UPDATE ON HYL TECHNOLOGIES

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Summary:

For more than 40 years, HYL has developed technologies designed to improve Hylsa's steelmaking competitiveness and productivity. The HYL direct reduction technology, while perhaps the best known, is accompanied by other technologies designed for making steel in more efficient, cost-effective ways. The HYL Process has been improved over generations and the current status of the technology, the HYL Self-reforming Process, was developed to allow reduction of iron ores in a shaft reactor without external gas reforming equipment. The HYTEMP System, developed to transport hot, high carbon DRI directly to the EAF meltshop, has been successfully implemented. Additional technologies related to steel production have been developed and implemented, such as improvements in hot rolled strip production to allow for ultra-thin gauge HRC, Hylsa's Multiple Slit Rolling technology for bar mills, and the HYL HY-Recovery Process for recuperation of iron units and heavy metals from steel mill waste. All of these technologies, in addition to training and technical assistance programs in all aspects of iron and steelmaking are detailed in this paper.

DRI, HYTEMP, Self-Reforming

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Introduction

Since 1957 when Hylsa started up the world's first successful direct reduction plant in Monterrey, Mexico, the focus of the company's research efforts has been on ways to make ironmaking and steelmaking as efficient and as economically productive as possible. This tradition not only has been of benefit to Hylsa, but it led to the formation of HYL as the company's technology division. As such, we have focused on providing these same technologies and services to the world's steel producers.

Today HYL provides proven, state-of-the-art direct reduction technology as well as other technologies and services both up and downstream of the direct reduction plant. Our consulting services for example include pellet plant training and technical assistance, design and operation for DR-quality pellet production. Our exclusive HYTEMP Pneumatic Transport System is designed to link the DR plant to the EAF shop, providing the benefits of hot, high-quality DRI directly to the steelmaking furnaces. Even the direct reduction process itself has been revolutionized, eliminating the need for external gas reforming equipment to make a compact, efficient DR furnace which carries out reforming and reduction within the same reactor vessel.

This paper will detail these technologies, as well as additional technologies for steel mills, which HYL has successfully developed and supplied to companies worldwide.

Direct Reduction: The HYL Self-reforming Process

The HYL Self-reforming Process (Figures 1-3) is a major step in reducing the size and improving the efficiency of direct reduction plants. Reducing gases are generated by self-reforming in the reduction reactor, feeding natural gas as make-up to the reducing gas circuit and injecting oxygen at the inlet of the reactor.

Since all reducing gases are generated in the reduction section, optimum reduction efficiency is attained, and thus an external reducing gas reformer is not required. Compared to a conventional DR plant including reformer, in addition to lower operating/maintenance costs and higher DRI quality, the total investment for an HYL self-reforming plant is typically 10 to 15% lower.

The overall energy efficiency of the self-reforming process is optimized by the integration of partial combustion, pre-reforming and "in-situ" reforming inside the reactor, as well as by a lower utilization of thermal equipment in the plant. Therefore, the product takes most of the energy supplied to the process, with minimum energy losses to the environment.

A remarkable advantage of this process scheme is the wider flexibility for DRI carburization, which allows attaining carbon levels up to 5.5%, due to the improved carburizing potential of the gases inside the reactor, which allow for the production primarily of iron carbide.

For the production of high quality DRI, i.e. 93% metallization, 4.3% carbon and discharged at 700°C, the energy consumption is 2.25 to 2.40 Gcal/ton DRI as natural gas and 60 to 80 kWh/ton DRI as electricity, with a remarkably low iron ore consumption of 1.35 to 1.40 t/t DRI, mainly due to high operating pressure.

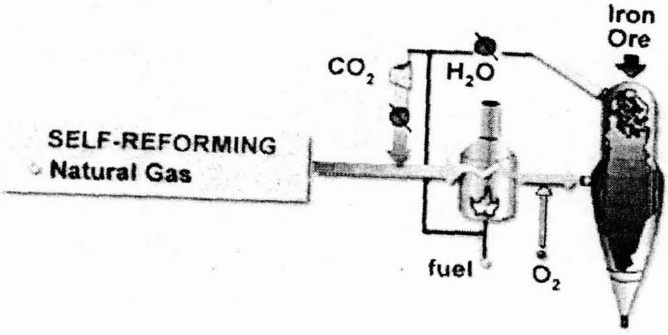

Figure 1. HYL Self-Reforming Process Diagram

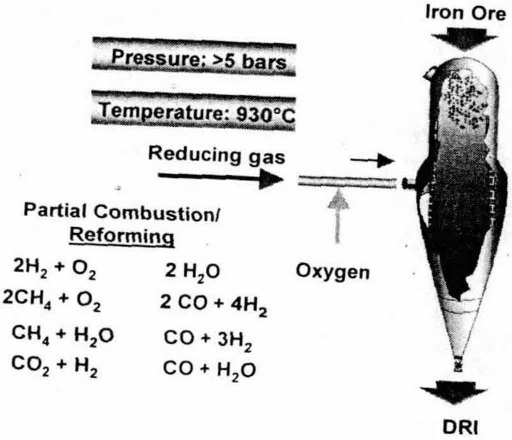

Figure 2. HYL Self-Reforming Process Partial Combustion & Reforming Reactions

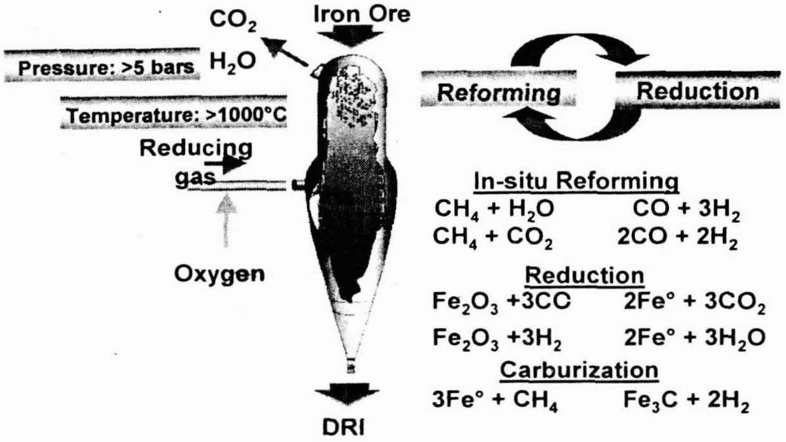

Figure 3. HYL Self-Reforming Process In-Situ Reactions

The impact of eliminating the external gas reformer on plant size is significant. For example, a plant of 1-million tpy capacity requires only 60% of the area needed by other process plants for the same capacity. For additional capacity, the area required is proportionally smaller in comparison as well, since for example, the same reactor size would be used for a 1 million or a 1.5 million tpy facility, and only the other related equipment would increase in size. This also facilitates locating the DR plant adjacent to the meltshop in existing operations. This plant configuration has been successfully operated at Hylsa's Flat Products Division in Monterrey since 1998 with the HYL 4-M plant.

Upgrading of Hylsa Plants 4M and 3M-5

Due to the increased cost of natural gas in Mexico, Hylsa was forced to take measures when the price reached and surpassed the level of US$5.00 per million Btu, going as high as US$9.00 per million Btu. The DR plants in Monterrey were temporarily shut down, restarting only the 4M plant when gas prices were controlled at US$4.00.

Since the 2M-5 and 3M-5 plants remained closed, Hylsa decided to increase the production of the 4M plant from 670,000 tpy capacity to over 1 million tons per year. This was done by adding the CO2 removal equipment from the 3M-5 plant to the 4M plant. The result is that the plant is now producing at a rate of 1 million tpy and gas consumption rates are significantly low – less than 2.2 Gcal per ton of product.

The 4M plant, even at its increased production capacity, is not able to supply all the DRI needed by Hylsa's Flat Products minimill. Hylsa is currently making up the shortfall by purchasing HBI and pig iron but after reviewing the status of the idled 2M-5 and 3M-5 plants, it was decided that the best option would be to convert the 3M-5 plant to the Self-reforming scheme and startup under that configuration.

The 3M-5 plant was initially started up in 1983 as a conversion of the original 1974-vintage fixed bed HYL plant 3M. As such, the reformer is now nearly 28 years old and was discovered to require a significant refurbishing when the plant was shut down a few months ago. Since the age and efficiency of the reformer would make the investment less than ideal at the moment, it was decided to convert the 3M-5 plant to the Self-reforming process configuration in order to more economically be able to startup the plant and provide the balance of DRI needed by the minimill meltshop.

The 3M-5 plant, starting up in July, becomes the second HYL Self-reforming plant in operation.

Of course, HYL plants can also use the conventional steam-natural gas reforming equipment, which has long characterized the process. Other reducing agents such as hydrogen, gases from coal, petcoke and similar fossil fuels gasification and coke oven gas, among others, are also potential sources of reducing gas depending on the particular situation and availability.

Raw Materials Flexibility

In terms of raw materials, the process is extremely flexible. In addition to reducing gas sources, the HYL process can also use a wide variety of iron ore feedstocks. Since iron ore is the largest component cost in the production of DRI, it is beneficial to reduce this cost by extending the reduction capabilities to include lower cost iron ores. HYL has done extensive research in the use of different iron ores and iron ore qualities at its pilot and industrial facilities in Monterrey. These experiences have been put into practice at industrial plants with great success.

Typically, for a DR plant using 100% pellets at international prices, the DRI direct production cost is estimated to be about US$90/ton. Nearly two thirds of this production cost is related to the iron ore cost, with the rest being costs for natural gas, electricity, water and miscellaneous items. Even with the current price situation for natural gas in several parts of the world, the iron ore cost continues to be the most significant item.

It is clear from these data, that the use of economic iron ores is the key for the feasibility of many direct reduction projects. Therefore, the flexibility of a DR technology is of prime importance in processing different iron ores, with satisfactory results in productivity, product quality, operating reliability and energy consumption. In this respect, HYL has made significant developments to process "difficult" iron ores as well as to significantly increase the percentage of lump ore in the charge, so as to decrease the cost of raw materials.

As mentioned above, one of the natural trends for cost reduction is to increase the amount of lump ore in the iron ore feed. However, although in most cases lump ore is cheaper than pellet, this is not a general rule and a cost comparison should be made for each particular case. In general, DR grade-lump ores available in the international market can be used in higher percentages in HYL DR plants.

An example of the impact of using a cheap lump ore in HYL plants in shown in Table 1. As it can be observed, some penalties have been considered in the iron ore and energy consumption and the production of briquettes (HBI) has been considered necessary due to an expected higher fines generation. The HBI production cost can be very attractive, provided that the DR plant is properly designed to process this specific raw material.

Item	**Unit**	**Cons.**	**Price (US$)**	**Cost (US$)**
Lump ore	ton	1.50	18.00	27.00
Natural gas	Gcal	2.50	8.75	21.88
Electricity	kWh	80.00	0.03	2.40
Water	m3	1.60	0.20	0.32
Miscellaneous	-----	-----	-----	8.00
Briquetting	-----	-----	-----	3.50
Direct production cost				**63.10**

Table 1 - HBI Production cost for 100% lump

The flexibility of the HYL process for the production of different product types and combinations of them, using different raw materials as pellets or lump ores, can be illustrated by the following examples of industrial HYL plants in operation:

Usiba

The Usiba plant, in Salvador Bahia, Brazil, started operations with the HYL moving bed process in December 1994. The nominal capacity of this plant is 310,000 ton/year of DRI.

Since start up, the Usiba plant has had a very smooth performance, with excellent results in production and quality. Since 1998, the percentage of lump ore in the iron ore feed has been increased, reaching a monthly average of 75%. Since 1999 the plant has run extended campaigns using virtually 100% lump ore in the charge with excellent results in both productivity and costs. For the period from June 1998 to the present, the plant productivity has averaged from 106 to 114%.

Vikram Ispat-Grasim

In some cases, it could be convenient to produce at the same time HBI and cold DRI to serve the export market and local market respectively. The Vikram Ispat (Grasim) plant in India is operating since June 1998 under this concept. The average HBI/DRI ratio in 1999 has been about 50/50.

The Vikram Ispat (Grasim) plant started up in October 1993, with a nominal capacity of 750,000 ton/year of HBI. Since June 1998, an external DRI cooler was incorporated to provide flexibility for the simultaneous production of both DRI and HBI, depending on the local and export market demand.

The Grasim plant has operated with a wide variety of raw materials. To date, 6 pellets and 8 lump ores have been successfully processed in this plant.

The plant has operated routinely with 30%-45% lump ore. In March 1999, when the plant reached a monthly productivity of 121%, the percentage of lump ore used was

33%. HBI production was 37,515 ton and DRI production reached 37,970 ton. The product quality at the Grasim plant typically averages 93.75% metallization and 1.17% carbon.

Direct Feeding of Hot DRI

There is no doubt that the direct feeding of high carbon-high temperature DRI is a breakthrough in the steel industry, and is also a revolutionary concept in the operating practices in flat products Mini-Mills. So much so, that others are already trying to devise methods to accomplish this as well.

Moreover, a very important fact is that HYL is now able to provide this proven and reliable technology. The self-reforming/HYTEMP plant (4M), feeding high carbon-high temperature DRI to the Hylsa Mini-Mill, is the only system of this type in the world, and is operating very successfully in Hylsa (Figure 4). From April 1998 to date, over two million tons of hot DRI have been transported pneumatically with total success in all respects.

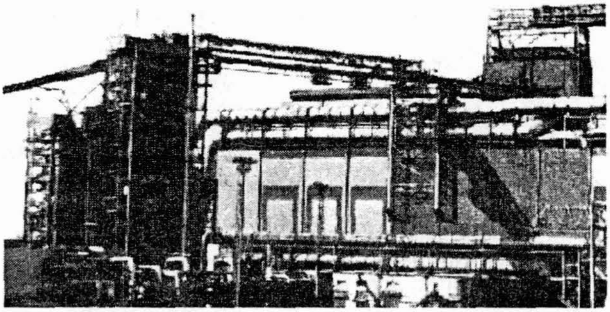

Figure 4. HYL Plant 4M – HYTEMP System – Hylsa Minimill

In order to evaluate the benefits of the use of high temperature-high carbon DRI on the production of liquid steel, a state-of-the-art EAF has been considered with the following characteristics for all cases:

- Capacity: 135 tons/heat (tapping).
- Average active power: 103 MW.
- Oxygen: 38 Nm3/t LS.

The analysis has been made to determine the liquid steel production costs and productivity for different DRI qualities, and also to evaluate the maximum production of a Mini-Mill, via the above mentioned EAF, with three different types of metallic charge to the furnace.

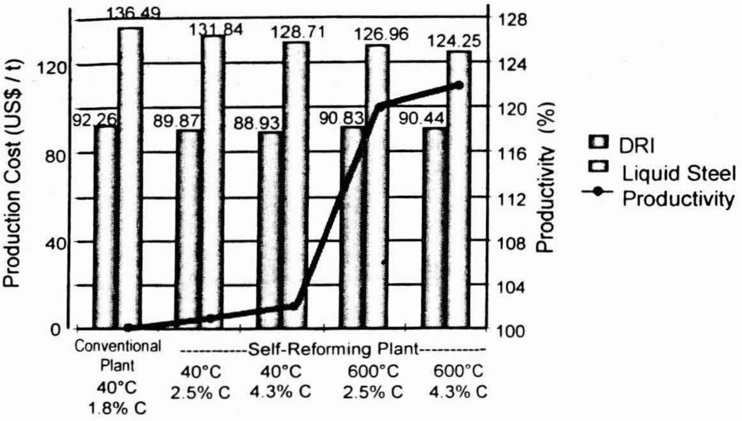

Figure 5. Production Costs and Productivity

According to the comparison of liquid steel production costs, as well as the productivity impact with different types of metallic charge, as indicated in Figure 5, the following conclusions can be made:

- The liquid steel costs decrease in relation to the increase of temperature and carbon in the DRI.

- The EAF productivity is increased with higher levels of temperature and carbon in the DRI.

The effect of high carbon in the DRI leads to lower production costs and improved plant productivity, due to the following main reasons: The feeding of graphite or any external source of carbon units is avoided, and the conversion of Fe_3C into iron and carbon is an exothermic reaction which improves the thermal efficiency of the system. This decreases the total electricity consumption and the tap-to-tap time in the EAF. When carbon in the DRI is increased from 1.8% to 4.3%, the liquid steel production cost is decreased by about US$8/ton and the furnace productivity can be increased by about 2%.

Regarding DRI temperature, the production costs are also decreased, but the main benefit is associated with much higher furnace productivity. Due to the contribution of the DRI sensible energy, the electric power consumption, electrode and refractory consumption, and the tap-to-tap time in the EAF are significantly decreased. Comparing a DRI fed at 40°C and 1.8% C with a DRI fed at 600°C and 4.3% C, the liquid steel production cost is decreased by more than US$12/ton and the furnace productivity is increased by about 22%.

In a typical flat product Mini-Mill, using 70% scrap and 30% DRI/HBI, the maximum liquid steel production which can be attained in the reference EAF (135 tons of liquid steel per heat) is about 1,180,000 tons/year of liquid steel. The corresponding slab production is about 1,145,000 tons/year.

In the case of a Mini-Mill feeding 100% cold DRI to the EAF, with 93% metallization and 1.8% carbon, the maximum liquid steel production for the reference EAF is about 1,165,000 tons/year of liquid steel. This means that the productivity of the EAF is very similar (1.3% lower) to that obtained in an operating practice feeding 70% scrap and 30% DRI/HBI. In this case, the slab production is about 1,100,000 tons/year.

However, when 100% high carbon-high temperature DRI is fed, with 93% metallization, 4.3% carbon and 600°C, the furnace productivity is dramatically increased, reaching a liquid steel production of 1,375,000 tons/year in the reference EAF. Compared to the operating practice using 70% scrap and 30% DRI/HBI, the productivity is increased by 16.5%. In this case, the slab production is about 1,335,000 tons/year.

On the other hand, considering the largest casters available in the market, a single HYL reduction unit of 1,500,000 tons/year of DRI can fulfill the metallic charge requirements of the largest single line Mini-Mill, using high carbon-high temperature DRI. This scheme is the optimum solution in modern steelmaking, and is supported by the industrial experience of the Hylsa Monterrey plant.

These breakthroughs in both direct reduction and minimill technologies are already available. There is no doubt they will be improved upon in the future, and we fully intend to do our part to bring about many of those improvements. With our fully enclosed system involving the DR plant, HYTEMP System and the modern EAF meltshop, this minimill concept is the most environmentally friendly production facility available. Until something totally revolutionary comes along, this is the DR-based minimill for the new millennium.

Mill waste recovery – HYL HY-Recovery System

The steel industry is typified by having small returns on large investments. The need to save in all areas of the production cycle has motivated HYL to develop other technologies and services toward that end.

The HY-Recovery System (Figure 6) was developed by HYL for recovering iron and heavy metals (Zn, Pb) from fines, mill scale and EAF dust. It is a gas-based process for the recovery of steel mill waste oxides. Unlike other processes that are typically coal-based direct reduction plants and which can accept mill oxides as part of the charge, the HY-Recovery Process is a dedicated operation aimed at solving the environmental problems facing steel mills as regards hazardous waste products. The plant is small and is designed to process the volume of waste oxides from a typical steel minimill; a plant capable of processing 20,000 tpy of mill oxides is sufficient for the needs of a steel mill producing 700,000 tpy of liquid steel.

The technology, which has been fully proven at pilot plant operations in Monterrey, will allow steel mills to comply with environmental regulations and eliminate the need for processing EAF dust outside the steel works. EAF dust and mill scale are processed for the recovery of iron units (as high quality DRI) and for the separation of zinc and lead (as both oxides and metals). For plants with onsite DRI production, iron ore and DRI fines can also be processed and recovered. With the HY-Recovery Process, the DRI is produced as an agglomerate and has very high metallization levels (93-96%), and the heavy metals are recovered with virtually no waste.

In the U.S. and Europe, the disposal of materials considered to be hazardous, such as heavy metals, is a critical problem. Transportation is prohibited in many areas and even after having "disposed" of the materials, the issue of "cradle-to-grave" liability continues to be present. The HY-Recovery Process will permit the economical recycling of iron units, which can be re-melted as DRI, and the heavy metals as saleable products. Hylsa's largest steelmaking operations are very highly DRI-based and therefore have significantly lower problems with zinc and lead disposal.

The first industrial-scale plant is being planned for Hylsa's North Plant bar mill near Monterrey. The North Plant is an entirely scrap-based operation that produces 460,000 tpy of billets for long products. EAF dust and mill scale for 2000 are estimated to total 8,900 and 4,700 tons respectively. The first HY-Recovery plant will have a capacity of 20,000 tpy and additional material from Hylsa's Flat Products mill can be transported the short distance for processing at the new North Plant facility.

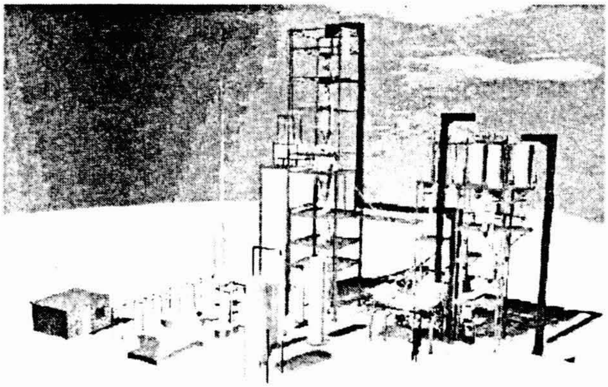

Figure 6. Illustration of HYL HY-Recovery System

The HY-Recovery System offers an ecological and economical solution to dust treatment, with plant sizes ranging from 30,000 to 250,000 tpy of waste oxides.

Hylsa Multiple Slit Rolling Technology

Hylsa's Multiple Slit Rolling technology (Figure 7) allows increased productivity for bar mills. Up to four and five strands from the same billet greatly increase productivity for the same production capacity. Hylsa's Multiple Slit Rolling technology is in operation at the Monterrey North Plant and has also been installed at Sheffield Steel in the U.S.

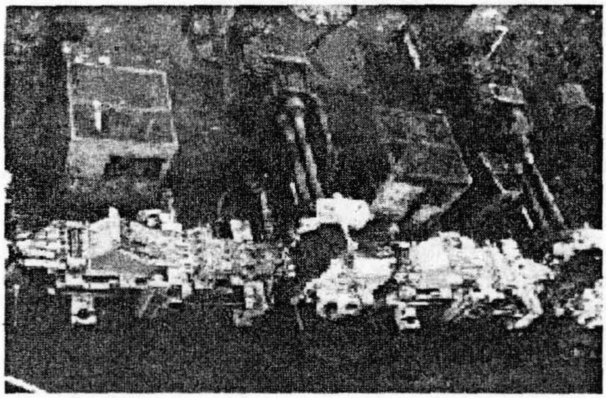

Figure 7. Multiple Slit Rolling Technology, Hylsa North Plant, Monterrey, Mexico

Technology Alliances

Several outside technologies have been implemented at Hylsa, where we have worked in co-development with those companies to improve and provide the technology to others. Among these alliances are:

SMS-Demag

After the installation of the SMS Continuous Strip Processing mill in Monterrey, Hylsa and SMS worked together to jointly develop improvements to the technology that allowed the first successful operation of ultra-thin hot strip rolling (under 1mm). Training and technical assistance has been provided by HYL to SMS customers to achieve this same capability. Additionally, HYL and SMS Demag have signed an agreement to develop and design electric furnaces specifically for DRI melting, including hot charging of DRI to the furnace.

Stantec

HYL and Stantec Global Technologies have formed an alliance to develop applications of Stantec's Goodfellow EFSOP System for EAFs using DRI and HBI. The EFSOP System uses state-of-the-art gas analysis combined with process data acquisition and model-based control to optimize operation of EAF steelmaking operations. Hylsa has successfully installed the EFSOP System at the Monterrey North Plant and is in the process of installing the system at the Flat Products Division minimill as well.

SAP

HYL has been providing services for setting up and customizing SAP software, based on the successful experience in the installation and use of this powerful database software in Hylsa's operating divisions. Hylsa was the first company to have gone live with all the SAP modules in real-time and has gained a wealth of expertise that it makes available to companies in both steel and non-steel industries.

Training and technical assistance programs

HYL has provided over 7,000 man-weeks of training, engineering, consulting services and technical assistance support in the past five years. Services provided to companies around the world covered a range of different specialized areas, including pelletizing, direct reduction, steelmaking production control, maintenance planning and control, total quality, SAP consultancy and other services designed to improve operations and maintenance efficiency for our customers.

Conclusion

While the current state of the steel industry is now in a valley, it is expected to start a recovery stage by next year and continue increasing in the following years. It is then necessary for steel companies to be constantly on the alert for technologies and services that will help them maintain a competitive edge in the market. HYL continues strongly in the development and supply of not only direct reduction technology, but also other technologies and services that will be of significance in improving steel making operations.