Greener steelmaking with the Midrex®
direct reduction process

The use of natural gas-based direct reduced iron processes, coupled with hot charging of DR pellets to EAFs provides steelmakers with the ability to significantly reduce total energy and CO₂ emissions when compared to the integrated BF/BOF route, as well as providing a valuable source of low residual content iron units.

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Worldwide, there is an increasing emphasis on environmental issues, and in the area of gaseous emissions, the Kyoto Protocol has put great pressure on industrialised countries to reduce emissions. Under the Protocol, those countries pledged to reduce their collective emissions of greenhouse gases by 5% compared to 1990 levels. When compared to the emissions expected with normal economic growth, this level represents a 29% cut. There are six gases of interest, with carbon dioxide (CO₂) the most significant. The agreement came into force on February 16, 2005 and almost all industrialised nations have ratified the agreement, the USA and Australia being the most notable exceptions.

The steel industry is now under intense scrutiny because it accounts for 5% of worldwide carbon dioxide emissions. Iron making and steel making are energy intensive and essentially all the carbon entering a steel complex leaves as CO₂. Although the steel industry has reduced energy consumption and the concomitant emissions significantly in recent years, much more will be required.

An active market in emissions trading has developed in Europe, with $30 billion worth of CO₂ traded in 2006. Under the European Union scheme, companies in energy intensive industries such as steel are allowed a certain amount of CO₂ emissions. For companies over the limit or considering expansion, 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% of the energy used to make steel comes from coal. 65% 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 (devolatilised 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 CO₂ emissions from iron and steelmaking production:

1) Reduce energy consumption so that less energy (and carbon) is required per tonne of steel produced
2) Sequester the CO₂ produced underground, either in storage or for enhanced oil recovery
3) Use an energy source with less carbon than coal

Option 1) has had a serious focus for many years. Since 1980, the USA steel industry has reduced energy consumption per tonne of steel produced by 45%, however, further gains are increasingly difficult as the processes become more efficient. Option 2) is being studied and shows promise, but it does nothing to reduce emissions from iron and steelmaking processes - it just reduces the CO₂ 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 (CH₄) whereas coal is a diverse mixture of compounds, and has a higher proportion of carbon to hydrogen than natural gas. Since almost all the carbon and hydrogen used in iron and
These methods lower the electricity required per tonne of steel produced and hence reduce CO₂ emissions from the power plant. The electricity savings occur because less energy is required in the EAF to heat the hot DRI to melting temperature. The rule-of-thumb is that electricity consumption can be reduced by 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 hence with the use of hot charging, the DR/EAF route becomes even more attractive.

PROCESS ROUTE COMPARISONS

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.

The calculations determined the energy requirements and CO₂ emissions for the entire processes, from iron ore and coke preparation through the production of liquid steelmaking are eventually converted to CO₂ and H₂O (water), natural gas produces much less carbon dioxide than does coal. Table 1 shows the CO₂ emission rates for combusting methane versus two types of coal. Natural gas emits only about one-half the CO₂ per unit of energy compared to coal, a characteristic that makes natural gas an ideal energy source for steelmaking. One proven method for producing steel using natural gas is the direct reduction (DR) shaft furnace followed by EAF. In this case, natural gas is used in a direct reduction technology such as the Midrex process 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 tonne of steel than does the BF/BOF process.

HOT CHARGING

In the DR/EAF route, carbon emissions can be further reduced by hot charging the DRI to the EAF. Traditionally, almost all Midrex plants with an adjacent melt shop have cooled the DRI and stored it for later charging to the EAF. Now, Midrex has developed three methods for discharging the DRI at elevated temperature, transporting it hot to the melt shop, and charging it to the EAF at 600-700°C (see Fig. 1). These methods lower the electricity required per tonne of steel produced and hence reduce CO₂ emissions from the power plant. The electricity savings occur because less energy is required in the EAF to heat the hot DRI to melting temperature. The rule-of-thumb is that electricity consumption can be reduced by 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 hence with the use of hot charging, the DR/EAF route becomes even more attractive.

Fig. 1 Hot discharge/transport/charging options
steel. Midrex originally performed these calculations in 2001 and for this paper, the hot DRI case was added. The results are shown in figure 2 and are presented per tonne of liquid steel produced.

The calculations were performed as follows. The BF/BOF figures used published data [1] for North American integrated mills for energy inputs and outputs throughout the steelmaking operation and thus represent typical North American practice. For the DR/EAF route, the DR consumption figures are based on actual operating data from 1.0–1.7 Mtpy Midrex Plants. An in-house EAF melt program was used to predict, from first principles, the major operating parameters (for example, electricity, flux, oxygen, yield, and thermal efficiency of melting). These were then fine-tuned using practical experience. The results from each individual process energy balance computations were converted to greenhouse gas emissions using conversion factors from several sources. Details of the procedure are given in reference [2].

As figure 2 shows, the lowest energy requirement and carbon emissions result from the use of 100% scrap steel in an EAF. This occurs because the energy required to melt steel is significantly less than that needed to reduce iron ore, 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% DRI and 20% scrap, which is a typical ratio in natural gas-rich areas, has significantly lower carbon emissions than does the BF/BOF route. If the DRI is allowed to cool and then charged to the EAF (CDRI), the emissions are 42% less. The use of hot DRI (HDRI) provides even greater savings of 47%.

In the case of a steel mill without a captive DR plant, the use of 70% scrap plus 30% alternate iron enables it to produce clean steel. Carbon emissions in those cases are much lower than for the BF/BOF option. For the process routes using a high percentage of iron, the total energy requirements are about the same, because the BF/BOF and 80% DRI/EAF cases are both energy efficient.

THE GREENER SOLUTION

Regions such as the Middle East, South America, and Russia have already discovered the benefits of the natural gas-based DR/EAF steelmaking route. In 2006, world DRI production was about 60Mt. Because of the flexibility and attractive economics in areas with abundant, low cost gas, much more capacity is on the way. Table 2 shows Midrex plants recently started and those under construction. Midrex expects to sign additional contracts in 2007.

Most of the countries that are installing natural gas-based DR plants have abundant gas reserves. Proven reserves in the Middle Eastern Russia, for instance, range from 50 years to several hundred years at present production rates.

With increasing focus on carbon emissions, there is now a compelling environmental reason to choose the natural gas-based DR/EAF route. A recent report prepared for Environment Canada [3] noted the environmental benefits of the Midrex Process:

“DRI plants using natural gas as the reduction material have lower CO₂ emissions than coal based plants... It was estimated that the BAT plant [Midrex plant] would emit 24% less CO₂ and at least 24% less TPM [total particulate matter], NOx, SOx, and VOCs than a conventional integrated BF/BOF plant.”

<table>
<thead>
<tr>
<th>Plant</th>
<th>Country</th>
<th>Start-up</th>
<th>Capacity (ktpy)</th>
<th>Product</th>
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</thead>
<tbody>
<tr>
<td>Essar Module V</td>
<td>India</td>
<td>2006</td>
<td>1,500</td>
<td>Hot DRI &amp; HBI</td>
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<tr>
<td>Mobarakeh VI</td>
<td>Iran</td>
<td>2006</td>
<td>800</td>
<td>Cold DRI</td>
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<tr>
<td>Nu-Iron</td>
<td>Trinidad</td>
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<tr>
<td>Acidar Expansion</td>
<td>Argentina</td>
<td>2007</td>
<td>250</td>
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<tr>
<td>AF-Tuwairqi</td>
<td>Saudi Arabia</td>
<td>2007</td>
<td>1,000</td>
<td>Cold DRI</td>
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<td>Hadeed Mod E</td>
<td>Saudi Arabia</td>
<td>2007</td>
<td>1,760</td>
<td>Hot &amp; Cold DRI</td>
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<tr>
<td>LGOK Module 2</td>
<td>Russia</td>
<td>2007</td>
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<td>HBI</td>
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<td>1,500</td>
<td>Cold DRI &amp; HBI</td>
</tr>
<tr>
<td>Shadeed</td>
<td>Oman</td>
<td>2008</td>
<td>1,500</td>
<td>HOTLINK &amp; HBI</td>
</tr>
<tr>
<td>Tuwairqi Steel Mills</td>
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<td>1,280</td>
<td>Hot &amp; Cold DRI</td>
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<td><strong>Total</strong></td>
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<td><strong>14,130</strong></td>
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need for innovative solutions to reduce carbon emissions from iron and steelmaking facilities. One approach is to use natural gas as a reductant and fuel source since it results in far less CO₂ than coal. A proven method is natural gas-based direct reduction, such as the Midrex process, paired with an electric arc furnace. Use of 80% hot charged DRI in the EAF results in 47% lower carbon emissions per tonne of steel produced than the blast furnace/BOF route. Many regions with abundant natural gas have seen major growth in DRI production and there are over 14Mt of new Midrex plant capacity recently started up or under construction in the Middle East, Latin America, Asia, and Russia. Several approaches hold the possibility of reducing carbon emission even further.

**REFERENCES**


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As steel companies become increasingly globalised, they will have many opportunities to incorporate this technology option into their CO₂ management plan by installing direct reduction plants in regions with low cost gas. It should even be possible to apply the carbon credits generated in those facilities to carbon restricted regions such as Europe and North America.

**THINKING OUTSIDE THE BOX**

Midrex continues to be proactive in reducing the environmental impact of its ironmaking processes and associated steelmaking technologies. There are several ways to reduce carbon emissions to even lower levels than shown in figure 2. If the electricity required for the Midrex process and for the EAF is generated by a non-hydrocarbon source, this would cut emissions even further. Possibilities are power generated from nuclear, solar, wind, and hydro sources.

It is even possible to build a Midrex plant with zero carbon emissions to the atmosphere. An amine type or pressure swing adsorption (PSA) CO₂ removal system would strip CO₂ from the top gas to create a high purity stream which could be injected underground for enhanced oil recovery or sequestration. Use for enhanced oil recovery is an excellent approach and many producers are now injecting CO₂ or steam in old oil fields, which can increase production two to three-fold. This should be a good possibility for Midrex plants, since they are located in gas-rich areas which often have oil as well.

**CONCLUSIONS**

The increasing emphasis on the environment creates a need for innovative solutions to reduce carbon emissions from iron and steelmaking facilities. One approach is to use natural gas as a reductant and fuel source since it results in far less CO₂ than coal. A proven method is natural gas-based direct reduction, such as the Midrex process, paired with an electric arc furnace. Use of 80% hot charged DRI in the EAF results in 47% lower carbon emissions per tonne of steel produced than the blast furnace/BOF route. Many regions with abundant natural gas have seen major growth in DRI production and there are over 14Mt of new Midrex plant capacity recently started up or under construction in the Middle East, Latin America, Asia, and Russia. Several approaches hold the possibility of reducing carbon emission even further.

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