $49.84/t. Newcomers to the industry (and even some old-timers with short memories) may forget that just over six years ago, the No. 1 HMS Price was less than $50/t. This puts today's consternation about scrap prices in perspective.

Figure 3 shows that the decline in prices for Cycles No. 1 and No. 3 was similar in percentage terms. During Cycle No. 1, prices were at 50 percent of the peak at 39 months. During Cycle No. 3, prices reached a trough of 51 percent at 36 months.

The Future

When will prices rebound? No one knows for sure, but they have slowly increased during the first half of 1999, and the consensus is that the bottom has been passed. The price increases occurred for four reasons: 1) lower prices and winter weather in America and Europe lead to a slowdown of scrap collections 2) abundant scrap inventories are now becoming depleted and need to be replenished 3) a number of merchant pig iron facilities have closed, driving up the price of pig iron and making DRI/HBI more attractive, and 4) Merchant DRI/HBI facilities have reduced their production reducing the amount of DRI/HBI available on the open market.

Over the long term, the steel and scrap markets will recover, given steel's importance to the world's economies. Scrap and other EAF raw materials will play an increasingly important role. In this recovery, the fundamental factors which caused scrap, HBI, and pig iron prices to increase substantially from the early 1980s to today will still apply. These include: 1) a continuing increase in world EAF production (from 20 to 34 percent of world steel production), and 2) an accompanying increase in the scrap intensity of steelmaking (from 25 to over 45 percent in the US), resulting in higher scrap demand.

Over the past 10-15 years, pricing data shows that steelmakers around the world value HBI equivalent to prime scrap; i.e., No. 1 Bundles in North America and Western Europe, and shredded scrap in the rest of the world. Recent data during this downturn shows that these relationships still hold, and Midrex expects they will continue to do so.

Conclusion

Although riding the roller coaster of the steel industry may not be as enjoyable as the roller coaster at the amusement park, in both cases when the highs and lows level out, we can be pretty sure that we will end up with our feet back on solid ground. A comparison of scrap prices during the present steel market downturn and the one in the early 1980s shows the declining percentages closely track one another. The industry rebounded from the earlier recession and it will come back from this one, too. Direct reduced iron and hot briquetted iron prices, which have dropped in tandem with scrap prices, will recover as well. The fundamental factors driving DRI demand will remain valid; i.e., growth in electric furnace steel production, the movement of EAF producers into higher quality markets, and an insufficient supply of prime scrap.

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[1]*Woedlinger, Reinhard, et al: "The Steel World After the Asian Crisis," presented to 4th Asian Steel Summit, Hong Kong, August 24-25, 1998, p.38*

GASIFICATION AND THE MIDREX® DIRECT REDUCTION PROCESS

A POWERFUL COMBINATION FOR MAKING DRI

By Rob B. Cheeley
Senior Sales Engineer
Midrex Direct Reduction Corporation

INTRODUCTION

The use of direct reduced iron (DRI) continues to rise, with a record high of 37.1 million tons of DRI produced in 1998. However, the production of DRI is concentrated in just a few countries, as Mexico, India, Venezuela, and five Middle Eastern countries combined to produce 68% of the world's DRI in 1998. In fact, 8 of the 13 largest steel producing countries produced no DRI and four others, the U.S., Germany, Russia, and Brazil, only produced a combined 4.1 million tons of DRI. Why is so little DRI produced in the major steelmaking regions?

One reason is that natural gas is the primary fuel source for almost all DRI produced. Thus, in countries with relatively high natural gas costs or limited availability of natural gas (both are applicable to Europe and most of Asia), DRI has not been an economically viable option.

One solution is the use of a gasifier to generate the necessary reducing gases for converting iron oxide into DRI. The typical gasifier fuels, coal and petroleum refining by-products (heavy fuel oil and petroleum coke), are easily transported and available at economically attractive prices in most parts of the world.

The use of a gasifier coupled to a MIDREX™ Direct Reduction Plant presents a strategic opportunity for steelmakers to manufacture DRI at attractive costs in countries throughout the world. This is particularly true for steelmakers in East Asia, India, South Africa, and Brazil. In addition, a gasifier plus a MIDREX Plant is an option for existing integrated steelmakers to replace inefficient or environmentally problematic blast furnace/oxygen furnace (BF/BOF) operations with an alternative means of producing iron.

The world's first gasifier plus DRI plant combination started-up this year at Saldanha Steel in South Africa. This facility includes a COREX® Plant, which uses a melter/gasifier to simultaneously produce pig iron and a by-product synthesis gas which feeds a MIDREX MEGAMOD™. Past *Direct From Midrex* articles, 1st quarter 1994 and 4th quarter 1996, have discussed the COREX/MIDREX combination. This article will concentrate on using commercial gasifiers whose sole function is to generate synthesis gas for feeding MIDREX Plants.

Gasification

Commercial gasifiers have been in operation for over 50 years. While there are distinct differences between each type of gasifier, they all operate on the same basic principles. In general, gasification can be defined as a partial oxidation process in which a carbonaceous fuel (gas, liquid, or solid) reacts at high temperature and usually at high pressure with oxygen and possibly steam to produce a synthesis gas. The synthesis gas contains mostly hydrogen (H_2) and carbon monoxide (CO), but also some water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrogen (N_2), and sulfur compounds (H_2S and COS).

A wide range of carbonaceous fuels have been used in gasifiers. The best fuel sources for the gasifier/MIDREX Plant application are heavy fuel oil, naphtha, and orimulsion (liquid fuels) and petroleum coke and coal (solid fuels).

The gasifier is a pressure vessel that is either refractory lined or has water cooled walls. The fuel, oxygen, and steam (if required) react inside the gasifier at high temperature to produce the synthesis gas. A small amount of slag is produced and removed.

The synthesis gas exiting the gasifier is cooled and scrubbed. Cooling removes most of the water vapor and scrubbing removes the remaining entrained particulates. The final step of the gas cleaning and conditioning step is to remove the acid gases via an amines-based system. The stripped acid gases are then converted into elemental sulfur.

Gasification provides a number of environmental benefits. Commercial gasifiers remove all sulfur compounds as elemental sulfur, and because they oper-

Photo reprinted with permission of Texaco/Alma Rodarte

120 MW Coolwater Coal Gasification Plant

ate at very high temperatures and in a reducing atmosphere, there is no generation of undesired by-products such as phenols, tars, heavy hydrocarbons, SOx, and NOx.

The basic objective of the gasification process is to generate desirable reducing gases for the MIDREX Plant. The key parameters for the reducing gas are the gas quality (or reductants to oxidants ratio) and the H_2/CO ratio. The gas quality is defined as (% H_2 + % CO) / (% H_2O + % CO_2). The MIDREX Process requires the gas quality to be at least 10 in order to efficiently produce DRI. Thus, the gasifier must be designed to achieve this.

The MIDREX Plant is very flexible with regard to the H_2/CO ratio. MIDREX Plants can readily operate using H_2/CO ratios ranging from 100 percent CO to 100 percent H_2, with actual plants having been designed for H_2/CO ratios ranging from 0.5 to 4.0. Typically, synthesis gas produced in a gasification plant has a H_2/CO ratio in the range of 0.5:1 to 1:1.

MIDREX Direct Reduction Process

The MIDREX Process converts iron oxide to DRI in a vertical shaft furnace. This is accomplished as the iron oxide flows downward through the shaft fur-

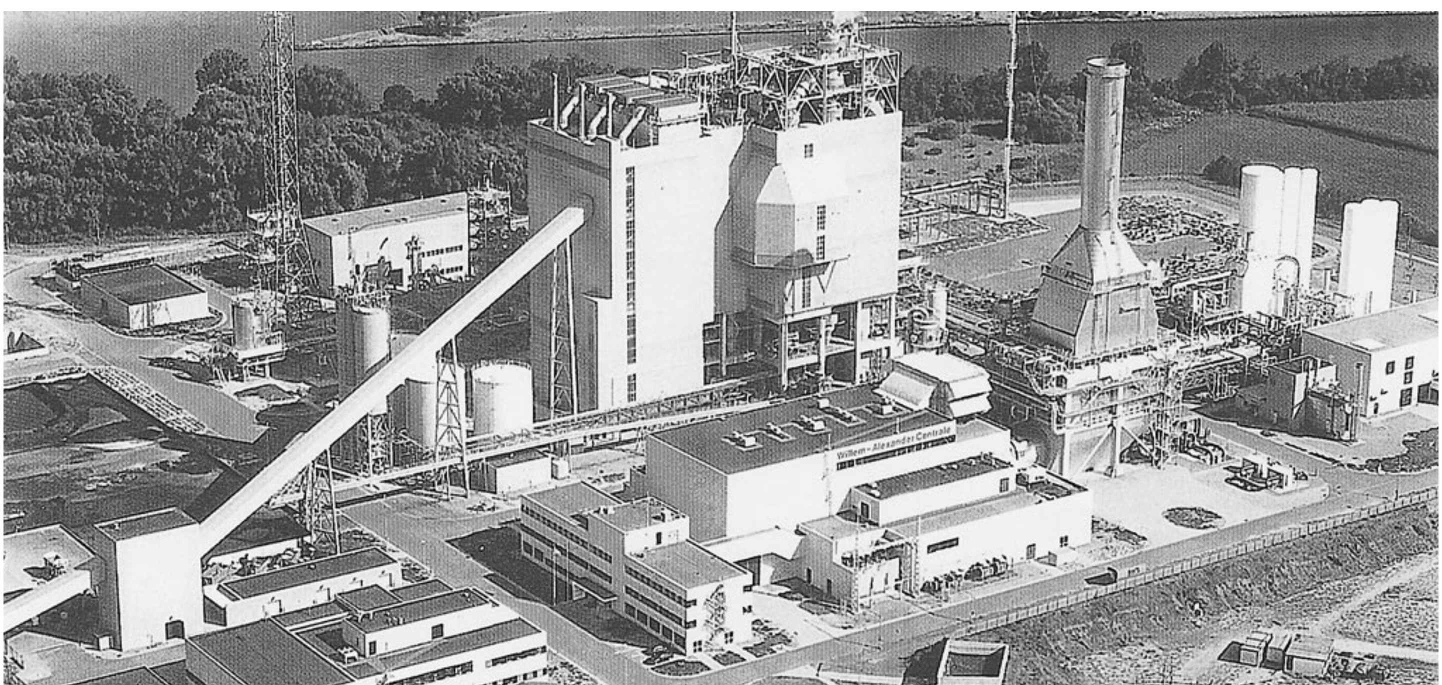

Photo courtesy of Demkolec

253 MW Demkolec Power Plant uses 2,000 t/d coal gasification with Shell process and combined cycle power generation

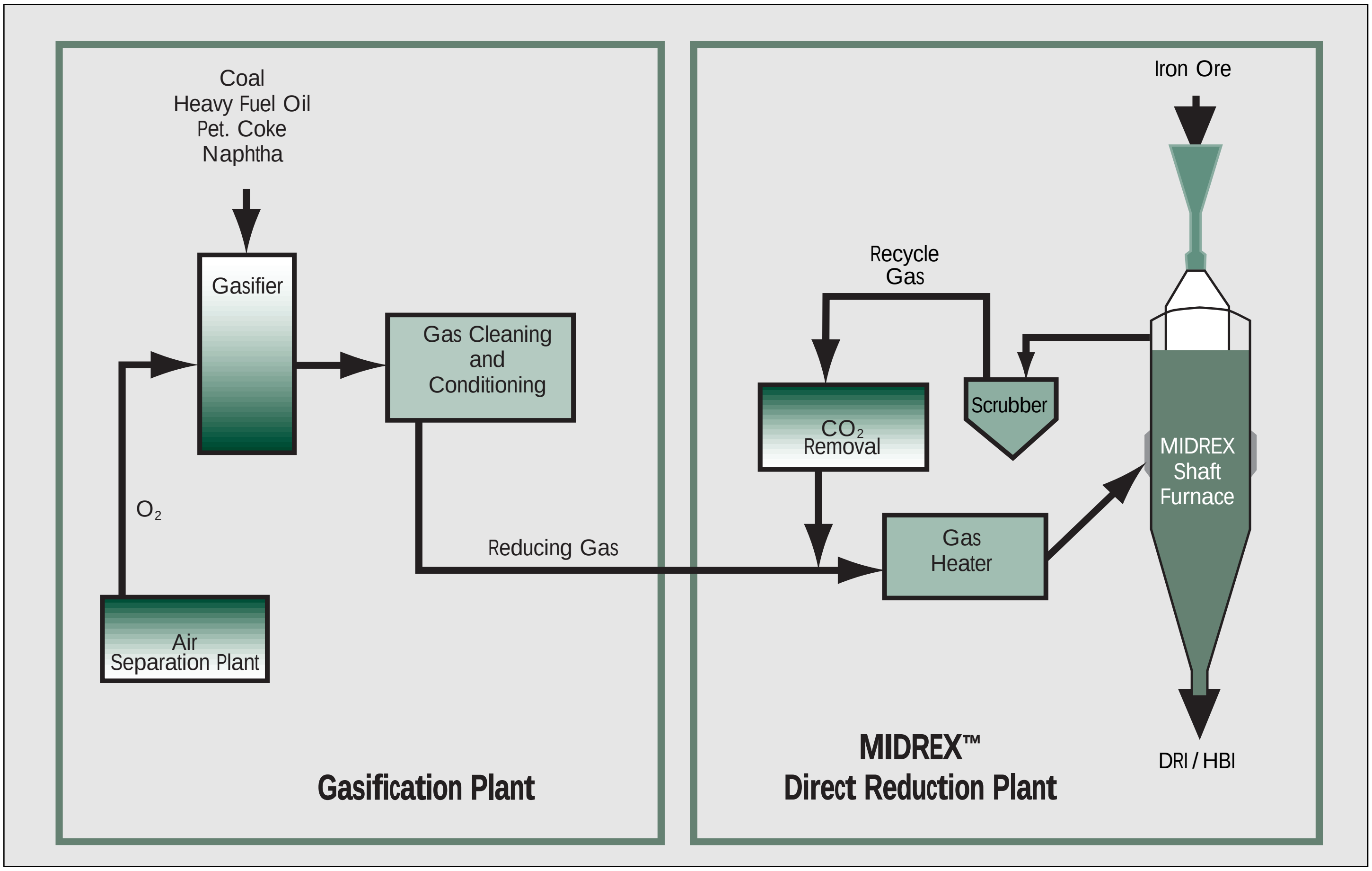

Figure 1 Gasifier/Midrex Flowsheet

nace by gravity, countercurrent to hot reducing gases which are rising through the shaft furnace. The hot reducing gases react with the iron oxide in the upper zone of the shaft furnace, stripping away the chemically bound oxygen.

The reduced iron (DRI) descends to the lower zone of the shaft furnace from which it is continuously discharged. In the lower zone, the DRI can be cooled to 50°C or it can be discharged hot at 700°C directly to an adjacent EAF via the MIDREX HOTLINK™ System.

The spent reducing gases (called top gas) exit the top of the shaft furnace and are scrubbed and cooled to remove entrained particulates and to condense most of the water vapor. The top gas at this point contains too much CO_2 for direct reuse in the shaft furnace. In a conventional MIDREX Plant, the gas is recycled through the MIDREX Reformer. However, when a gasifier is involved the top gas passes through a vacuum pressure swing adsorption system (VPSA) to remove most of the CO_2 before being mixed with fresh synthesis gas and recycled back to the shaft furnace. This mixed gas becomes the reducing gas for the MIDREX Process.

The target reducing gas temperature is 900°C or greater. However, the synthesis gas from the gasification plant and the recycled top gas from the VPSA system are at ambient temperature. Therefore, after mixing they must be heated to 900°C. This is accomplished in a two step process. In the first step, the gases are heated to about 400°C in an indirect contact heat exchanger. In the second step, the gases are heated to 900°C or greater in a partial oxidation reactor in which a small amount of oxygen is mixed with the reducing gas to promote limited combustion, raising the gas temperature to the desired level.

The overall process flowsheet for the gasification system and the MIDREX Plant is shown in Figure 1 and the typical Operating Parameters are shown in Table I.

Integrated Mini-mill

The gasifier/MIDREX Plant combination is ideally used to provide DRI for an integrated mini-mill. The integrated mini-mill would consist of a gasifier, a MIDREX Plant, an Integrated Gasification Combined Cycle (IGCC) power plant, and a steel mill. The only major raw material inputs are the gasifier fuel source and iron oxide to the MIDREX Plant.

The gasifier would be sized to generate enough synthesis gas for both the MIDREX Plant and the power plant. In addition, the oxygen plant within the Gasification Complex would be enlarged to produce enough oxygen for the steel mill's requirements. For both the gasifier and the oxygen plant, excellent economies of scale can be achieved as the units are enlarged.

The on-site power plant would be sized to generate all of the electricity required for the oxygen plant, MIDREX Plant, and the steel mill. In most parts of the world, an IGCC based power plant provides electricity at a significantly reduced cost relative to power from the grid. For example, in Western Europe, power can be generated in gasifiers using high sulfur fuel oils or petroleum coke for prices of US$ 0.03-0.04/kWh. The IGCC based power plant is also a significant advantage in countries with unreliable power grids, such as India and China, and in areas without enough available power.

To minimize power consumption in the EAF, the MIDREX HOTLINK™ system could be used to "hot charge" a significant portion of the DRI directly into an adjacent EAF. It is estimated that hot charging via the MIDREX HOTLINK system can save 140 kWh/t in the steel mill.

		Gasifier	MIDREX MEGAMOD
Product		Synthesis gas	DRI
Annual Capacity		1.2 billion Nm³	1,600,000 t
Input	**Units**	**Per t of DRI**	**Per t of DRI**
Iron oxide	t	--	1.45
Electricity	kW-h	140	150
Oxygen	Nm³	see Note 2	see Note 2
Coal	t	0.5	--
Water	m³	0.8	1.2
Maint. & Supplies	US$	3.00	2.00
Limestone	kg	6	--
Labor	man-hour	0.1	0.1
H.P. Steam credit	t	(0.6)	--
Sulfur credit	kg	(2)	--
Slag credit	kg	(55)	--

Notes:

(1) All of the Gasification Plant consumption rates can vary significantly depending on the specific fuel utilized. The listed values represent "typical" expected values.

(2) The oxygen plant is contained within the Gasification Plant. The gasifier electricity consumption is primarily for the production of oxygen.

(3) The DRI Product Characteristics are: 93% metallization, 2% carbon, and 700°C discharge temperature.

(4) For this table coal was chosen as the gasifier fuel source. Depending on the project location, other fuels such as petroleum coke, heavy fuel oil, naphtha, or orimulsion may be a more economical choice.

Table I Typical Operating Parameters

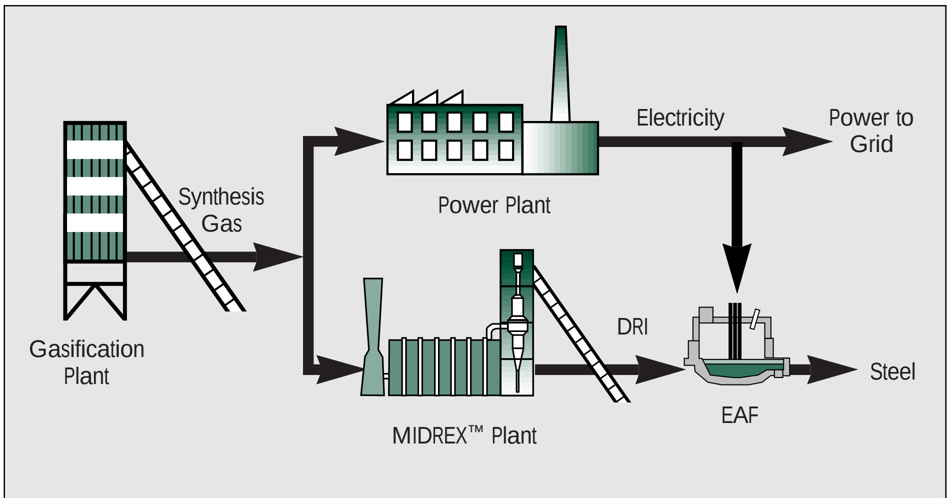

Figure 2 Integrated Mini-mill Flowsheet

The key advantages of the Integrated Mini-mill concept are:

- Production of higher grade steel using "clean" DRI as the primary feedstock in areas with high cost natural gas.
- Replacement of an inefficient BF/BOF with an electric steel making shop.
- Production of higher grades of steel using an environmentally friendly electric steelmaking line, eliminating the need for coke ovens, sinter plants, and other environmentally "undesirable" unit operations in a traditional BF/BOF based steelworks.
- Utilization of low cost coal, and petroleum refining by-products to generate synthesis gas in regions where standard fossil fuel power plants are no longer able to use these high sulfur fuels due to SOx emissions.
- Ability to sell excess electricity to the local power grid.
- Gasifier feedstock flexibility.

The overall process flowsheet for the Integrated Mini-mill is shown in Figure 2.

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. Even better economics can be derived when the project includes a meltshop and an Integrated Gasification Combined Cycle-based power plant. This Integrated Mini-mill complex is able to utilize low cost coal, and petroleum refining by-products to produce reasonably priced DRI and low cost electricity to allow competitive manufacture of liquid steel.

The Integrated Mini-mill application is best suited for the countries of Asia, where DRI is needed, but power and natural gas costs are high. Other possibilities include major iron ore producing areas, such as Brazil, South Africa, India, and the Ukraine, where natural gas is not economically available. The Integrated Mini-mill may provide a viable option for existing integrated steelmakers in the US and Western Europe to replace BF/BOF complexes with electric steelmaking lines and to eliminate the need for environmentally undesirable coke and sinter plants.

Hoeganaes Corporation Awards Contract for Ladle Metallurgy Facility to EMCI

Hoeganaes Corporation has awarded a contract to EMC International, Inc., for the complete, turnkey supply of a Ladle Metallurgy Facility (LMF) for their plant in Gallatin, Tennessee. The LMF will be erected in the existing melt shop scrap handling/charging bay. The facility has a planned start-up of September 1999.

The facility will include EMCI's "EMARC" solid state, hydraulic electrode regulator system, automated alloy and flux addition systems and cored wire feeding. The equipment will include a prefabricated Operator Control Pulpit with adjoining Metallurgical Laboratory housing an optical emission spectrometer. Operation and control of the equipment will be through a PLC-based, Level 1 and Level 1.5 control system with redundant color graphic human-machine interface (HMI) terminals featuring touchscreen control. Stirring of the molten steel will be performed by percolating inert gas through a refractory plug arrangement in the bottom of the ladle or by top lance stirring. Fumes and particulate emission at the LMF will be collected in a lateral draft type fume collection hood and evacuated to a dedicated, modular, pulse jet cleaning baghouse. Ancillary equipment includes a ladle transfer car.

Saldanha Steel – Breaking the Mold

Saldanha Steel

Midrex Direct Reduction Corporation celebrates the start-up of the 804,000 t/y MIDREX™ Shaft Furnace at Saldanha Steel. The first-of-a-kind direct reduction plant is fueled by the offgas from a COREX® Plant. Saldanha Steel's MIDREX™ Plant is the first direct reduction plant to use a synthesis gas as the source of reductant. Offgas from the COREX Plant is cleaned, put through a CO_2 removal system, and fed to a MIDREX Shaft Furnace. In the case of Saldanha Steel, the gas is first fed to a reforming gas buffer station where it can be stored to enable the MIDREX Plant to continue operating if there is an interruption in the supply of reforming gas. Current production rates are around 85 percent of capacity. Improvements to the material handling system, scheduled to be completed in late September, will enable the plant to operate at 100 percent of capacity by early October.

Saldanha Steel plans to produce 1.25 million tons of hot rolled coil per year, which will be exported.

Midrex's start-up and commissioning team and CIL's operations crew are ready to begin production

Commissioning Begins

Construction has been completed on Caribbean Ispat Ltd.'s MIDREX MEGAMOD™ in Port Lisas, Trinidad & Tobago, and at press time the plant was going through commissioning and start-up procedures. The plant is expected to reach full capacity in the third quarter, making it the largest single module direct reduction facility in the world.

MIDREX Strengthens Its New Steelmaking Team and EMCI Builds Up Its Sales Force

Midrex has added a member to its new steelmaking team. Sara Hornby Anderson has joined the company as Product Manager–Steelmaking/Melting. Sara holds a PhD in Industrial Metallurgy and has over 29 years experience working in the steel industry. Prior to joining Midrex, Sara was the Director of Steelmaking Technologies for Goodfellow Technologies, Inc. As part of the Steelmaking Team at Midrex, Sara will help research new techniques for melting DRI and HBI as well as assessing the potential for new applications for DRI and HBI. She will also help identify new business opportunities for Midrex products and technical services in the steelmaking sector.

EMC International, Inc. is pleased to announce that Warren R. (Rusty) Wenner, Jr., has joined the company as a Sales Engineer. Rusty is a graduate of Bowling Green State University and has over 20 years experience in sales to the steel industry prior to his association with EMCI.

Midrex Congratulates Donald Beggs Scholarship Winners

Donald Beggs Scholarship Winners
M. Lorraine Elliot (l), and Andrew Warnke

Hard work has paid off for the children of two Midrex employees who were chosen as the winners of the Donald Beggs Scholarship. M. Lorraine Elliot and Andrew Warnke each receive a $3,000 academic scholarship. Ms. Elliot is the daughter of Antonio Elliot, a Senior Sales Manager at Midrex, and is starting her third year at the University of North Carolina – Chapel Hill. Ms. Elliot is majoring in Economics.

Andrew Warnke is the son of Philip Warnke, a Senior Research Technician at Midrex. Andrew is entering his third year as a Civil Engineering major at North Carolina State University.

Midrex would like to congratulate this year's winners and wish them luck in the future.

QASCO Gives MIDREX Plant Special Accreditation

As Qatar Steel Co. Ltd. celebrated their 100th board meeting on January 27, 1999, special accreditation was given to the MIDREX® Direct Reduction Plant for setting several new production and quality records. One of the new records was for annual production. The new record of 705,868 tons broke the old record of 635,021 tons which was set in 1996.

With two milestones quickly approaching, QASCO has set some ambitious goals. On August 16, 1999, QASCO will celebrate its 21st anniversary. At the same time, they are approaching 11 million tons of DRI produced since the plant began operation. QASCO has challenged themselves to reach the 11 million ton milestone before the August 16 anniversary. There are no major plant upgrades planned during this time so the plant operators will have to rely on their skill and expertise in order to meet the challenge.

Qatar Steel Company Ltd.

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