



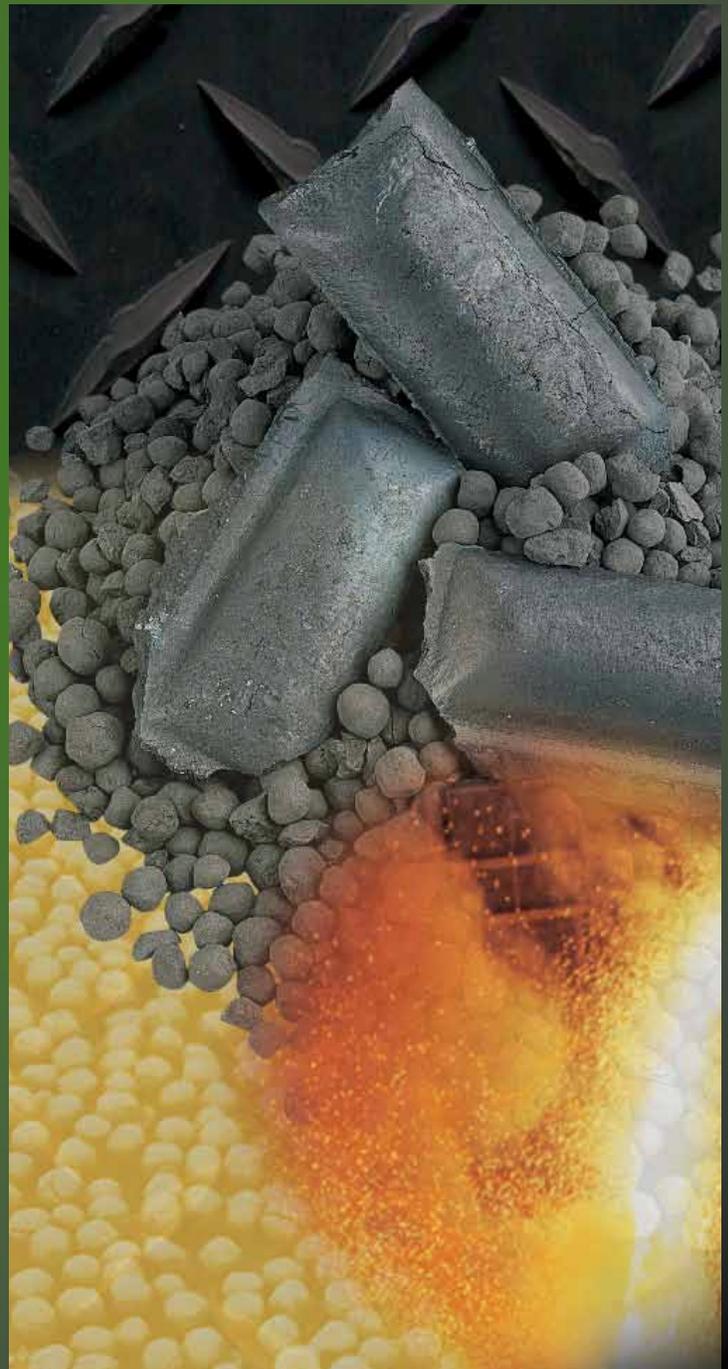
**2ND QUARTER 2010**

# **DIRECT FROM MIDREX**

## **CONTENTS**

- 2 COMMENTARY:  
5 Questions with...  
Stephen C. Montague**
- 5 Massive CO<sub>2</sub> Savings by Use of  
HBI Made with Natural Gas: Blast  
Furnace Economics**
- 10 Environmental Benefits of  
Natural Gas Direct Reduction**
- 14 NEWS & VIEWS:  
MXCOL™ Highlights better way  
to make DRI using Coal**

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## COMMENTARY

### 5 Questions with... Stephen C. Montague

**V**ice-President of Commercial and Technology, Stephen C. Montague, recently took time out from his travels and work to talk about Midrex from a rather unique perspective. Montague began his career at Midrex more than two decades ago and knows both the company and technology quite well. He has had a wide variety of experience, including “hands on” work in plants, plant design, technology development and project development.

#### *Tell us about your career and how you started with Midrex?*

I first started at the company while in college in 1987 as a draftsman on the old style drawing boards. It was about as low as you could start, working on drawings in the pre-CAD era. By my second summer, I advanced to working on my first real project of designing some larger equipment for the interior of the MIDREX® Shaft Furnace. Some of these drawings and designs, under guidance of the Principal Equipment Engineer Gil Whitten, became the basis for the MEGAMODs of the 1990s. That was the start, but it was just the taste of what Midrex had to offer in the next decade.

In 1989 I began helping with the start-up of new plants.. My first assignment was to OPCO (now FMO) in Venezuela, but soon after I was assigned to other locations like Venprecar. I was in the trenches, so to speak, spending months at a time at plant sites. I learned a lot from the experiences and the people I worked with at these sites. The 1990s kept Midrex particularly busy and kept me on the ground out in the field.

In 1994 I spent a full year in India heading up the commissioning and start up of what was our first MIDREX® MEGAMOD at NDIL, now Ispat Industries. By 1997 I was doing the same for IMEXSA (now Arcelor-Mittal Lazaro Cardenas) the 2nd MIDREX MEGAMOD. By the end of the 1990s I worked at Saldanha Steel (now Arcelor-Mittal South Africa) before moving to the Technology Development group as Product Manager. It was about this time that we began designing the SUPER MEGAMOD® and various other advancements and innovations including centrifugal compressors, larger briquetters and hot transport options, all of which have been implemented in new plant construction and design.

In 2001 I became Director of Engineering, and then moved to the commercial group in 2006 as Vice President of Commercial and Technology. Through my entire career at Midrex, I've tried to stay close to the Technology. In fact, I may be the only executive that could walk into a MIDREX® Plant and actually run it. I'm quite proud of that fact. I've been very blessed to have the opportunity to participate in nearly all aspects of the lifecycle of a MIDREX Plant.



**Stephen C. Montague**  
Midrex Vice President of  
Commercial & Technology

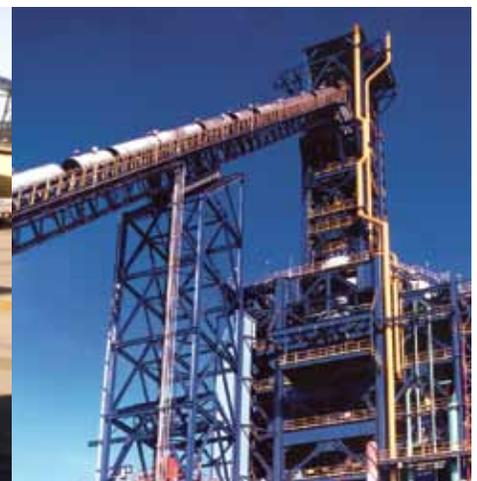
It has given me unique insight to take what I've learned and observed and bring it back full circle into our new designs.

#### *Why was the MIDREX® MEGAMOD such an important milestone?*

The MEGAMOD brought MIDREX® and the DR industry into a new age. Before the 1990s, our previous plants had proven capacities of 400,000 up to 900,000 tons per year, but the larger MEGAMOD quickly demonstrated capacities well over



Miguel Esacaboza & Stephen Montague circa 1997 at start up of ArcelorMittal Lazaro Cardenas (formerly IMEXSA).





## COMMENTARY

*Continued from page 2*

one million tons per year. The importance was in the economy of scale. By going larger and being able to produce at these higher capacities while improving product quality and operational availability, the MEGAMOD simply represents a better value to the client. The MEGAMOD size also pairs very well to the capacity of modern EAF's for those plants producing steel onsite.

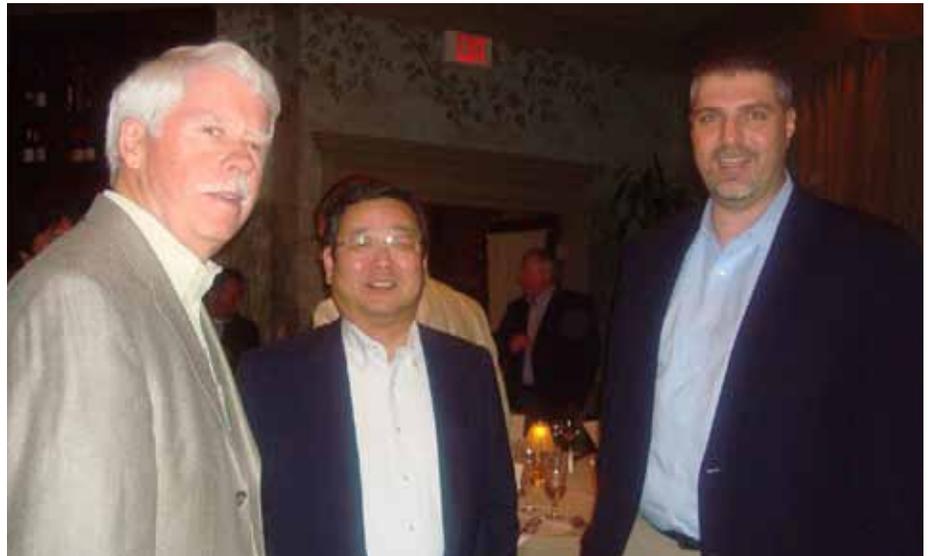
NDIL and IMEXSA launched the MEGAMOD brand and excelled with greater than expected results. IMEXSA alone produced 16 million tons in its first decade of operation – that is 1.6 million tons per year. Truly amazing when you consider the economic situation during that period that idled and shut down many North American producers.

The MEGAMOD changed the game. With the SUPER MEGAMOD we plan to do it again.

### ***Why is the SUPER MEGAMOD® a game changer?***

Once again it's all about bringing value to the client and giving them a new competitive advantage. In 2000, our Technology Development group began designing the next generation of MEGAMOD, known as the SUPER MEGAMOD, for capacities in excess of two million tons per year. Now our clients can confidently take the leap to the latest technology because they understand how much effort and care has been put into the development of this design and they know it is not such a large leap from the proven capacities of our MEGAMOD plants.

These larger plants fill a need within an industry to be more efficient and competitive while being more environmentally friendly.



Former Midrex President & CEO Winston Tennesse along with Akira Kawamura of Kobe Steel and Montague at Kawamura's retirement dinner in Charlotte

The higher production rates of a SUPER MEGAMOD will challenge the blast furnace and help people rethink newer mills.

### ***You've recently introduced MXCOL™; what impact will it have for the industry?***

MXCOL (pronounced "MX Coal") is going to be big because it opens up new markets by providing a more economical and environmentally friendly alternative to the blast furnace, especially in areas such as India. Currently India is the world's largest producer of DRI. A quarter of their annual production is from seven natural gas-based plants, six of which are MIDREX® Plants. Natural gas-based MIDREX Plants would be the preferred option for new facilities, but the

availability of low-cost natural gas is too limited.

MXCOL allows us to produce DRI for this region by using syngas made from coal. MXCOL can use a wide range of low cost fuels, such as bituminous and sub-bituminous coal, lignite, pet coke, petroleum refinery bottoms, COG, etc. For India this is a win, win situation. It means cleaner and better DRI production while using the domestic coal resources and eliminating the need for coke, which



Montague, with Executive Officer of Kobe Steel, Ltd. Shohei Manabe and current Midrex President & CEO James D. McClaskey, celebrating the 25th anniversary of Kobe's acquisition of Midrex.



## COMMENTARY

*Continued from page 3*

is often necessary to import.

The new project for Jindal Steel & Power Ltd. is a perfect example of the MXCOL Technology and will serve as a model for other regions where natural gas as an energy source is not a viable option, and/or for areas with low grade coal resources.

***With your background in technology, what developments do you see on the horizon; what's new and exciting for Midrex?***

There's always something new in the pipeline. Our Technology Development group continually improves on equipment and design.

I've heard competitors say we've done nothing new to the MIDREX® Technology over the past 20 years. It is true that the core process is fundamentally sound and therefore has not changed significantly. We make no apologies for our predecessors getting it right the first time and providing a solid foundation from which we continue technical innovation. However, the Technology is most certainly changing. Just look at the older plants that now produce 1.5 or 2.0 times the original rated capacity. Look at the new plants that can produce various combinations of DRI/HBI/Hot DRI simultaneously and those that transport Hot DRI directly to the meltshop. We are not the same old Midrex and the next few years are going to push the envelope even further.

We've already introduced MXCOL and we hope to announce the first SUPER MEGAMOD contract in the next year, and this is just a sampling of what's ahead. The first ITmk3® Plant is in operation offering



At Kobe Steel headquarters in Tokyo, Japan.



Representing Midrex at Steel Success Strategies XXV in NYC in 2010.

a new DRI alternative: a clean, slag-free premium pig iron product for use in EAFs. The MIDREX® Process is already one of the greenest ironmaking technologies in the world, but we've created a new even lower emission flowsheet for steelmakers who need to drastically curb their carbon footprint and other greenhouse gas emis-

sions. We're also using technology to provide solutions that allow our clients to better utilize an even wider range of iron ores.

So, what's new and exciting for Midrex? Just about everything for next few years. ■



## Massive CO<sub>2</sub> Savings by Use of HBI Made with Natural Gas: Blast Furnace Economics

By Robert Hunter,  
Product Application Manager  
Midrex Technologies, Inc.

**Editor's Note:** This is the third and final article in this series. The first, published in the 3rd/4th Quarter 2009 Direct from Midrex, discussed the remarkable contribution of ironmaking to the world's output of manmade CO<sub>2</sub>. The second article, published in 1st quarter 2010 DFM, investigated the logistics of moving iron ore from the mines to the blast furnaces and methods for incorporating natural gas fueled direct reduction into that flow of material. This article looks into the economics of this practice.

### INTRODUCTION

Ironmaking accounts for almost six percent of mankind's entire carbon footprint (Figure 1). Total production of CO<sub>2</sub> by human activities is currently around 31 billion tons per year.<sup>1</sup> Steelmaking accounts for a significant share of this, over 7%. But, remarkably, ironmaking alone constitutes the lion's share of steelmaking's CO<sub>2</sub> output. We estimate, based upon the world steel industry's coal consumption, that approximately 1.8 billion tons per year of CO<sub>2</sub> are formed just by the manufacture of iron.

Reduction with natural gas creates only one third as much CO<sub>2</sub> as reduction with coal and thus there is a far smaller carbon footprint of ironmaking when natural gas is used as the fuel/reductant rather than coal. Also, by feeding the direct reduced iron (DRI) made with natural gas to a blast furnace, it is possible to economically use that DRI in the existing process stream. (Normally, DRI fed to blast furnaces is in the form of Hot Briquetted Iron, or HBI.) Since the iron is already metallic when charged to the blast furnace, hot metal production is greatly increased, by 8% for each 10% of metallic iron in the burden, and coke savings are similarly impressive, 7% for each 10% of metallic iron in the burden. In addition, CO<sub>2</sub> emissions decrease by the same amount as coke consumption. This practice has been employed quite profitably by AK Steel's Middletown works north of Cincinnati, Ohio for over 20

<sup>1</sup>It should be noted that 'world total' figures for CO<sub>2</sub> production differ markedly from source to source and are actually only accurate to about two significant digits. Therefore, we have not attempted to show any greater accuracy, even when it is possible.

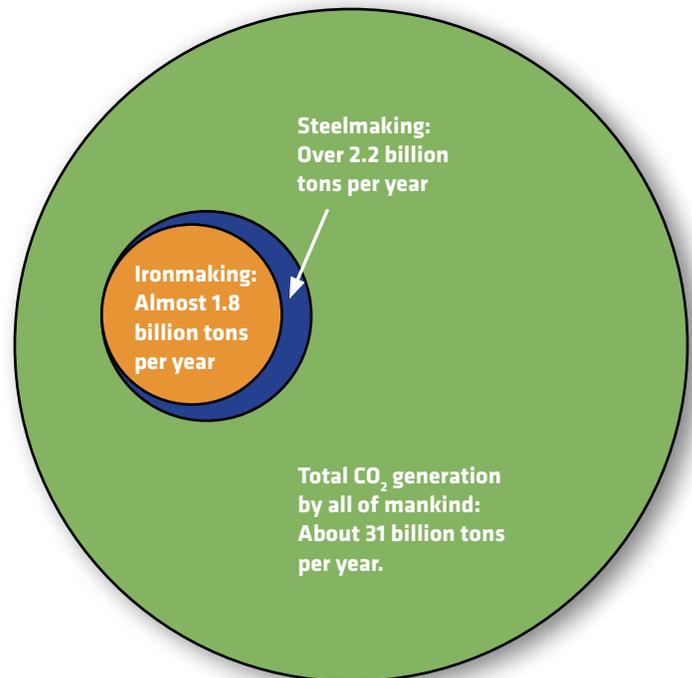


FIGURE 1 Ironmaking's annual contribution to the total world CO<sub>2</sub> generation, nearly 6%

years. During that period, the Middletown works made nearly 50 million tons of steel, using metallic iron as approximately 30% of iron units fed to the blast furnace.

Iron ore flows from the mines to the integrated steelworks. Most merchant iron ore comes from the southern hemisphere, primarily Brazil and Australia, and moves to the northern hemisphere, major consumers of merchant ore being China, Japan and other East Asian countries as well as Western European nations. When examined, there are a number of likely possibilities where this ore transits close by very large reserves of natural gas. Thus there are opportunities to modify business practices to take advantage of natural gas-based direct reduction for **Massive CO<sub>2</sub> Savings**.

### ECONOMICS OF HBI USE IN BLAST FURNACES

This article is being written to briefly discuss the economics of feeding of HBI reduced with natural gas to blast furnaces. An in-depth economic analysis is necessary for any specific steelworks, since the cost and price elements vary markedly from works to works. So, we will outline the general areas that must be considered and then create a spreadsheet calculation for a specific, and hopefully typical, works.



TABLE I Blast Furnace profit margin with HBI charged

<b>Plant location</b>	Chicago								
<b>Case</b>	290	kg/t HM minimum coke rate							
<b>MIDREX plant output</b>	1.6	Mtpy							
<b>Pellet Fe Metallization</b>	89.98%								
	93.00%								
		<b>Case A</b> zero HBI added		<b>Case B</b> 100 kg HBI per t of H.M.		<b>Case C</b> 200 kg HBI per t of H.M.		<b>Case D</b> 300 kg HBI per t of H.M.	
<b>Blast furnace</b>	<b>\$/unit</b>	<b>kg/t HM</b>	<b>\$/t HM</b>	<b>kg/t HM</b>	<b>\$/t HM</b>	<b>kg/t HM</b>	<b>\$/t HM</b>	<b>kg/t HM</b>	<b>\$/t HM</b>
HBI added	0.26	0	0	100	26	200	53	300	79
Pellets	0.08	1,500	120	1,397	112	1,304	104	1,221	98
Coke	0.3	350	105	325	97	300	90	290	87
PCI	0.12	150	18	139	17	128	15	102	12
CO <sub>2</sub>	0.05	1,490	75	1,380	69	1,270	64	1,180	59
Fixed cost	30		30		28		26		25
Sum			348		349		352		360
Cost difference					2		5		12
Profit margin (\$/t HM)			100		98		95		88
Productivity (t HM/day)		10,000		10,672		11,344		12,016	
Total profit (\$/day)			1,000,000		1,047,920		1,080,718		1,052,636

To accomplish this analysis, five factors must be addressed; the cost of iron units, the cost of metallurgical coal (or coke), the possibility of shuttering any existing ironmaking capacity, savings generated by abatement of carbon dioxide, and finally increased productivity of the works and the increased profits contributed by that added production. These must be balanced against the increased cost of the iron units being fed to the blast furnace as HBI, which are already metallic.

Undoubtedly, the use of HBI increases the total cost of iron oxide charged to the blast furnace. Lower value, lower cost blast furnace feeds such as sinter or blast furnace grade pellets are being replaced by higher value, but higher cost reduced iron. This added cost is normally greater than the savings made through decreased coke/fuel costs and the cost per ton of hot metal increases. This result has caused management at many steelworks, especially blast furnace management, to reject the practice without further examination. But it must be understood

that in some cases, the factors increasing profit outweigh the higher iron oxide cost.

In the following calculation, a typical, average blast furnace iron oxide charge cost of \$80/t is used. This is approximately the average cost of pellets from the Minnesota Iron Range over the past six years (2005-2010, inclusive) rounded to the nearest \$5/t. So, for Case A, with zero HBI added, one thousand five hundred kilograms of iron oxide pellets are needed to produce one ton of hot metal at a cost of \$120 (1.5 tons times \$80 per ton). For the case with HBI added to the blast furnace charge, the delivered cost of the HBI is taken to be \$260/t. The HBI is added in increments of 100 kg per ton of hot metal. Thus Cases A through D use zero to 300 kg of HBI respectively. Sample calculations are shown in Table I. These use the relationships described above regarding the effect of burden metallization on productivity and fuel consumption, as shown in Figure 2. The costs of materials that are used in this analysis might seem low when compared to today's



costs. The extreme volatility experienced over the past few years made it difficult to select typical costs. Therefore, the numbers used are simply time averages of the costs of these commodities over the past five to ten years (such as noted above for pellets).

For a works that is limited by its production of hot metal, as many are, an increase in the output of hot metal will engender an increase in steel products of the same magnitude. That is, a 10% increase in hot metal will result in a 10% increase in steel products. (It is assumed that the ratio of hot metal to cold charge at the steel furnace is held constant.) The additional profits made from this added tonnage are often extremely large; in some cases in the tens of millions of dollars per year of added profit.

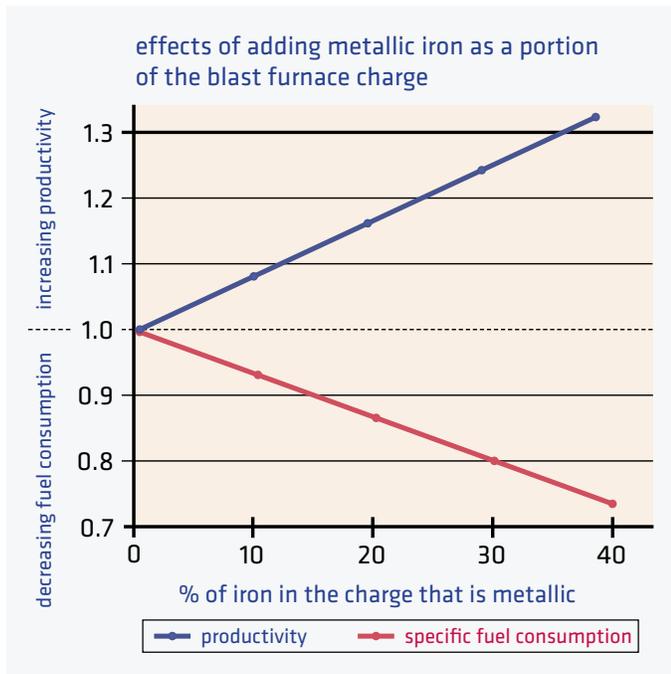


FIGURE 2 Effect of Use of HBI on Blast Furnace Productivity and Fuel Consumption

Also, without any doubt, the specific fuel consumption (coke plus other fuels) per ton of hot metal will decrease. The relationship in Figure 2 shows that adding 30% metallic iron to the burden by use of HBI decreases specific fuel consumption 21%. At today's very high costs for coke, metallurgical coal, and other fuels, this savings can easily reach into the tens of millions of dollars per year for a typical steelworks. For instance, if a three million ton per year steelworks normally uses 500 kg of coke and other fuels per ton of hot metal at an average cost of \$246 per ton of coke/fuel, and the specific coke/fuel rate is cut by 21%, the savings is \$63 million per year. [The example shown in Table I uses these costs, \$300/t of

coke and \$120 per ton of PCI or other fuel with a weighted average of 70% coke (350 kg/t-hm) and 30% PCI/other fuel (150 kg/t-hm)].

Next, there should be some consideration of capital cost savings. The practice of feeding of metallic iron to a blast furnace is a significant process modification from the historical standard; to such an extent that some "plant and equipment" might no longer be needed. For instance, in the case of AK Steel an old, outdated blast furnace at Hamilton, Ohio was closed. At some locations, it might also be possible to shutter aging coke batteries and related equipment (coal processing and handling, coke oven gas processing, etc.). Even though this equipment might be many years old, it might have become re-capitalized via recent mergers and acquisitions. The ability to shutter such plant and equipment can have a remarkably strong effect on the overall economics of a steelworks. This factor is not considered in the calculations shown in Table I because it is simply too site specific.

Finally, today, as concerns about global warming are forcing governments to monetize carbon dioxide generation, any technology that is capable of abating CO<sub>2</sub> must be evaluated. Let us consider a works with a 2 million t/y blast furnace, feeding a 2.4 million t/y BOF. Via application of HBI sufficient to metallize the burden to 30%, the output of the works is expanded by 24% to 2.48 million t/y of hot metal and 2.976 million t/y of steel products. For this added 0.576 million t/y of steel products there is a savings of 0.8 tons of CO<sub>2</sub> for each ton of hot metal. If the monetization system applies a cost of \$30 per ton of CO<sub>2</sub>, as is believed to be very likely within only a few years, then the CO<sub>2</sub> abatement savings would exceed \$13 million per year.

For a specific steel works, it is possible to analyze the combination of factors that make it feasible to use HBI. Figure 3 is an example of such a calculation showing the effect on yearly profit of variations in HBI use, profit per ton of hot metal, and cost of CO<sub>2</sub>. Four cases representing two levels of profit margin and two values of CO<sub>2</sub> are investigated, shown by the four lines; a profit margin of \$50/t of hot metal and of \$100 per ton of hot metal, and carbon dioxide values of \$50/t of CO<sub>2</sub> and of \$100/t of CO<sub>2</sub>. Notably, in some cases the overall profits do not necessarily increase as more and more HBI is added to the charge. Also, the factor referred to as "blast furnace profit" should be explained. Since blast furnaces do not actually sell their hot metal to the steelmaking shop, this is a calculated number. As an example, if a works produces 2.3 million tons of saleable product from 2.0 million tons of hot metal, and averages \$80/t of profits per ton of steel products, then the profit per ton of hot metal is  $\$80 \times 2.3/2.0$ , that is \$92.

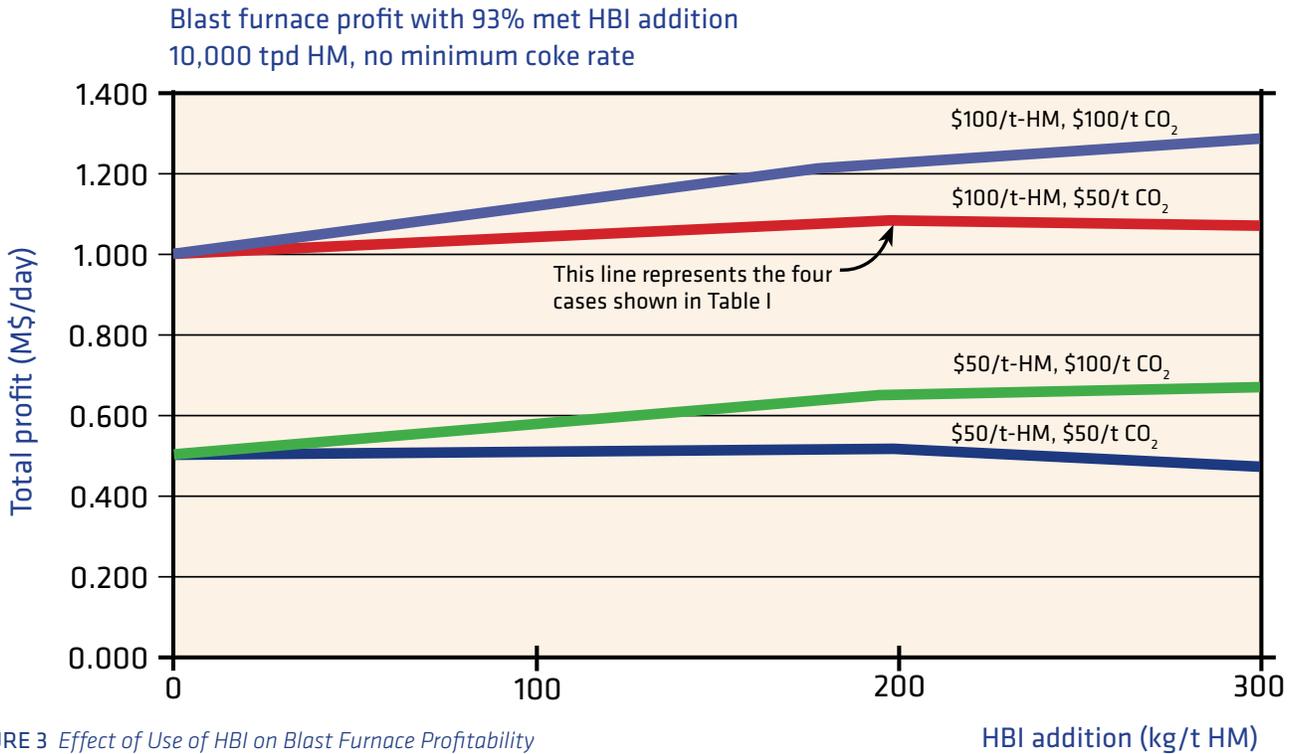


FIGURE 3 Effect of Use of HBI on Blast Furnace Profitability

**Note:** In all calculations coke costs were set at \$300/t. PCI or other fuel costs were set at \$120/t. Fixed costs for the blast furnace complex were set at \$30 million per year.

Here we see the average profit for a works over the tonnage that is produced without any HBI and then additional profits made by virtue of the increased tonnage produced. Even though costs increase with the addition of HBI to the blast furnace charge, profits also increase.

In summary, it has been shown that feeding blast furnaces with iron reduced by natural gas is by far the most effective means of lowering carbon dioxide generation for ironmaking. It is a well proven technology. Logistics of iron ore supply to the world's steel plants are such that it can be applied on a broad scale. Economically, it is attractive. In some cases it can even improve the profitability of a steelworks.

No analysis like this will apply to all steelworks. Rather, it is necessary to calculate the profitability on an individual works by works basis. As governments monetize the generation of carbon dioxide by placing limits, taxes and tariffs on the CO<sub>2</sub> that is made, we suggest that each and every integrated works so affected should re-visit the question of using HBI as an added charge material to augment steel production, save on coke and fuel use and greatly lower amount of CO<sub>2</sub> that is made.





## Environmental Benefits of Natural Gas Direct Reduction

By Gary Metius and John Kopfle  
Midrex Technologies, Inc.

**Editor's Note:** This article is adapted from a paper presented to AISTech 2010.

### INTRODUCTION

**Worldwide, there is an increasing emphasis on environmental issues.** In the area of gaseous emissions, the Kyoto Protocol and subsequent agreements have put great pressure on the industrialized countries. Under the Protocol, those countries pledged to reduce their collective emissions of "greenhouse gases" by five percent compared to 1990 levels. When compared to the emissions expected with normal economic growth, the level represents a 29 percent cut. There are six gases of interest, with carbon dioxide (CO<sub>2</sub>) the most significant. At the United Nations Climate Change Conference (COP 15) held in December 2009, the United States and numerous other countries, including China, India, and Brazil, agreed to take actions to reduce global warming.

The steel industry is now under intense scrutiny because it accounts for about five percent of worldwide carbon dioxide emissions. Ironmaking and steelmaking are energy intensive and essentially all the carbon entering a steel complex leaves as CO<sub>2</sub>. Although the steel industry has reduced energy consumption and the concomitant emissions significantly, much more will be required. In addition to CO<sub>2</sub>, emissions of concern are SO<sub>x</sub>, NO<sub>x</sub>, and particulates. In certain areas, limits on those emissions are very strict.

An active market in emissions trading has developed in Europe. Under the European Union scheme, companies in energy intensive industries such as steel are allowed a certain amount of CO<sub>2</sub> emissions. For companies over the limit or considering expansions, there are two options: purchasing credits from other producers with excess or installing production technologies with lower emissions. Since the purchase of credits involves significant financial penalties, the great promise is to incorporate "cleaner" processes, which is the focus of this paper.



### LOWERING IRON AND STEELMAKING CARBON EMISSIONS

Worldwide, about 90 percent of the energy used to make steel comes from coal. Sixty-five percent of the world's steel is made by the blast furnace/basic oxygen furnace (BF/BOF) route. This process is very coal intensive, since coke (devolatilized coal) is used in the BF and often the electricity for the facility is generated from coal. Even electric arc furnace (EAF) steelmaking often relies on coal to produce the electricity required.

On a macro basis, there are three ways to lower CO<sub>2</sub> emissions from iron and steelmaking production: 1) reduce energy consumption so that less energy (and carbon) is required per ton of steel produced, 2) sequester the CO<sub>2</sub> produced underground, either in storage or for enhanced oil recovery, and 3) use an energy source with less carbon than coal. **Option 1)** has been a serious focus for many years. Since 1980, the USA steel industry has reduced energy consumption per ton of steel 45 percent. However, further gains are increasingly difficult as the processes become more and more efficient. **Option 2)** is being studied and there is promise, but it does nothing to reduce emissions from the iron and steelmaking processes, it just reduces the CO<sub>2</sub> emitted to the atmosphere. Also, there are significant practical limitations that must be overcome for this approach to have a major impact. **Option 3)** may hold the most promise for significantly reducing carbon emissions. An attractive energy source is natural gas.

Natural gas is primarily methane, with a chemical formula of CH<sub>4</sub>. Thus, there are four hydrogen atoms for each carbon atom. Coal is a diverse mixture of compounds, but it has a higher proportion of carbon to hydrogen than does natural gas. Since almost all the carbon



TABLE I CO<sub>2</sub> Emissions for Iron and Steelmaking Energy Sources

Energy Source	CO <sub>2</sub> Emissions	
	(t/TJ)	(lbs/MMBtu)
Natural gas (CH <sub>4</sub> )	49	115
Bituminous metallurgical coal	90	212
Bituminous steam coal	94	220

and hydrogen used in an iron and steelmaking facility are eventually converted to CO<sub>2</sub> and H<sub>2</sub>O (water), natural gas produces much less carbon dioxide than does coal. Table I shows the CO<sub>2</sub> emission rates for combusting methane versus two types of coal.

As the table shows, natural gas emits only about one-half the CO<sub>2</sub> per unit of energy as does coal. This characteristic makes natural gas an ideal energy source for steelmaking. One proven method for producing steel using natural gas is the shaft furnace direct reduction (DR) plus EAF steelmaking route. In this case, natural gas is used as a reductant to remove oxygen from iron and as a fuel to provide heat. Natural gas can also be used to produce the electricity required for the EAF. The DR/EAF combination has much lower carbon emissions per ton of steel than does the BF/BOF process.

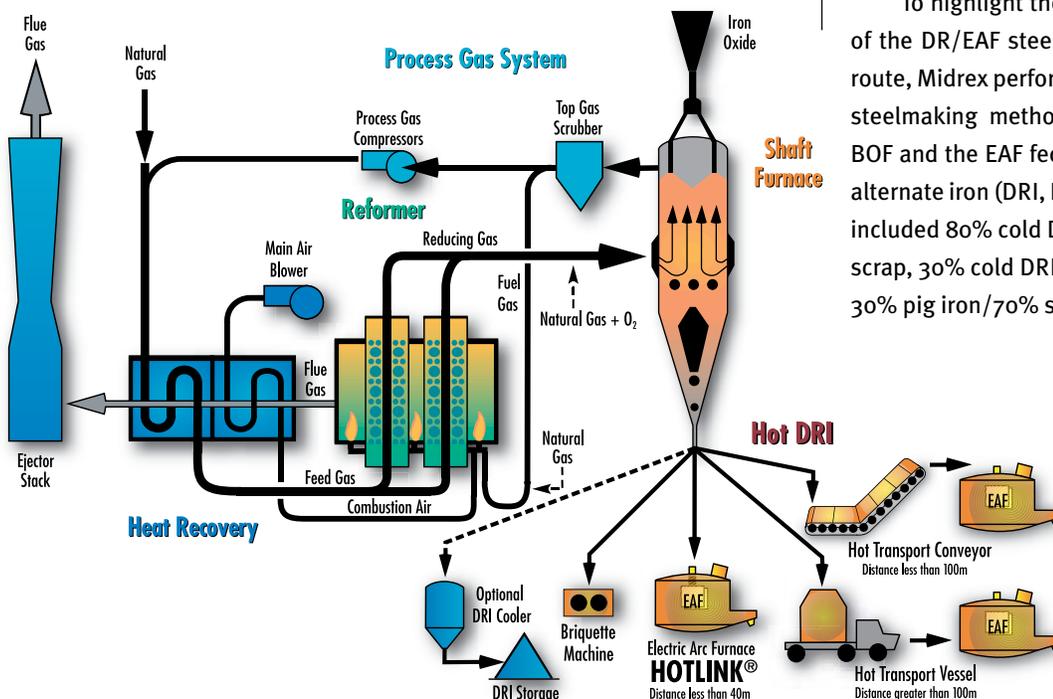
### A CARBON FRIENDLY STEELMAKING APPROACH

The standard MIDREX® Process flowsheet includes a reformer to convert natural gas into a high quality syngas that is used directly for iron ore reduction in a shaft furnace. Traditionally, almost all DR plants with an adjacent meltshop have cooled the DRI and stored it for later charging to the EAF. This option has considerably lower CO<sub>2</sub> emissions than the BF/BOF route. Carbon emissions can be further reduced by discharging DRI hot from the shaft furnace, transporting it to the meltshop, and charging it to the EAF at 600-700° C (see Figure 1). This can be done using gravity (HOTLINK®), a hot transport conveyor, or hot transport vessels. All three methods lower the electricity required per ton of steel produced, which also reduces CO<sub>2</sub> emissions from the power plant.

The electricity savings occur because less energy is required in the EAF to heat the DRI to melting temperature. The rule-of-thumb is that electricity consumption can be reduced about 20 kWh/t liquid steel for each 100° C increase in DRI charging temperature. Thus, the savings when charging at over 600° C are 120 kWh/t or more. With the use of hot charging, the DR/EAF route becomes even more attractive.

To highlight the significant emissions advantage of the DR/EAF steelmaking route versus the BF/BOF route, Midrex performed a detailed analysis of various steelmaking methods, including the blast furnace/BOF and the EAF fed with various mixes of scrap plus alternate iron (DRI, HBI, and pig iron). The EAF options included 80% cold DRI/20% scrap, 80% hot DRI/20% scrap, 30% cold DRI/70% scrap, 30% HBI/70% scrap, 30% pig iron/70% scrap, and 100% scrap.

FIGURE 1 Hot Discharge/Transport/Charging Options



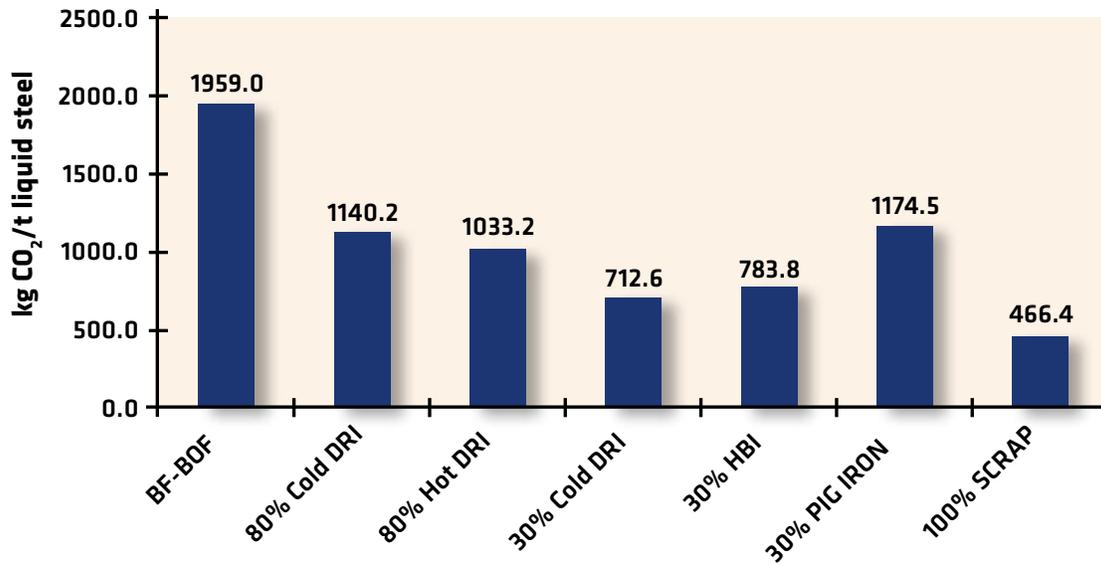


FIGURE 2 Carbon Emissions for Steelmaking Routes

The calculations determined the CO<sub>2</sub> emissions for the entire processes, from iron ore preparation through the production of liquid steel. Details of the procedure are given in reference 1. The results are shown in Figure 2 and are presented per ton of liquid steel produced. The emissions levels in Figure 2 assume a USA mix of electricity generation – i.e., coal, nuclear, natural gas, hydro, etc. If the electricity is generated entirely from natural gas, as would be the case in many of the places where DR plants are built, the emissions levels are even lower. In that case, the CO<sub>2</sub> emissions for the 80% cold DRI case drop to 1051 kg/t and for the 80% hot DRI case drop to 972 kg/t.

As the graph shows, the lowest carbon emissions result from the use of 100 percent scrap steel in an EAF. This occurs because scrap is a valuable “natural resource” that should be used when possible. All the energy used to produce that steel has been spent, and thus the energy required to recycle it is low, as are the carbon emissions. However, there is a limit to the amount of scrap that can be collected and used, so it is necessary to process iron ore to satisfy the world’s steel needs. Also, it is often not possible to produce “clean” steels with good processing characteristics from many grades of scrap, and a source of nearly pure iron is required. Thus, process technologies using iron ore, such as the BF/BOF and DR/EAF combinations, are necessary.

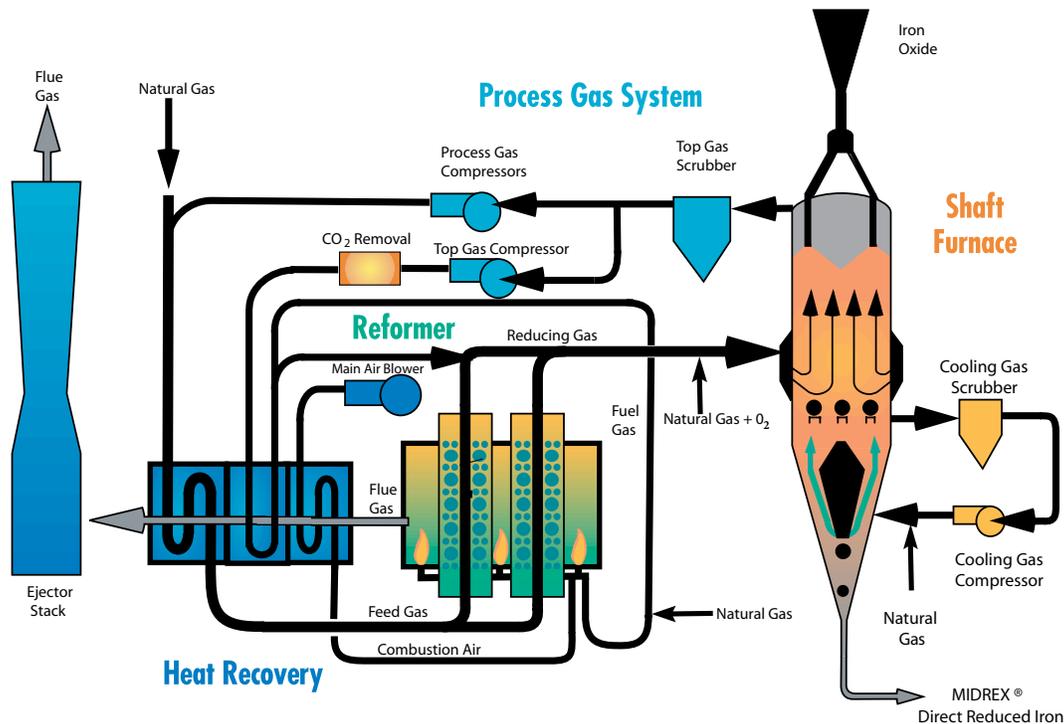
The DR/EAF route using 80 percent DRI and 20 percent scrap,

which is a typical ratio in natural gas-rich areas, has significantly lower carbon emissions than does the BF/BOF method. If the DRI is allowed to cool and then charged to the EAF (CDRI), the emissions are 42 percent less. The use of hot DRI (HDRI) provides even greater savings of 47 percent. Assuming electricity generated from natural gas entirely, the emissions decreases are 46 percent and 50 percent respectively.

In the case of a steel mill without a captive DR plant, the use of 70 percent scrap plus 30 percent alternate iron enables it to produce clean steel. Carbon emissions in those cases are much lower than for the BF/BOF option.

### LOWERING CO<sub>2</sub> EMISSIONS FURTHER

Although the standard MIDREX flowsheet plus EAF enables a decrease of about 50 percent in steelmaking CO<sub>2</sub> emissions versus the blast furnace/BOF, some steelmakers desire greater reductions. Midrex has developed a new concept, shown in Figure 3, employing a CO<sub>2</sub> removal system that allows for even lower emissions. This option uses an amine-type system that removes CO<sub>2</sub> from the top gas. This stream is then preheated, with part of it added to the reformed gas, which goes to the shaft furnace. The remainder is used for top gas fuel in the reformer burners. Figure 3 shows a cold DRI plant, but this scheme can also be employed for hot DRI.

FIGURE 3 MIDREX Process Low CO<sub>2</sub> Option

The advantage of this option is the flexibility it provides the plant operator, with relatively small changes in capital cost, operating consumptions, and operating cost. If the removed CO<sub>2</sub> is used for enhanced oil recovery, sequestered underground, or sold into a pipeline, stack CO<sub>2</sub> emissions per ton of DRI are reduced by 250 kg/t DRI, about 50 percent. At a CO<sub>2</sub> cost of \$50/t, this represents \$12.50/t DRI. Use for enhanced oil recovery is an excellent approach. Many producers worldwide are now injecting CO<sub>2</sub> or steam in old oil fields, which can increase production two to three-fold. This should be a good possibility for direct reduction plants, since they are located in gas-rich areas which often have oil as in addition to natural gas.

There are several implications of this approach for plant construction and operation. For a new facility, capital cost is estimated to increase by five to ten percent versus the standard plant. Natural gas use drops five percent and the electricity consumption increases by 20 kWh/t DRI. Midrex expects that in most cases, this will result in a net decrease in operating cost. This option can also provide significant benefits for an existing MIDREX Plant. The use of CO<sub>2</sub> removal allows for higher DRI production without adding additional reformer bays, and lowers natural gas consumption, in addition to the benefits of lower CO<sub>2</sub> emissions.

It is even possible to build a MIDREX Plant with essentially zero carbon emissions to the atmosphere. In addition to removing CO<sub>2</sub> from the top gas, a system could strip it from the flue gas as well. The recovered CO<sub>2</sub> from both streams could be injected underground or sold into a pipeline. However, this scheme would increase capital and operating costs significantly compared to the standard configuration.

As steel companies become increasingly globalized, they will have many opportunities to incorporate low CO<sub>2</sub> technology options into their carbon management plans by installing direct reduction plants in regions with low cost natural gas. It may even be possible to apply the carbon credits generated in those facilities to carbon restricted regions such as Europe and North America.

### THE GREEN SOLUTION

In addition to its CO<sub>2</sub> benefits, natural gas direct reduction is a “green” technology with regards to other emissions. Generally, natural gas has low levels of sulfur and particulates. NO<sub>x</sub> emissions can be controlled with the use of selective catalytic reduction (SCR), which is well-proven technology. It employs a catalyst system and ammonia to convert NO<sub>x</sub> to elemental nitrogen. It is possible to reduce NO<sub>x</sub> emissions by 90 percent using SCR, to

TABLE II *Typical Environmental Parameters for MIDREX Plants*

Source	Air emissions (kg/t DRI)				CO <sub>2</sub>	
	PM <sub>10</sub>	SO <sub>2</sub>	NOx	Standard plant	Low CO <sub>2</sub> option	
Charge hopper	0.0006	trace	0.003	trace	trace	
Combustion system (reformer stack)	0.04	0.02	0.04*	500	250	
Dust collection system (typical for one system)	0.004	trace	0.005	trace	trace	

\*Controlled value. Uncontrolled value is ~0.4 kg/t DRI.

Source	Water emissions	
	Suspended solids (kg/t DRI)	Flow (m <sup>3</sup> /t DRI)
Plant blowdown	0.01	0.2-1.5

Source	Noise level (db)
Inside blower area	95-105
Immediately outside blower area	85-90
Miscellaneous stations around plant	80-90
At plant boundaries	70-80

less than 20 PPM in the flue gas. Midrex is also considering the use of low NOx burners in the reformer. Table II shows typical environmental parameters for MIDREX Plants. These parameters meet applicable World Bank standards and can be designed to satisfy even stricter local requirements.

Regions such as the Middle East, North Africa, South America, Russia, and Southeast Asia have already discovered the benefits of the natural gas-based DR/EAF steelmaking route. In 2009, world DRI production was 64.4 million tons, of which natural gas processes accounted for 73 percent. Because of the flexibility and attractive economics in areas with abundant, low cost gas, much more capacity can be expected.

## CONCLUSIONS

The increasing emphasis on the environment creates a need for innovative solutions to reduce carbon and other emissions from iron and steelmaking facilities. One good approach is to use natural gas as a reductant and fuel source, since it results in far less CO<sub>2</sub> output than coal. A proven method is natural gas-based direct reduction paired with an electric arc furnace. Use of 80 percent hot charged DRI in the EAF results in up to 50 percent lower carbon emissions per ton of steel produced than the blast furnace/BOF route. Use of a CO<sub>2</sub> removal system and a modified flowsheet cuts them even further. In addition to the carbon benefits, emissions of PM<sub>10</sub>, SO<sub>2</sub>, and NOx using the standard flowsheet generally meet world and local standards and plants can be designed for even lower levels.

1. McClelland, James, Sara Hornby Anderson, and Gary Metius: "Future Green Steelmaking," presented to SEAISI 2002 Conference, Tokyo, Japan, April 2002



## MIDREX News & Views

### MXCOL™ Highlights better way to make DRI using Coal

With a strong need for utilization of the world's abundant coal resources and more intense focus on environmental issues, Midrex Technologies, Inc. has introduced MXCOL™ to the market. MXCOL™ (pronounced "M X coal") is the new name and trademark for the production of direct reduced iron (DRI) using the commercially proven combination of a MIDREX® Shaft Furnace with syngas made from coal. There are many potential sources of syngas including coal gasifiers, coke oven gas, BOF gas, etc.

"The concept of MXCOL™ has been in place for years, but the rationale behind branding MXCOL™ is to highlight better ways utilize coal for the production of iron than traditional blast furnaces and rotary kilns," said Stephen Montague, Commercial Vice-President for Midrex Technologies, Inc. "The MXCOL™ Direct Reduction Plant is an economical and environmentally sound solution for the iron and steel industry in areas of the world where natural gas as an energy source is not a viable option."

# MXCOL™

The environmental benefits of MXCOL™ versus a blast furnace include reduced air emissions (significantly lower SOx, NOx, and particulates) and avoidance of coke ovens and sinter plants. In addition, a 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.

In December 2009, Jindal Steel & Power Limited (JSPL) contracted with Midrex to build a 1.8 million ton per year MXCOL™ Plant in Angul, Orissa, India. The new MIDREX® Module will pair commercially available gasification technology from Lurgi GmbH of Germany with a MIDREX® Shaft Furnace to produce DRI for use in a newly constructed EAF. This is the first time a Lurgi gasifier will be paired with a MIDREX® Shaft Furnace; the new installation will use indigenous coal and iron ore.

Christopher M. Ravenscroft: Editor

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