Latest Advances in Direct Reduction integrated to Meltshop

By:

Pablo E. Duarte, DR Sales Director, HYL Technology Division, Hylsa, Monterrey, Mexico.

Summary

For more than 40 years, HYL has developed technologies designed to improve Hylsa's steelmaking competitiveness and productivity. The HYL direct reduction (DR) 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 ZR (or 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 operating since 1998. This process scheme has the ability to produce high carbon DRI or High Carbide Iron (HCI®), which allows producers to obtain maximum benefits of carbon in the steel making process, while for merchant sale of the product, eliminating the need for costly briquetting equipment thanks to its highly improved stability.

Additionally, based on the ZR process scheme, HYL is offering an arrangement combining a coal gasifier with the HYL module, for places lacking availability of natural gas.

1. The HYL ZR Process

The HYL ZR Process (Figure 1) is a major step in reducing the size and improving the efficiency of direct reduction plants. Reducing gases are generated by in-situ 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 a ZR plant is typically 10 to 15% lower.

The overall energy efficiency of the ZR process is optimised 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 carburisation, which allows attaining carbon levels up to 5.5%, due to the improved carburising 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. 94% metallisation, 4% 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 remarkable low iron ore consumption of 1.35 to 1.40 t/t DRI, mainly due to high operating pressure.

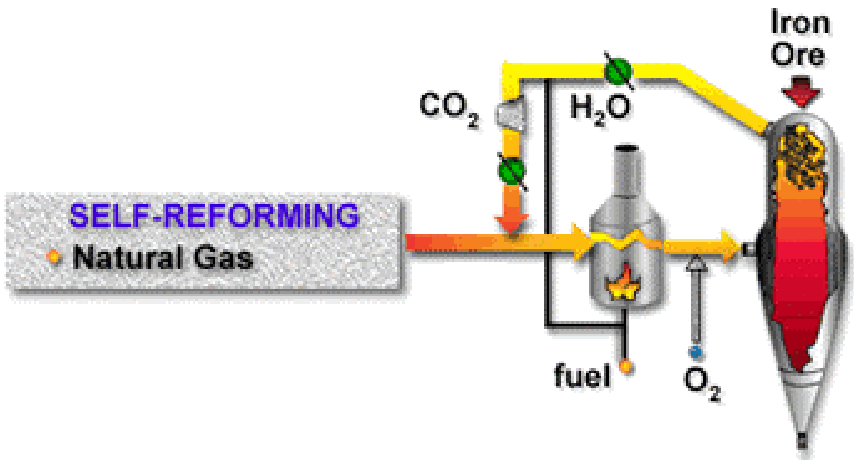


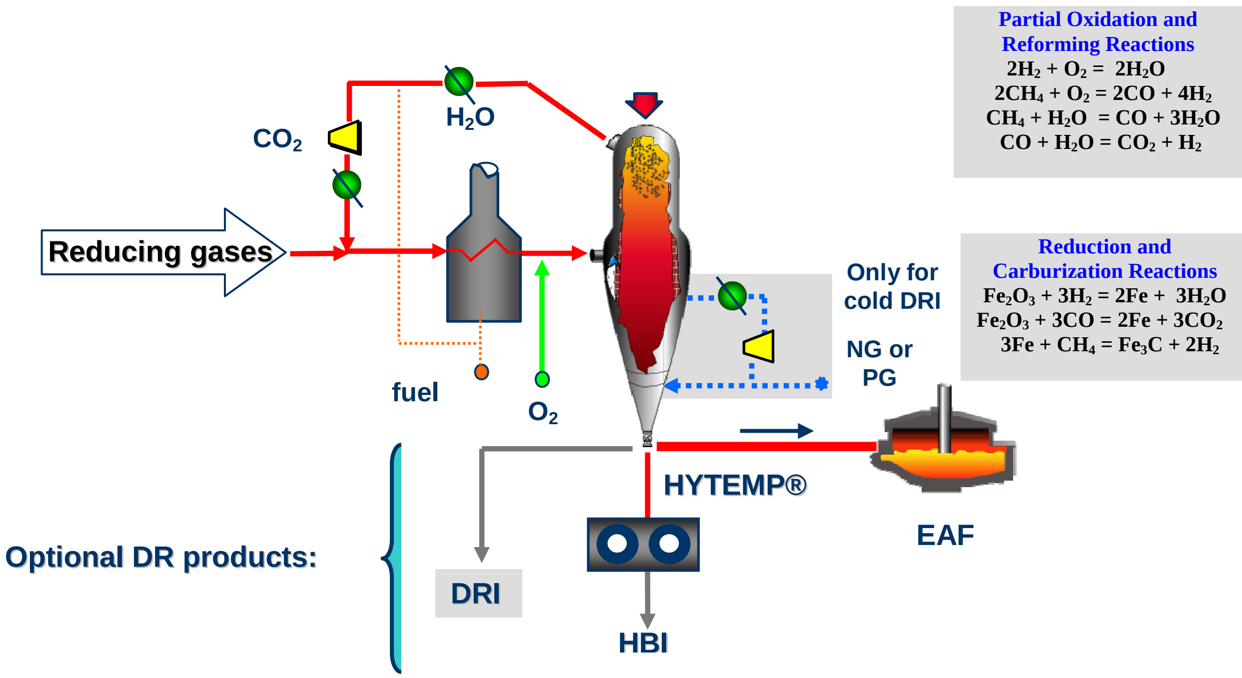
Figure 1. HYL ZR or Self-Reforming Process Diagram

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 since 1998 with the HYL DR 4M plant and was also recently incorporated (in 2001) in the 3M5 plant, both at Hylsa's Flat Products Division in Monterrey.

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.

2. Description of the HYL ZR Process Scheme

The HYL ZR Process is based on the reduction of iron ores with reducing gases, which are generated from partial combustion and in-situ reforming of natural gas, taking advantage of the catalytic effect of the metallic iron inside the reduction reactor. The plant can be designed for production of cold DRI or hot DRI for direct charging to a melting facility. The general scheme of the HYL DR process is shown in Figure 2.



DRI: **for internal use or regional export**

HBI: **as merchant product for export**

HYTEMP® iron: **hot DRI, transported pneumatically to the EAF**

Figure 2. HYL ZR Process Flowsheet

The process scheme includes the following features which, when combined, eliminate the need for a reducing gas generation system:

<u>Partial combustion of the reducing gas:</u> Partial combustion of natural gas with oxygen before the reactor inlet provides the additional energy, which is required for natural gas reforming in-situ, and for the carburisation of the metallic iron.

<u>“In-situ“ reforming in the lower part of the reactor’s reduction zone:</u> Once in contact with the solid inside the reactor, further methane reforming in-situ takes place due to the catalytic effect of the metallic iron.

<u>Adjustable composition of the reducing gas:</u> The level of metallisation and carbon can be controlled independently by adjusting main process parameters and the gas composition.

Because of partial combustion, the reducing gas temperature at the reactor inlet is very high – above 1000°C. Due to the endothermic behaviour of the combined chemical reactions taking place inside the reactor, the resulting temperature at the reduction zone is below the potential condition for material cluster formation.

The reactor operates at elevated pressure (6 bar, absolute), allowing a high reactor productivity of about 10 t/h x m² and minimising dust losses through top gas carry-over. This is reflected in low iron ore consumption, which allows keeping the operating cost low.

One of the inherent characteristics of the HYL process scheme and of high importance for this application is the selective elimination of both by-products generated from the reduction process; water (H_2O) and specifically carbon dioxide (CO_2), which are eliminated through top gas scrubbing and CO_2 removal systems, respectively.

The main characteristics of possible DR products, which can be produced in an HYL DR facility, are presented in Figure 3.

Item/use	DRI on-site consumption	HYTEMP® Iron direct feed to EAF	HBI overseas export
Metallisation	**93–95**	**93–95**	**93–95**
Carbon	**2.5 - 5**	**2.5 - 5**	**1 - 2**
Temperature (°C)	**40**	**> 600**	**40**
Bulk density (t/m^3)	**1.6**	**1.6**	**2.5**
App. density (t/m^3)	**3.2**	**3.2**	**5.0**
Nominal size (mm)	**6–13**	**6–13**	**110x60x30**

Figure 3. DR Products Typical Characteristics

3. DRI quality – HYL High Carbide Iron (HCI)

Carbon in the DRI, mostly as iron carbide (Fe_3C), is derived mainly from methane (CH_4) and in less extent from CO. The level of carbon is adjusted by controlling the reducing gas composition and/or oxygen injection. Most of the carbon in DRI currently being produced in the HYL ZR scheme is in the form of Fe_3C (see Figure 4).

DRI produced with the ZR scheme is characterized by a higher stability than DRI typically obtained in other DR process schemes. The reason for this is the high cementite or Fe_3C content, which inhibits the re-oxidation of metallic iron in contact with air. Most of the Carbon in the DRI is present as Fe_3C. For a carbon content of 4% approximately 95% is present as Fe_3C. In general every 1% of combined carbon corresponds to 13.5% of Fe_3C. A DRI with 4% Carbon contains more than 50% of Fe_3C.

The high percentage of Fe_3C in the DRI of the 4M plant makes the product very stable. This highly improved product has been registered as High Carbide Iron or HCI to distinguish it from typical reduced iron products.

Perhaps the three most significant factors which act to stabilize DRI and reduce or control the reactivity tendency are the carbon content (and form) of the reduced product, the reducing agent itself and the temperature of reducing gases in the process. A combination of these factors makes DRI much more stable than it was in the past, and although it is necessary to follow proper handling procedures, it is evident that the product is now more stable for shipping and handling.

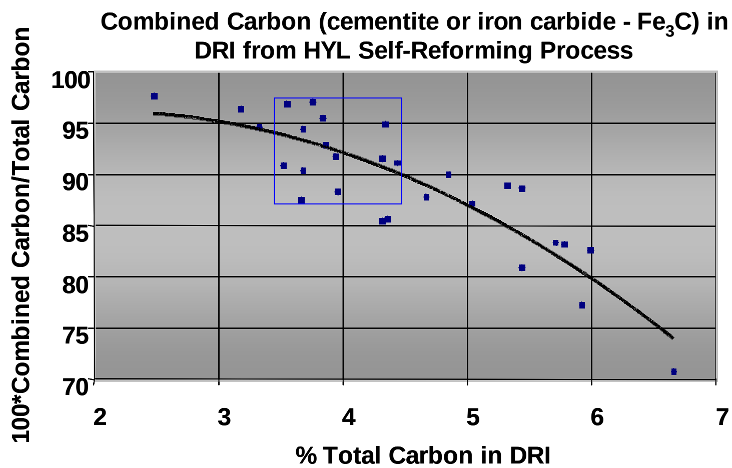


Figure 4. Combined Carbon in DRI

HYL High-Carbide DRI vs. Conventional DRI

HYL ran extensive tests to determine whether the combined carbon in DRI was a factor in improving product stability over that of conventional DRI, whether produced by HYL plants or other process technologies.

Currently, there are two plants operating under the HYL ZR process scheme: the Hylsa Monterrey 3M5 plant produces cold-discharge DRI, and the Hylsa Monterrey 4M plant produces hot-discharge DRI, using the HYTEMP System for hot DRI transport to the meltshop, and cold DRI is also produced via an external cooler.

To the end of December 2004, the accumulated production of high-carbon DRI (94% metallisation, carbon range from 3.5 - 4.2%) from both Monterrey HYL Process plants was more than

In general, HYL High-Carbide Iron is more stable than conventional DRI. This has been proven in specific tests that were performed for DRI being produced at the 3M5 plant, before and after its conversion to the ZR scheme. These test results are included in Figures 5, 6 and 7. Both products were tested in contact with air, in contact with air and water and with salty water, to simulate stability behaviour in contact with seawater. The high-carbide iron produced in the HYL ZR process proved to be significantly more stable due to the protective effect of the combined carbon in the product.

Results of the test with salty water, as per Figure 7, are of relevant importance due to the low risks for HCI overseas transportation.

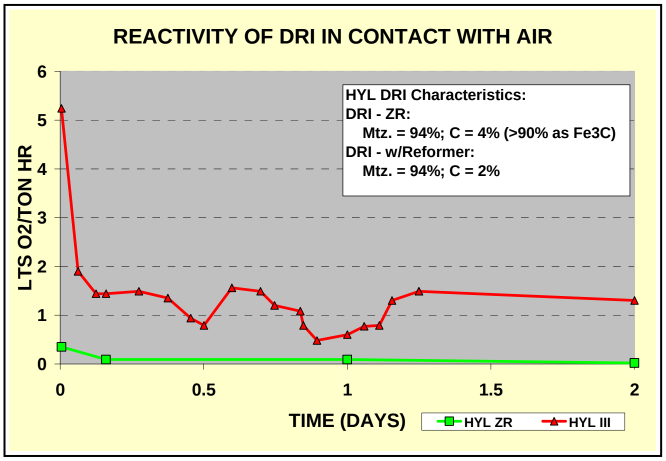


Figure 5. DRI Reactivity with Air

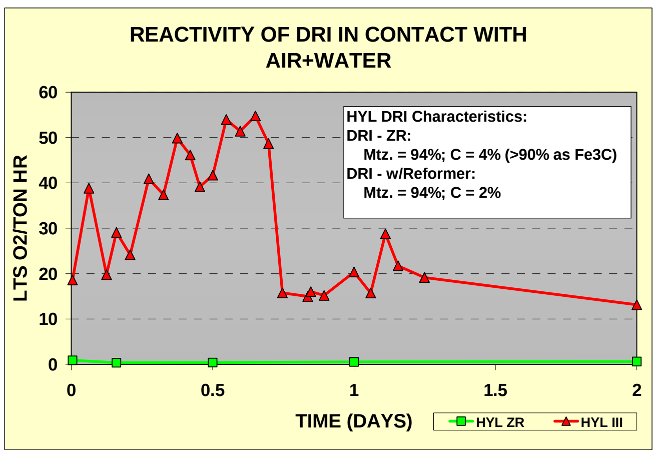


Figure 6. DRI Reactivity with Water

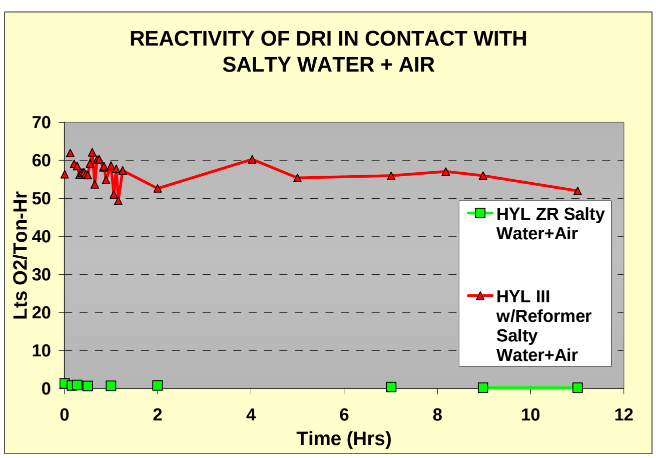
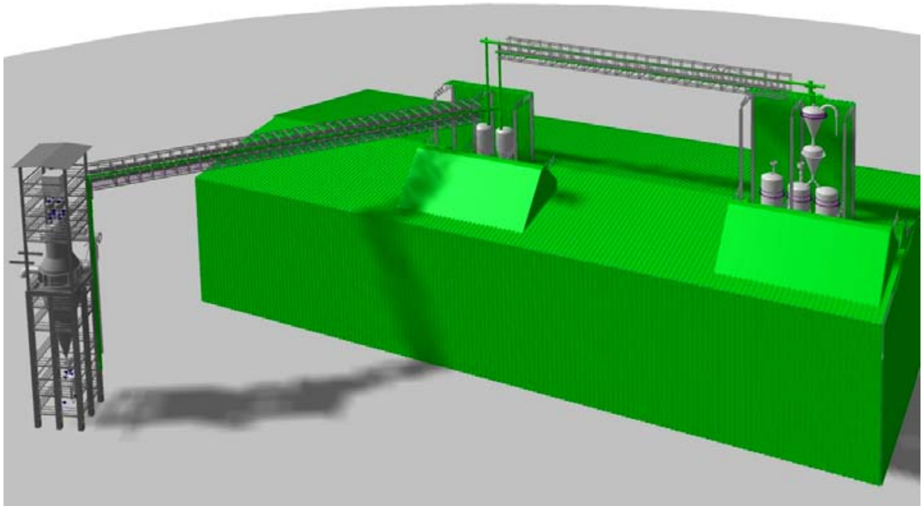


Figure 7. DRI Reactivity with Salty Water

4. Use of high-carbon hot DRI in Hylsa's EAF.

As EAF's need to become more productive, one of the areas for improvement is preheating of the metallic charge. Scrap preheating has been around for some time without much success until recently with the system of preheating on top of the EAF.



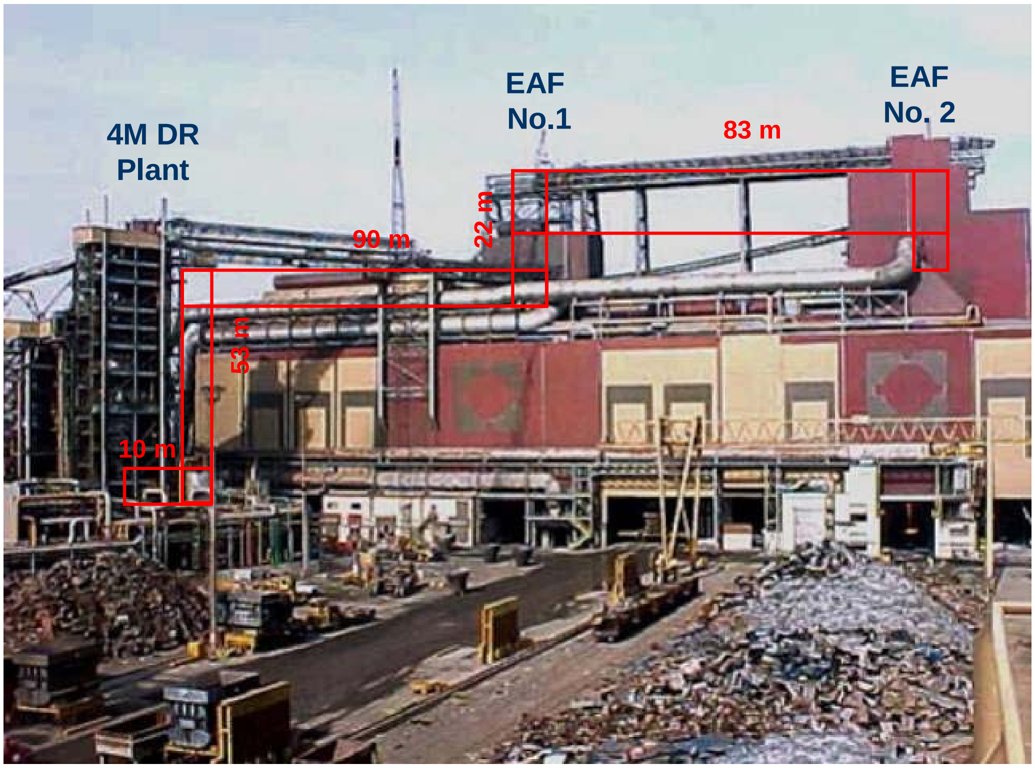


Figure 8
4M-DR Plant – HYTEMP System – EAF's Arrangement

Use of hot DRI is a proven concept in the Hylsa melt shop. In the 4M DR plant at Hylsa Monterrey, the hot DRI is pneumatically transported to 2-EAF's. To date, this is the only proven technology for hot DRI transport-charging to the meltshop. The system is presented in Figure 8 above. In this plant, hot DRI is transported through HYTEMP® and fed to the EAF-DC type of the CSP mill of Hylsa's meltshop. Close to 6 million tonnes of DRI have been transported since initial start-up in 1998.

Benefits of high-carbon hot DRI in meltshop operations has been demonstrated in Hylsa's EAF. Before start-up of operations of the 4M DR plant, only cold DRI to EAF was entirely produced in 2M5 and 3M5 DR plants. Typical DRI quality from these plants was of 93-94% metallisation and about 2.2% carbon. After 4M plant start-up, hot DRI quality has been 94% metallisation and 4% carbon.

The EAF #2 is a Danieli DC-type with capacity of 135 t Liquid Steel (LS)/heat and average active power is 110 MW. The figures included below correspond to EAF operation with different percentages of DRI in the metallic charge, keeping constant the metallisation at 94% for various levels of carbon. Oxygen injection is 25 Nm^3/tLS for 2.2% carbon DRI and 42 Nm^3/tLS for 4% carbon DRI.

High-Carbon DRI

In general, carbon in the DRI provides chemical energy input to the EAF, decreasing electric power requirements. As compared to other sources of carbon injection, cementite in DRI is characterised by a higher recovery yield in the EAF. Besides, EAF's quality carbon is normally available at higher cost than the carbon obtained from natural gas in DRI. Adequate oxygen injection is required to take advantage of this carbon.

Impact of DRI carbon in the EAF is presented in Figure 9. Graphite injection is about 12 kg/tLS for DRI with 2.2% carbon and 0.5 kg/tLS for DRI with 4.0% carbon. For these operating conditions, the change from 2.2% to 4% carbon in cold DRI represents a decrease of 11-kg graphite and 58-kWh/tLS. This power saving is a result of the replacement of graphite by cementite related to yield and heat reaction. In terms of transformation costs, incorporation of high-carbon DRI has been reflected in more than 4-$US/tLS, for Hylsa's particular conditions.

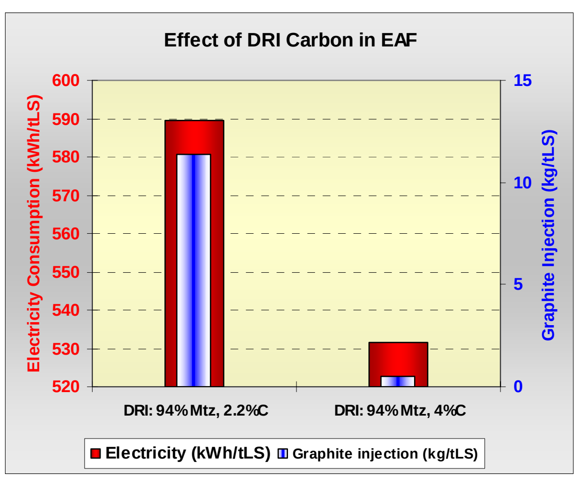


Figure 9. Effect of DRI Carbon in EAF Performance

High-Carbon Hot DRI

Production of high-carbon, high-temperature DRI is reflected in important savings in the meltshop. However, to include the overall system, it is necessary to determine additional costs in the DR plant when producing hot DRI with high carbon content.

Changes of DRI quality and temperature imply variations of energy consumption in the DR plant, mainly related to natural gas and oxygen. The sensitivity analysis for two levels of carbon (2.2% and 4%) in DRI at different feeding temperature to EAF is shown in Figures 11. For these cases, DRI metallisation is constant at 94%.

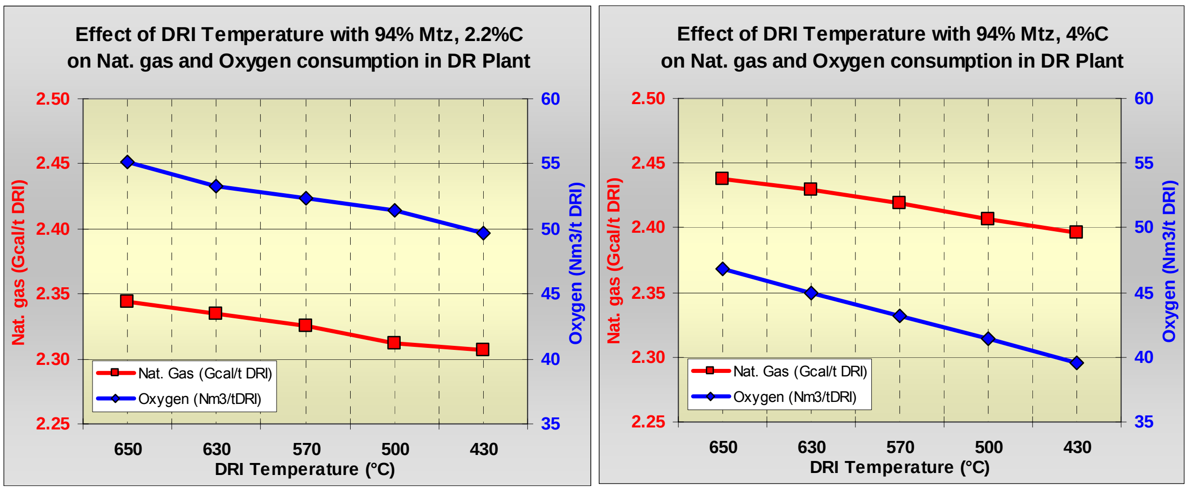


Figure 10. Effect of DRI Temperature on Nat. gas and Oxygen Consumption in DR Plant

On the other hand, hot DRI feed provides additional sensible heat to the EAF, reducing power consumption and tap-to-tap time, which are reflected in productivity increase. Direct feed of hot DRI in Hylsa's meltshop is carried out through HYTEMP® system. Comparative analysis based on results of hot charging to EAF #2 related to electricity consumption are presented in Figure 10 while the effect on power on time –consequently on productivity- are shown in Figure 12.

Data for different percentages of DRI with 94% metallisation and various carbon levels has been included. Difference between cold DRI with 2.2% C (Ref. 1) and hot DRI at 500°C with 4% C (Ref. 2), for 100% charge to the EAF are: a decrease of about 180-kWh/tLS and about 12 min on power on time, which may represent over 25% potential productivity increase.

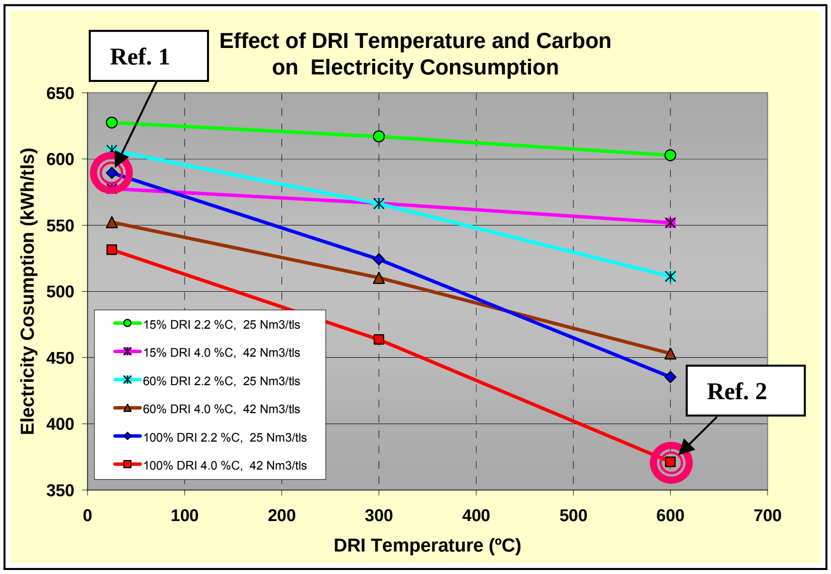


Figure 11. Effect of DRI Temperature and Carbon on Electricity Consumption in EAF

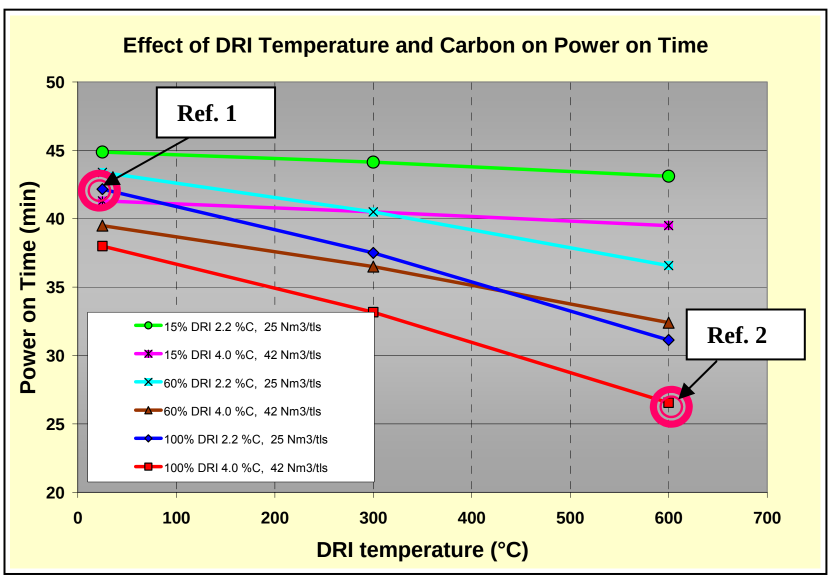


Figure 12. Effect of DRI Temperature and Carbon on Power on Time in EAF

5. Cost Analysis

Based on the above results, indicative cost analysis is presented in Table 1. Although typical cost figures for consumables have been considered, the analysis can be adapted to local cost structure. It can be observed that additional energy cost in the DR facility, required to obtain higher carbon, higher temperature DRI, is almost negligible as compared to the costs savings in the EAF. For 100% DRI charge, impact of carbon, from 2.2% to 4%, is about 2 US$/tLS while an increase of temperature from ambient to 600°C, is over 7 US$/tLS. Besides, the potential productivity increase of liquid steel, up to 36%, is the most important benefit in the EAF, which should be credited when applicable.

Effect of DRI Carbon and Temperature on Liq. Steel Production Cost										
Metallization	**%**		**94**		**94**		**94**		**94**	
Carbon	**%**		**2.2**		**4**		**2.2**		**4**	
Temperature	**ºC**		**25**		**25**		**600**		**600**	
	Unit	Price US$/unit	Consump. Unit/tls	Cost US$/tLS	Consump. Unit/tls	Cost US$/tLS	Consump. Unit/tls	Cost US$/tLS	Consump. Unit/tls	Cost US$/tLS
DR Plant										
Iron ore pellets	t	70	0.97	67.6	0.97	67.6	0.97	67.6	0.97	67.6
Lump ore	t	50	0.41	20.7	0.41	20.7	0.41	20.7	0.41	20.7
Natural gas	Gcal	7.9	2.31	18.3	2.41	19.1	2.33	18.5	2.43	19.3
Oxygen	Nm^3	0.05	50	2.5	41	2.1	53	2.7	45	2.3
Electricity	kWh	0.035	60	2.1	60	2.1	60	2.1	60	2.1
Water	m^3	0.02	1.3	0.0	1.3	0.0	1.3	0.0	1.3	0.0
Other consumables	US$			1.2		1.2		1.2		1.2
Maintenance				3.0		3.0		3.0		3.0
Labour	m-h	7	0.17	1.19	0.17	1.19	0.17	1.19	0.17	1.19
Total DRI cost				**116.7**		**117.0**		**117.0**		**117.4**
EAF										
DRI charge	kg	0.1167	1195.9	139.5						
	kg	0.1170			1217.7	142.5				
	kg	0.1170					1195.9	139.9		
	kg	0.1174							1217.7	142.9
Electricity	kWh	0.035	589.6	20.6	531.4	18.6	435.4	15.2	371.2	13.0
Magnesite	kg	0.39	1.66	0.6	1.5	0.6	1.2	0.5	1.0	0.4
Graphite	kg	0.15	11.35	1.7	0.5	0.1	11.4	1.7	0.5	0.1
Lime	kg	0.05	10.96	0.5	10.9	0.5	11.0	0.5	10.9	0.5
Dolo-lime	kg	0.06	40.81	2.4	40.2	2.4	40.8	2.4	40.2	2.4
Oxygen	Nm^3	0.05	24.99	1.2	42.0	2.1	25.0	1.2	42.0	2.1
Electrodes	kg	2.63	1.57	4.1	1.4	3.7	1.2	3.1	1.0	2.6
Refractories & WCP	US$			2.1		1.9		1.5		1.3
Maintenance	US$			4.0		4.0		4.0		4.0
Direct labour	US$			0.9		0.9		0.9		0.9
Total LS cost	**US$**			**177.8**		**177.3**		**171.0**		**170.2**
Annual Capacity	**ktLS/yr**		**839**		**903**		**1,031**		**1,140**	

Table 1.
Cost Analysis for DR and EAF
for different levels of Carbon and Temperature

6. Alternate Energy Use – Coal Gasification

One of the main advantages of the HYL process is the configuration based on independent reducing gas generation and reduction sections and the selective elimination of both gaseous products from reduction: water (H_2O) and carbon dioxide (CO_2). Under these conditions the only requirement for the reduction process is a pipe supplying the required amount of hydrogen and carbon monoxide with no changes involved in the process scheme. For the HYL process there is a wide flexibility for using alternate sources of reducing gases:

- Hydrogen
- Conventional reformed gas
- Gases from coal gasification processes
- Coke oven gas
- Gases from hydrocarbon gasification
- Gases from smelter gasifiers
- Others.

For DRI production in locations lacking availability and/or low price of natural gas, HYL is offering an approach based on a coal or other carbonaceous fuel as source of reducing gas to a standard HYL ZR DR module. By using synthesis gas (syngas) from a gasifier as source of reducing agents, the amount, quality and conditions of the gases required for the reduction process are the most important parameters for definition of the most adequate gasifier-DR scheme. Characteristics of this syngas can be adjusted through gas conditioning to enhance H_2 content. Scheme reference is included in Figure 13 below.

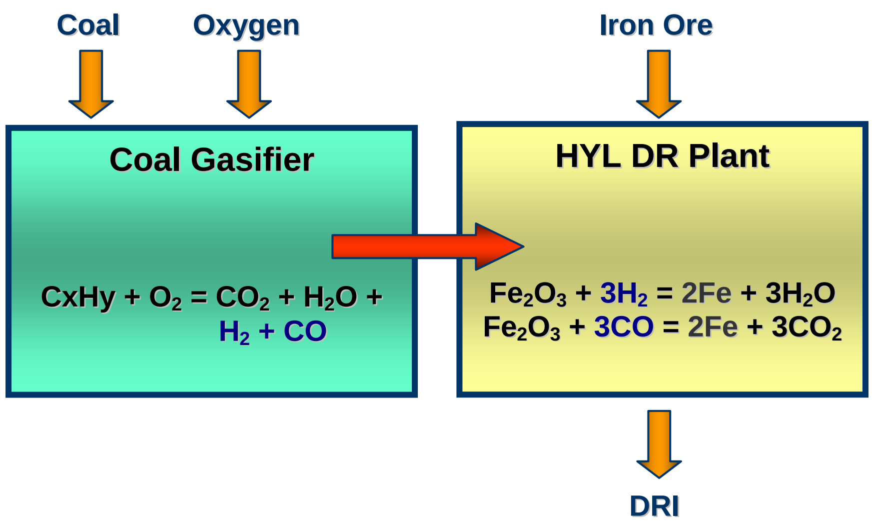


Figure 13
HYL DR plant with Coal Gasifier - General Arrangement

7. Coal gasification: general background

Gasification refers to the partial oxidation of a fossil fuel, forming syngas which consists primarily of hydrogen (H_2) and carbon monoxide (CO). The HYL process is characterized by the use of H_2-enriched gas and most gasifiers produce syngas with suitable analysis for use in the DR process. Gasification or partial oxidation consists of converting low-grade fuel that is often "dirty" (such as coal, refinery residues and biomass). The partial oxidation reaction for carbon is:

$$C + 1/2\ O_2 = CO$$

This reaction is exothermic and thus, water is introduced into the gasifier in the form of steam or liquid water to moderate the temperature of the reaction by the endothermic reaction:

$$C + H_2O = H_2 + CO$$

Other reactions that occur within a gasifier are the shift reaction:

$$CO + H_2O = H_2 + CO_2$$

and the hydro-gasification reaction:

$$C + 2H_2 = CH_4$$

The sulfur present in the feed is evolved mostly as H2S with some as COS. CS2 and mercaptans are insignificant when the gasification reaction occurs at high temperature (>1090°C).

For a typical syngas analysis, the total requirement of gas is shown in Figure 14 below.

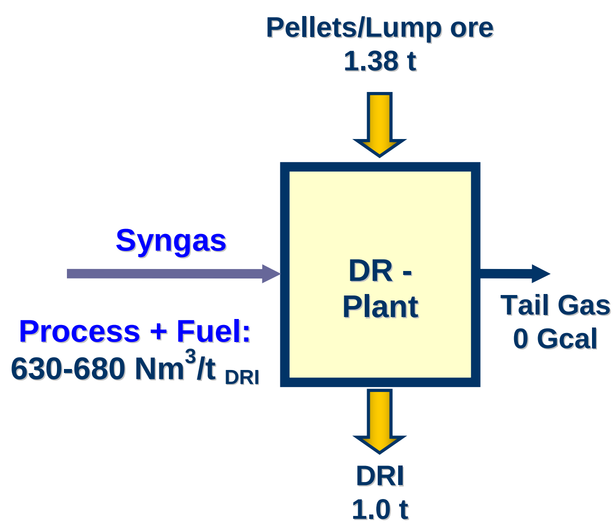


Figure 14
Syngas Requirements to HYL-ZR DR Plant

For any DR process, carbon from the reducing gases make-up (either in the form of CO or CH_4) must be eliminated from the DR plant. Typically for other DR process, this carbon is purged from the system via tail gas, which is used as fuel in reforming/heating equipment. In the HYL process, due to selective carbon elimination through CO_2 removal, the purge is minimized and recycling/reuse of reductants is maximized thus optimizing reducing make-up requirements. Because of this fundamental reason, for other DR processes this application is only possible by implementing: 1) once-through or 2) partial recycling configurations, as shown in Figure 15 below, demanding more than necessary syngas make-up.

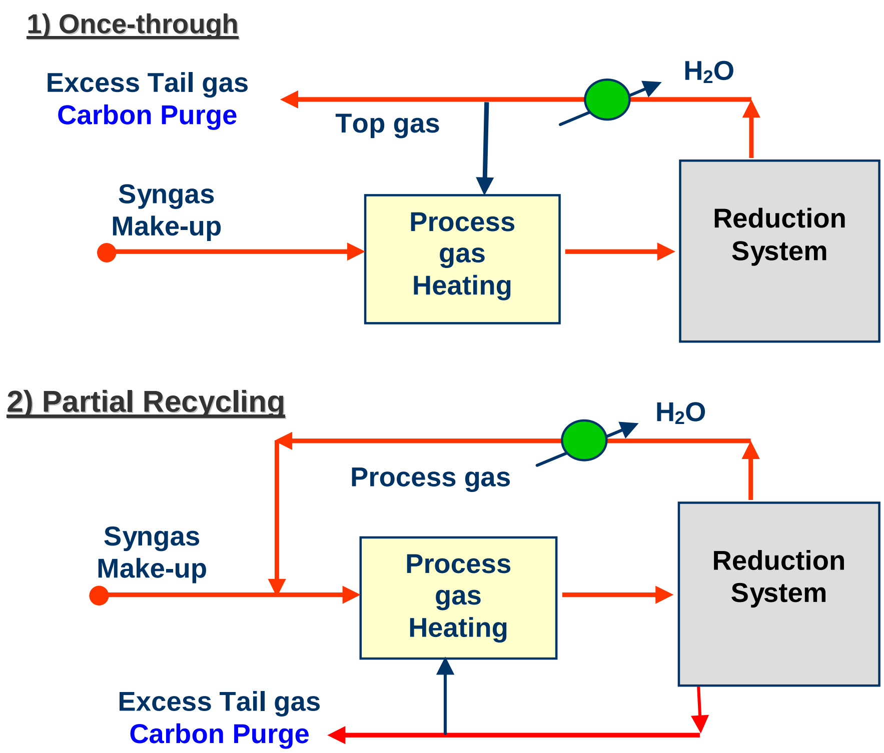


Figure 15
Possible Gasification-based Configurations for Other DR Processes

For the HYL process, the application of the ZR scheme is direct and natural, minimizing the process syngas needs, as shown in Figure 16 below.

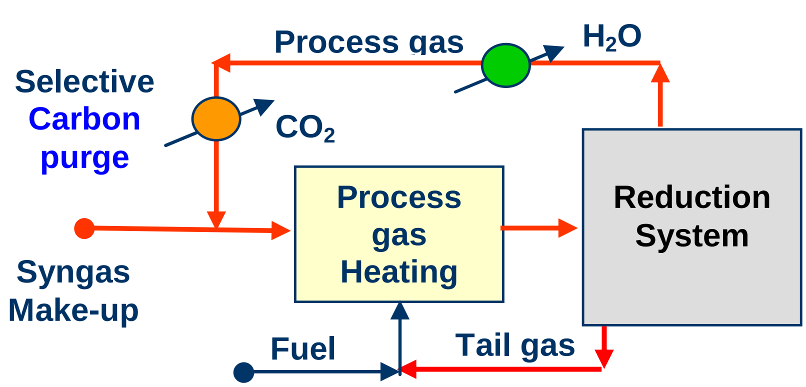


Figure 16
Gasification-based Configurations for HYL DR Process

8. HYL - Gasifier scheme

As presented in Figure 6 below, the treated, H_2-enriched syngas from the gasifier is fed to the standard HYL ZR DR plant. Adequate CO_2 removal from the syngas optimizes the reuse of top-recycle gas. The mixture of syngas make-up and recycle gas is preheated in a direct gas heater up to 930° C and fed to the reactor. After reduction of iron ores in the DR reactor, top exhaust gas is passed through a scrubbing unit for dust removal and cooling. The gas is then recycled by the compressor. To further decrease energy consumption, a top gas heat recuperator can be incorporated.

Specific requirements of syngas per tonne of DRI correspond basically to the typical make-up of the conventional HYL gas scheme (about 685 Nm3/t DRI). In case of a steel mill, pneumatic transport of hot DRI (HYTEMP®) to the Electric Arc Furnace (EAF) has been incorporated as part of the basic plant arrangement.

This scheme is similar to the plant arrangement of the 4M DR plant at Hylsa, in Monterrey, Mexico, described above.

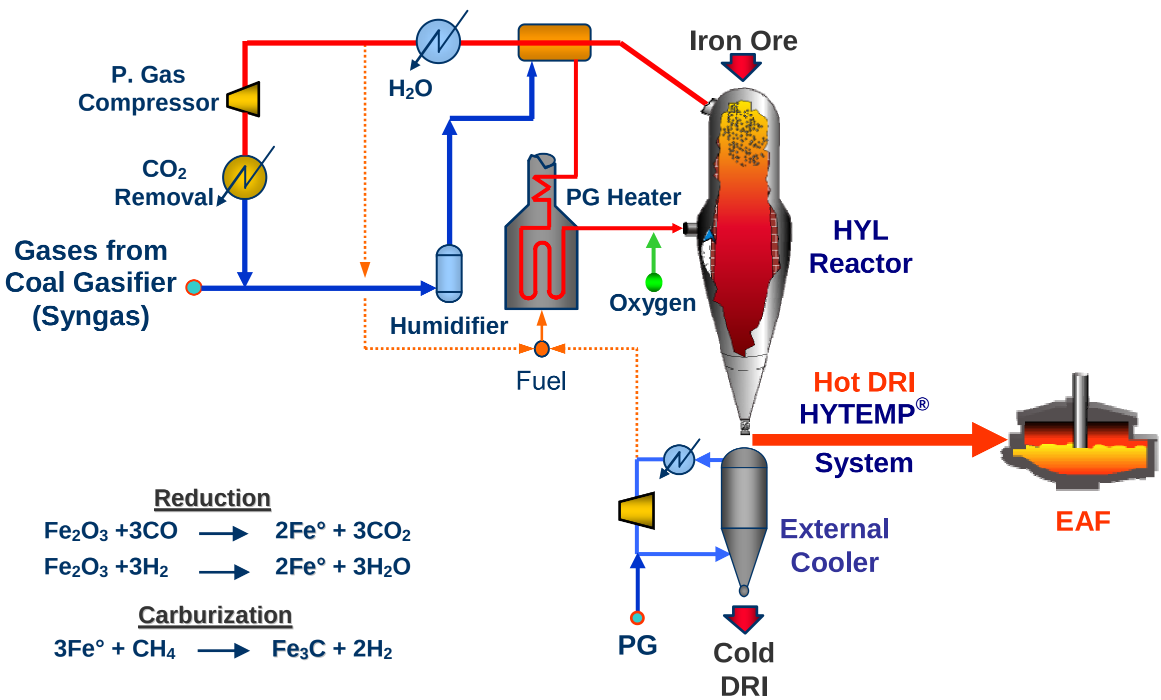


Figure 17
HYL-ZR DR Plant with Syngas from Gasifier

By comparing the scheme based on syngas with the conventional ZR scheme (refer to Table 2 below) it can be noticed the similarity of reducing gases entering the DR reactor; hence no technological risk is foreseen for this application. Based on the analysis of treated syngas (typically from a Lurgi gasifier), expected DRI characteristics for coal-syngas are 93% metallization and up to 2% carbon.

Item Vol. %	Syngas Make-up	NG Make-up	Syngas to Reactor	ZR to Reactor
H_2	55		54	55
CO	25		20	14
$CH_4 + C_nH_m$	16	97	18	22
CO_2	2	2	2	3
H_2O	0		4	5
$(H_2+CO)/(CO_2+H_2O)$			13	9
N_2	1	1	4	2

Table 2
Comparative Reducing Gas Analysis

Depending on particular applications, optional schemes, which can be incorporated are:

- *In plant electrical generation*
  This is achieved by installing a turbo expander in the treated syngas stream before being fed to the DR module. This allow potential power savings of about 3-6 MW (depending on gasifier technology) for typical plants of 1.2 MM tpy DRI by taking advantage of the gasifier high operating pressure.

- *Carbon dioxide (CO_2) recovery*
  For sale as by-product.

9. Most suitable DR technology for using syngas from coal gasification

When comparing the basic HYL Process scheme to the one required for syngas from coal gasification, the following main aspects related to the HYL Process application can be easily noticed:

- *General process scheme*
  No major changes and innovations are required in the basic process scheme. The reduction section is incorporated as it is in typical HYL ZR plants.

- *H2-rich gases use in DR plants*
  Syngas is conditioned through shifting and CO2 removal to produce the H_2-rich gases which characterize the HYL Process.

- *Optimization of Process syngas consumption*
  Recycling of reducing gases, through CO_2 removal, minimizes syngas make-up.

- *HYTEMP® Iron use*
  Potential incorporation of the HYTEMP® System for use of hot DRI to the EAF leads to important economic benefits related to power savings and productivity increase. The HYTEMP® iron presents a unique option as alternate product for integrated steelmaking facilities based on the use of syngas from coal gasifiers.

10. Overall Plant Performance

As compared to other existing and emerging coal-based DR technologies, this scheme offers the possibility to install a DR plant of any size up to 1.6 million tonnes/year of DRI in a single module. This approach is based on the incorporation of proven technologies: Gasifier unit and HYL DR plant. Expected plant performance figures, including an example of DRI operating cost estimate is presented in Table 3.

DR Plant	Unit	Unit Cost	**HYL DR Module based on Syngas** 70% pellets; 30% lump ore	
Metallisation	%		≥ 93	
Carbon	%		2.5	
DRI Temperature at EAF	°C		600	
Concept		US$/unit	**Specific Consumption**	$US/t DRI
Pellets	t	60.0	**0.97**	57.96
Lump ore	t	45.0	**0.41**	18.63
Total Syngas	Nm3	0.033	**625**	20.38
Electricity	kWh	0.05	**65**	3.25
Oxygen	Nm3	0.05	**5**	0.25
Water	m3	0.02	**1.0**	0.02
Other consumables	$US			0.50
Variable Cost	**$US**			**100.99**
Maintenance	$US			3.01
Labour	m-h	3.00	**0.17**	0.51
G&A	$US			1.00
Fix Cost	**$US**			**4.52**
Total Operating Cost	**$US**			**105.51**

Table 3
HYL DR plant with Coal Gasifier
Expected Operating Performance and Operating Cost Estimate (Example)

These figures are based on the syngas analysis shown in Table 2.

11. HYL DR Modules

HYL currently offers the following standard single-reactor modules:

- Micro-Module: 200,000 tpy
- Mini-Module: 500,000 tpy
- Midi-Module: 800,000 tpy
- Mega-Module: 1,200,000 tpy
- Macro-Module: 1,600,000 tpy

The HYL Micro or Mni-Module is a low capacity plant with a significantly lower investment cost than the typical DR plant, and which offers shorter construction time to reach full production. The plant is a simple yet technologically advanced design and produces high quality, high carbon DRI at production cost, which is attractive to the quality EAF steel producer.

Advantages of a DR Micro-Module or Mini-Module in a Minimill

For steel mills, a DRI integrated facility presents a number of advantages: DRI would be available on-site, allowing steel production to be less dependent on prevailing market fluctuations and conditions relevant to the metallics. Liquid steel quality is improved by the availability of DRI, thus enabling the minimill to meet any finished product specification. Additionally, the steel mill would benefit from flexibility in DRI quality in terms of metallisation and carbon, depending on the particular steelmaker requirements. There are also implicit cost benefits, since the cost of briquetting is avoided when buying HBI. Furthermore, the DRI production rate can be tailored to meet the metallics requirements of the minimill, thereby avoiding financial participation and off-take commitments in external high capacity DRI plants.

Besides the advantages for a minimill of an integrated DR plant, the HYL Micro-Module or Mini-Module concept presents features, which are reflected in benefits associated to both operating and investment costs. Among these features, the following are the most important:

- Small plant size. The main hurdle to integrate DR plants in minimills have been the investment cost associated with conventional (high capacity) DR plants, which makes the installation of DR plants in general not attractive for minimills. With this in mind, the Micro-Module and Mini-Module have been developed under an optimised concept for a low investment cost DR plant with a capacity of 0.2 – 0.5 Mtpy. This range of plant size was selected to cover most cases for the required amount of virgin metallics.
- Low investment cost. Adapting the latest developments and improvements of the HYL Technology based on the ZR process scheme has significantly reduced the specific capital investment.
- Optimised process design. Specific optimisation of process parameters, as a result of the industrial operation of the Hylsa 4M DR plant, has been incorporated in the design of the HYL Mini-Module.
- Prefabricated equipment (skid-mounted, modular design). There has always been an economic compromise between prefabricated equipment and erection time.
- Short erection time. As mentioned above, this is the result of modular design and prefabrication of most equipment.
- Compact, optimised layout. The required area for a Mini-Module of 0.5 Mtpy (Figure 1) is only 52.5 m x 70.0 m, which can be easily implemented in existing facilities.
- Synergy by using existing and/or common utilities/services. Most of the existing infrastructure and utilities; i.e. oxygen plant, water systems, etc., can be utilised and/or modified to serve the Mini-Module. In such cases, additional investment can be reduced.

Other inherent characteristics of the HYL Micro-Module or Mini-Module are related to plant simplicity. The simple and compact plant allows for low maintenance cost and minimum manpower requirements. The plant is also easy to operate and has low operating costs, basically due to its flexibility in processing a wide range of cheaper iron ores (pellets/lumps), and the uniformity of the finished DRI product.

12. Conclusions

The HYL ZR process has the flexibility to produce cold and/or hot High Carbide Iron, which allows producers to obtain maximum benefits of temperature and carbon in the steel making process, while for merchant sale of the product (cold DRI), eliminating the need for costly briquetting equipment thanks to its highly improved stability.

On the other hand, the route of coal gasifier feeding H_2-rich gases to an HYL DR unit offers a reliable technical solution for coal-based DRI production. As compared to available and emerging technologies, this approach presents major advantages related to:

- Use of commercially proven and reliable technologies; commercial gasifier and HYL ZR DR plant.
- Production of uniform DRI quality resulting in uniform steel qualities.
- Use of low-grade fuels including low-grade least-cost coals and coal fines, which characteristics do not affect final DRI product quality.
- Competitive liquid steel production in EAF when comparing HYTEMP® vs. hot liquid iron + DRI.
- Proven operation practices for most EAF's when feeding DRI.
- Low environmental impact; the gasifier and DR plant are designed to operate to stringent environmental regulations and produces by-products which are marketable or acceptable for non-hazardous landfills. Main by-products are: inert slag, sulfur cake, carbon dioxide and iron ore fines. DRI dust pollution is avoided due to enclosed HYTEMP® system.

The concept of the HYL Micro-Module or Mini-Module offers a unique possibility for local low-size steel mills to have a DRI integrated facility, with inherent benefits related to less dependency on metallics market fluctuations in terms of price and availability, and enabling the minimill to meet any steel product specification. The small DR module has higher flexibility for processing wider range of pellets and lumps available with no technological risks, since it is based on the successfully proven HYL ZR technology, in operation at industrial scale since 1998.

13. References:

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3. Pablo E. Duarte; Klaus Knop; Peter Masloch. The HYL Mini-Module Concept: The Optimum Integration of a DR Plant in Minimills. MPT International 4/2002.