HYL Direct Reduction Technology: Adaptations for the Indian Market

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Abstract

One approach for large DRI production units in India can be based on coal-based gasification linked to a conventional HYL Self-Reforming (ZR) plant. Currently, most of the available coal-based DRI technologies rely on the combination of ore either as fines or lump and coal, which at first glance, makes economical sense for locations lacking natural gas at low price/availability. However, they present limitations in plant size and product qualities. Rotary kiln coal-based DR plants, based on single module, are designed for up to a maximum of 0.250 M tonnes per year (million tpy) of DRI, requiring high capital cost for larger capacities.

When using ore fines and coal, gangue and sulfur stemming from coal is normally reflected in higher transformation costs in the steelmaking step. Additionally, most of the new coal-based DR processes require implementation of novel technologies still not proven at commercial scale.

To counter these potential disadvantages HYL is suggesting an approach based on a gasifier for carbonaceous material feeding syngas to a standard HYL ZR DR module.

This scheme presents low production cost per tonne of liquid steel, as compared to other technologies. Main reasons are: potential production of hot DRI (HYTEMP® system), optimization on gasifier size and operation mode, use of low-grade fuels (coal, heavy residuals, or emulsions or petroleum coke) with no influence on DRI quality, uniform steel qualities, minimum environmental impact, etc.

As compared to other existing and emerging coal-based DR technologies, this scheme offers the flexibility to install a DR plant of any size up to 1.6 million tonnes/year of DRI in a single module, using various gasifying units.

A second approach is focused on HYL Micro-Modules of 200,000 tpy DRI, based on natural gas (NG), to fulfill small steelmakers' onsite needs. Proper engineering to simplify plant design and equipment sourcing, mostly of local supply, has achieved a feasible natural gas-based DR plant of small capacity.

This paper focuses on the technical solution for the combination of coal gasifier and the HYL DR plant and the application of the Micro-Module to supply the DRI Indian market. These solutions are capable of providing the Indian market with reliable and proven technology, high product quality and attractive operational and investment costs.

1 Overview

1.1 Coal-based DR Processes

Important limitations among other coal-based DR processes are: size of single module-plants available, restrictions on the use of high sulfur coals, undesirable amount of gangue and sulfur in the DRI product, unproven technologies and high operating costs. A summary of existing and emerging coal-based DR processes is included in Table 1.

Table 1
Coal-based DR Processes

Process	Raw material	Product	Largest single module ($x10^6$ t/y)	Status
ACCAR/Grate Car	fines	solid	0.35	operating
AISI/Cyclone	fines	molten	0.50	pilot plant
AISI/Pellet	pellets	molten	0.35	development
Circofer	fines	solid	0.50	lab scale
Corex	pellet/lump	molten	1.20	operating
DIOS	fines	molten	1.00	pilot plant
DRC	pellet/lump	solid	0.15	operating
Fastmet	fines	solid	0.45	pilot plant
Finex	fines	solid	0.25	development
HIsmelt	fines	molten	0.50	pilot plant
INMETCO	fines	solid	0.30	pilot plant
Romelt	fines/lump	molten	0.40	pilot plant
SL/RN	pellet/lump/fines	solid	0.25	operating
Tecnored	fines	molten	0.30	pilot plant

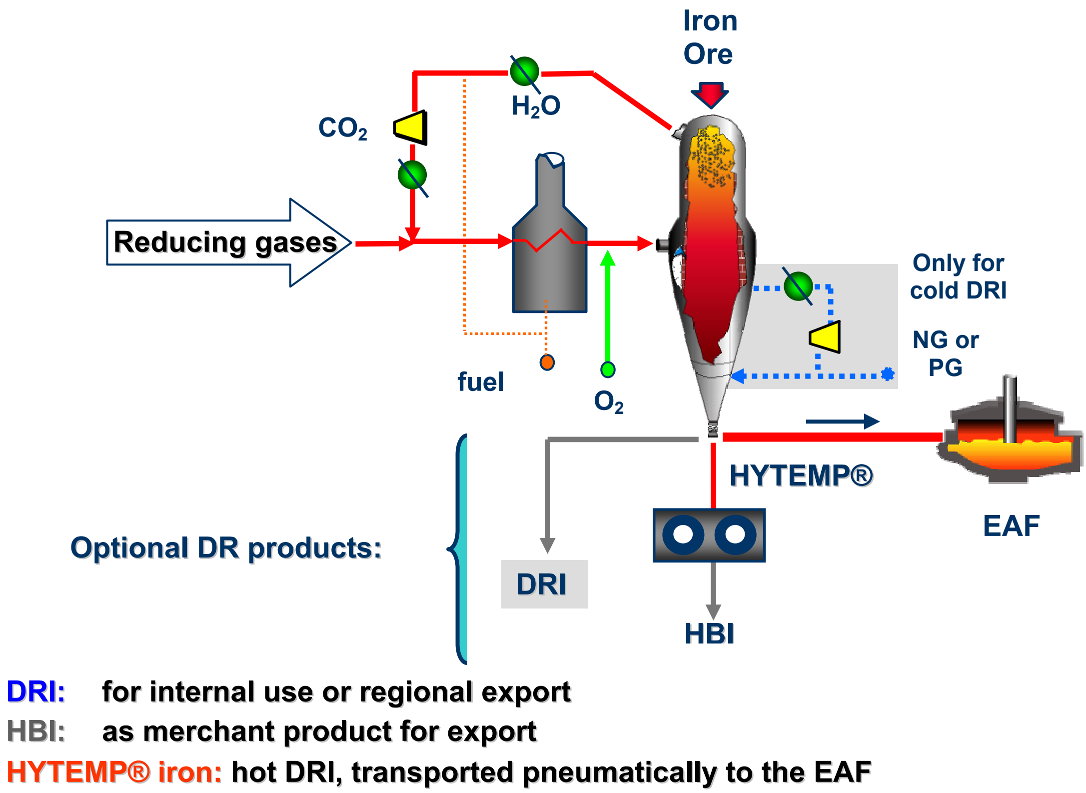
Most of the processes available are of limited capacity, have high investment requirements or are commercially unproven.

1.2 General outline on HYL DR Technology

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). As it can be observed from Figure 1 below, 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:

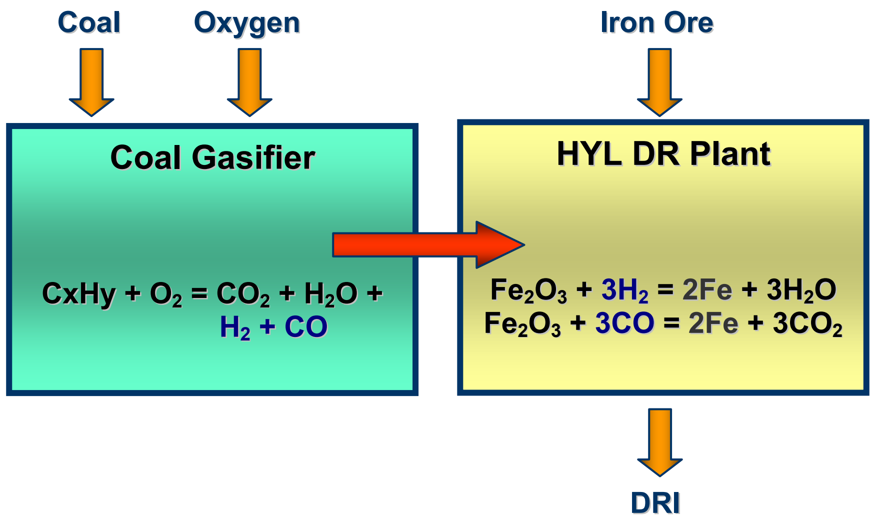
- Hydrogen
- Conventional reformed gas
- Gases from coal gasification processes
- Coke oven gas
- Gases from hydrocarbon gasification
- Gases from smelter gasifiers
- Others.

Figure 1
HYL General Process Scheme and Product Options



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 2 below.

Figure 2
HYL DR plant with Coal Gasifier
General Arrangement



2 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 H_2S with some as COS. CS_2 and mercaptans are insignificant when the gasification reaction occurs at high temperature (>1090°C).

There are three major types of gasifiers:

1. The moving bed gasifier as exemplified by the Lurgi gasifier consists of introducing coarse solids at the top of the gasifier while the oxidant and steam are introduced at the bottom of the gasifier. The gasifier may be divided into four distinct zones: **(1)** the top being the drying/preheating zone followed by **(2)** the devolatilization zone followed by **(3)** the gasification zone and at the bottom **(4)** the combustion zone. The gases that leave at the top of the gasifier contain H_2, CO, CO_2, H_2O, CH_4 and other hydrocarbons including oils and tars as well as other organic compounds, sulfur compounds such as H_2S, COS, some CS_2 and mercaptans, nitrogen compounds such as NH_3 and HCN. The tars also contain some sulfur and nitrogen. The thermal efficiency of the gasifier is high but since it produces the tars and oils, the gas clean up is more complex, and the gasifier cannot handle fines in the feed. The British Gas Lurgi gasifier which is similar to the original Lurgi in many respects, however, recycles the tars and oils separated from the gas to the gasifier by introducing these components in to the bottom section of the gasifier along with fines.

2. The fluidized bed gasifier as exemplified by the Kellog Rust Westinghouse gasifier consists of introducing dried feed that is typically less than 6 mm size, at the bottom of the gasifier and accomplishing devolatilization and gasification in the bed fluidized by the oxidant and steam. Recycle synthesis gas may also be used to maintain the required gas velocity for fluidization of the bed material. The bottom of the gasifier where oxidizing conditions prevail, the temperature is high enough to fuse the ash particle together to form agglomerates while in the top section of the gasifier where gasification reactions predominate, the temperature is in the neighborhood of 980° to 1040°C. The gases leaving the gasifier are essentially free of hydrocarbons heavier than CH_4.

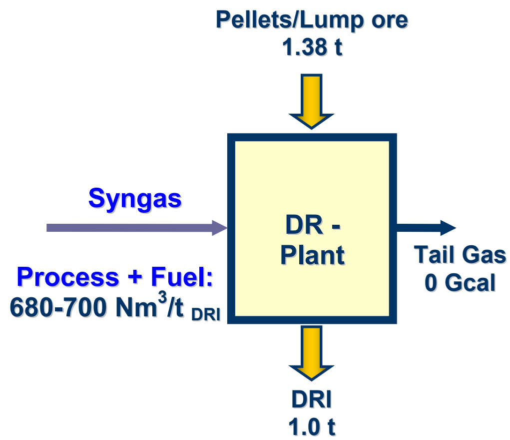
3. The entrained bed gasifier as exemplified by the Noell, Texaco and Shell gasifiers consists of introducing finely ground feed in the case of solids, or liquid feed into the gasifier along with the oxidant and steam or liquid water as the moderator. In the case of the Texaco gasifier, the solids are introduced in the form of water slurry while in the case of the Noell and Shell gasifiers, the solid feed is fed dry and requires drying prior to grinding the solids and steam as the temperature moderator. The gasification occurs at temperatures typically in excess of 1200°C with the ash forming a slag while the gases leaving the gasifier are free of any hydrocarbons, especially those heavier than CH_4.

The raw gas leaving a gasifier is cooled either by a heat exchanger while generating steam or is directly quenched with water if the gas contains particulates that are in the molten or semi-molten state. The cooled gas is purified by further treatment to remove the particulates, alkalis, chlorides as well as the nitrogen and sulfur compounds.

From an environmental point of view, the high normal operating temperatures eliminate the formation of tars and phenols and sulfur is not emitted to the atmosphere but converted to a saleable sulfur byproduct.

For a typical syngas analysis, the total requirement of gas is shown in Figure 3 below.

Figure 3
Syngas Requirements to HYL-ZR DR Plant



3 HYL Direct Reduction Process

HYL is a process designed for the direct reduction of iron ores by use of reducing H_2 and CO gases. As presented in Figure 1 above, there are three process schemes available for producing:

DRI: Cold DRI discharge is commonly used in an adjacent meltshop close to the DR facilities. It can also be shipped and exported, provided some procedures are followed to avoid reoxidation.

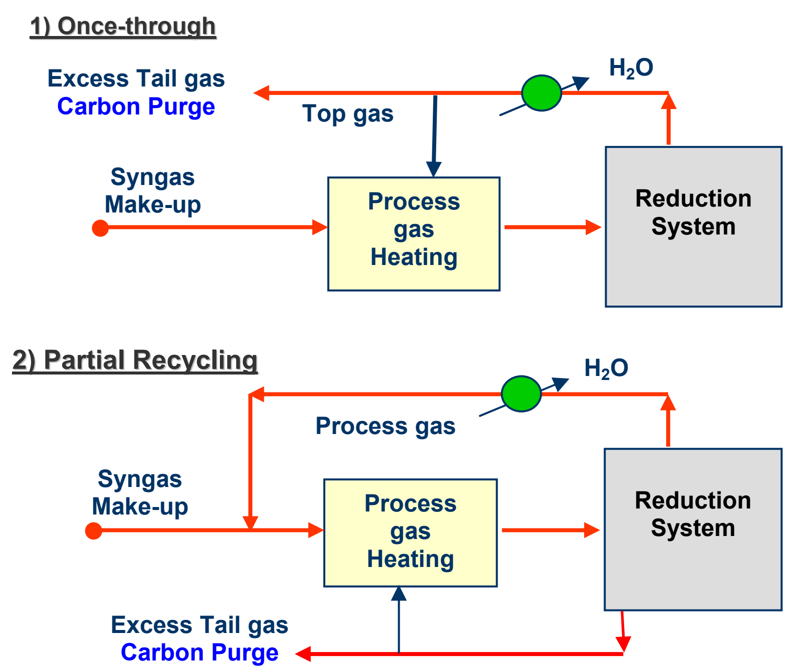
HBI: DRI hot discharged and briquetted, most commonly used in merchant plants for overseas export.

HYTEMP® iron: Hot discharged DRI pneumatically transported from the DR plant to an adjacent meltshop for its direct feed in the EAF.

As can be observed, the HYL process scheme features the best flexibility for adapting to different reducing gas sources. As commented before, the unique configuration of the HYL process is the best scheme for this particular application. The reason is the selective elimination of H_2O and CO_2 from the reduction circuit, which provides the optimization of the syngas consumption.

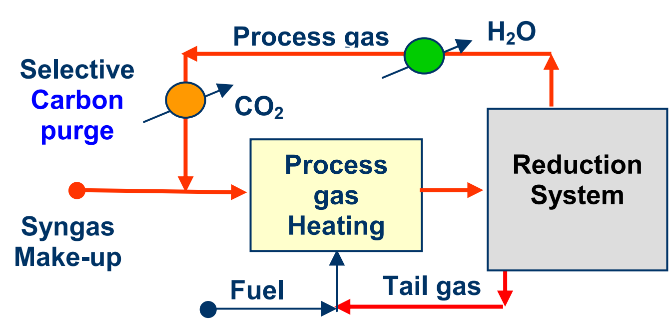
For any DR process, carbon from the reducing gases make-up (either in the form of CO or CH_4) must be eliminated from the DR plant. Typically for other DR process, this carbon is purged from the system via tail gas, which is used as fuel in reforming/heating equipment. In the HYL process, due to selective 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 4 below, demanding more than necessary syngas make-up.

Figure 4
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 5 below.

Figure 5
Gasification-based Configurations for HYL DR Process



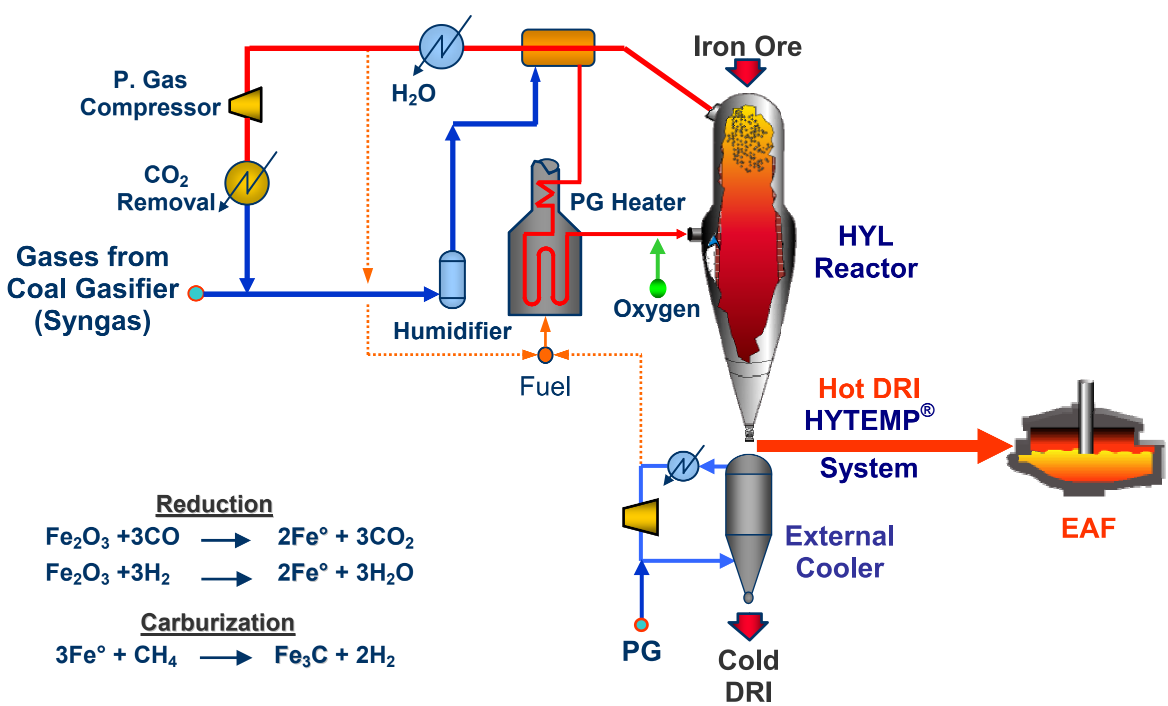
3.1 HYL - Gasifier scheme

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 Nm^3/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. 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.

Figure 6
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.

Table 2
Comparative Reducing Gas Analysis

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

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.

3.2 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.
- *H_2-rich gases use in DR plants*
  Syngas is conditioned through shifting and CO_2 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.

3.3 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.

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

DR Plant	Unit	Unit Cost	HYL DR Module based on Syngas 70% pellets; 30% lump ore	
Production	tpa		1,200,000	
Metallisation	%		≥ 93	
Carbon	%		2.0	
DRI Temperature at EAF	°C		600	
Concept		US$/unit	**Specific Consumption**	$US/t DRI
Pellets	t	37.0	**0.97**	35.74
Lump ore	t	32.0	**0.41**	13.25
Total Syngas	Nm3	0.033	**685**	22.34
Electricity	kWh	0.05	**65**	3.25
Oxygen	Nm3	0.05	**5**	0.25
Water	m3	0.02	**1.0**	0.02
Other consumables	$US			1.20
Variable Cost	**$US**			**76.05**
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**			**80.57**

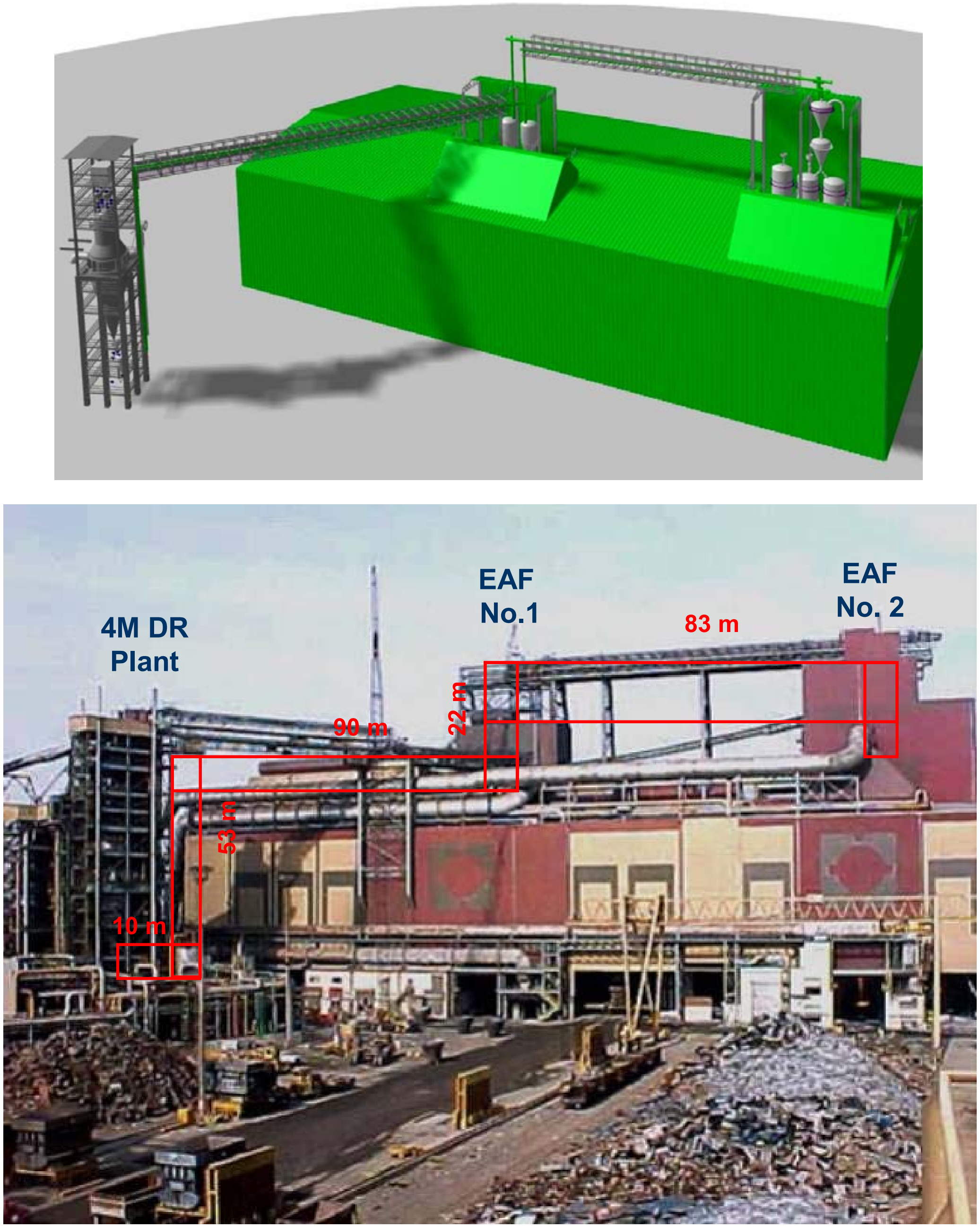
These figures are based on the syngas analysis shown in Table 2.

4 Use of hot DRI

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.

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 7.

Figure 7
4M-DR Plant – HYTEMP System – EAF's Arrangement

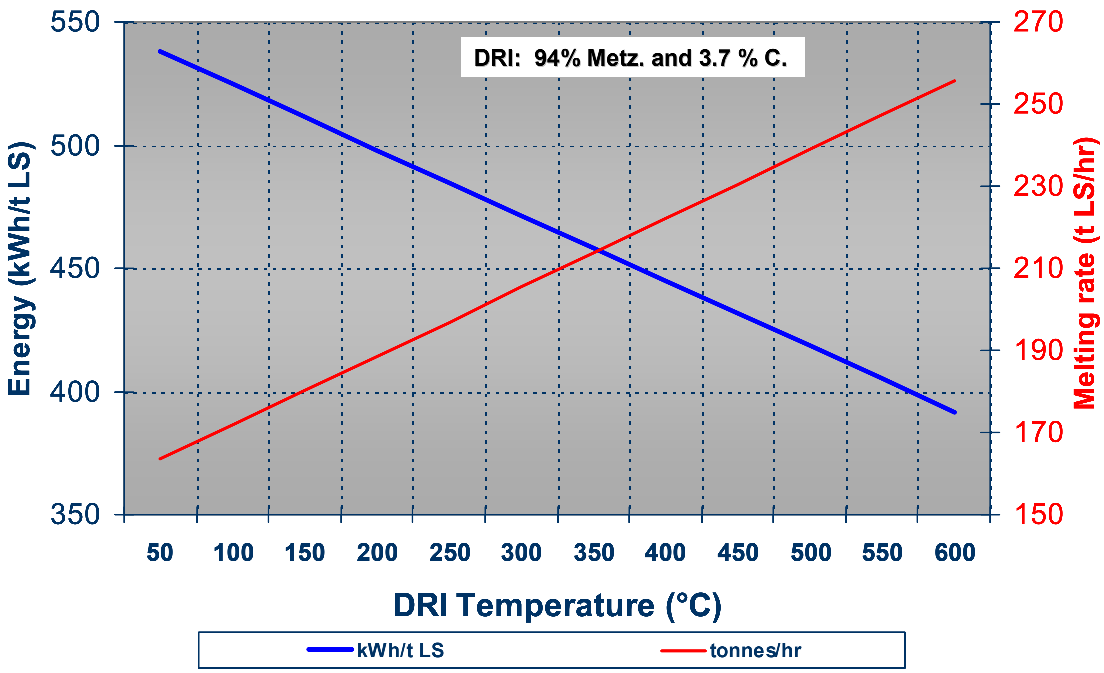


The main benefits of hot DRI are in the savings of electrical energy and the reduction of tap-to-tap time. Figures 8 shows the temperature effect on electrical energy consumption and melting rate for 100% of DRI in the metallic charge, with 94% metallization and 3.7% carbon, which are the current product quality levels at the 4M plant.

Characteristics of the EAF considered for this analysis are: capacity: 135 t/heat (tapping); average active power: 113 MW; oxygen: 25 Nm^3/t liquid steel (LS).

Savings of about 25% per ton of liquid steel can be achieved by feeding DRI at 600°C into the EAF. For EAF productivity, hot DRI can provide about a 20% increase.

Figure 8
EAF Performance with 100% Hot DRI Charge



5 Economical Analysis

For the economical analysis, the overall arrangement consists of a single unit of 1.2 million tonnes per year of DRI feeding one EAF of 1.0 – 1.2 million tonnes of liquid steel per year capacity. Based on the proposed arrangement, the feed to EAF consists of 98% HYTEMP® DRI and 2% revert scrap. Calculations for operating costs for DRI are included in Table 3 and for liquid steel, production costs are presented in Table 4, for both cold and hot DRI.

Typical costs for raw materials' prices, maintenance and related items are based on typical figures. In any case, these data can be adapted to local conditions.

From Table 4, it can be observed that the Liquid Steel production cost based on the configuration gasifier-HYL DR route is less than US$150/tonne LS.

Table 4
HYL DR plant with Coal Gasifier
Expected EAF Operating Cost and Productivity (Example)

EAF Concept	Unit	Unit cost US$/unit	Hot DRI unit/tLS	Hot DRI US$/tLS	Cold DRI unit/tLS	Cold DRI $US/tLS
DRI	kg	0.081	1189.42	95.83	1189.42	95.83
Revert scrap	kg	0.179	24.76	4.43	24.76	4.43
Electric Energy	kWh	0.050	460.68	23.03	601.24	30.06
Magnesite	kg	0.490	1.50	0.73	1.96	0.96
Dolomite	kg	0.200	0.00	0.00	0.00	0.00
Graphite	kg	0.181	15.21	2.75	15.21	2.75
Lime	kg	0.059	11.24	0.67	11.24	0.67
Dol-Lime	kg	0.057	35.05	1.99	35.05	1.99
Limestone	kg	0.015	0.00	0.00	0.00	0.00
Oxygen	Nm3	0.050	24.99	1.25	24.99	1.25
Electrodes	kg	2.044	1.42	2.90	1.85	3.79
Shell WCP	$US	-	-	0.08	-	0.11
Roof WCP	$US	-	-	0.29	-	0.38
Roof refractaries	$US	1.000	2.40	2.40	-	3.13
Shell refractaries	$US	0.800	0.30	0.24	-	0.31
Variable cost	**$US**			**36.33**		**45.39**
Maintenace	$US	5.000		5.00		5.00
Labour	$US	3.000		0.60		0.60
General expenses	$US	0.200		0.20		0.20
Fix Cost	**$US**			**5.80**		**5.80**
Metallic cost	**$US**			**100.26**		**100.26**
Transformation cost	**$US**			**142.39**		**151.45**
Production	**k tLS/year**			**1,213**		**1,010**

From this analysis, it can be observed the low production cost of liquid steel, based on the gasifier-HYL DR route. Main reasons for this result are:

- Use of low grade-least cost coal for the gasifier.
- Overall low operating consumption figures.
- Incorporation of the HYTEMP® system to feed hot DRI in the EAF.

Capital costs have not been included; however, according to published information, specific investment cost per annual tonne of DRI produced is expected to be lower than other available technologies in the market.

Where to consider coal gasification?

This scheme shall be considered for locations where there is no natural gas or its price is too high to justify its use. As compared to natural gas-based DRI production, the break-even cost of natural gas for the coal gasification-based DRI approach, is US$3.50 /MM BTU. This figure is calculated for locations where iron ore is imported and it includes operating and capital costs.

6 HYL DR Micro-Module

The HYL Mini-Module is a 0.200 Mtpy plant with low investment cost. The plant is a simple yet technologically advanced design and produces high quality, high carbon DRI at a production cost which is attractive to the quality EAF steel producer.

6.1 Advantages of a DR Micro-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 metallization 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 concept presents features which are reflected in benefits associated to both operating and investment costs. Among these features, the following are the most important:

- <u>Small plant size</u>. 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, HYL has developed an optimized concept for a low investment cost DR plant with a capacity of 0.200 Mtpy. This plant size was selected to cover most cases for the required amount of virgin metallics in the Indian market.

- <u>Low investment cost</u>. Adapting the latest developments and improvements of the HYL Technology based on the ZR process scheme has significantly reduced the specific capital investment.

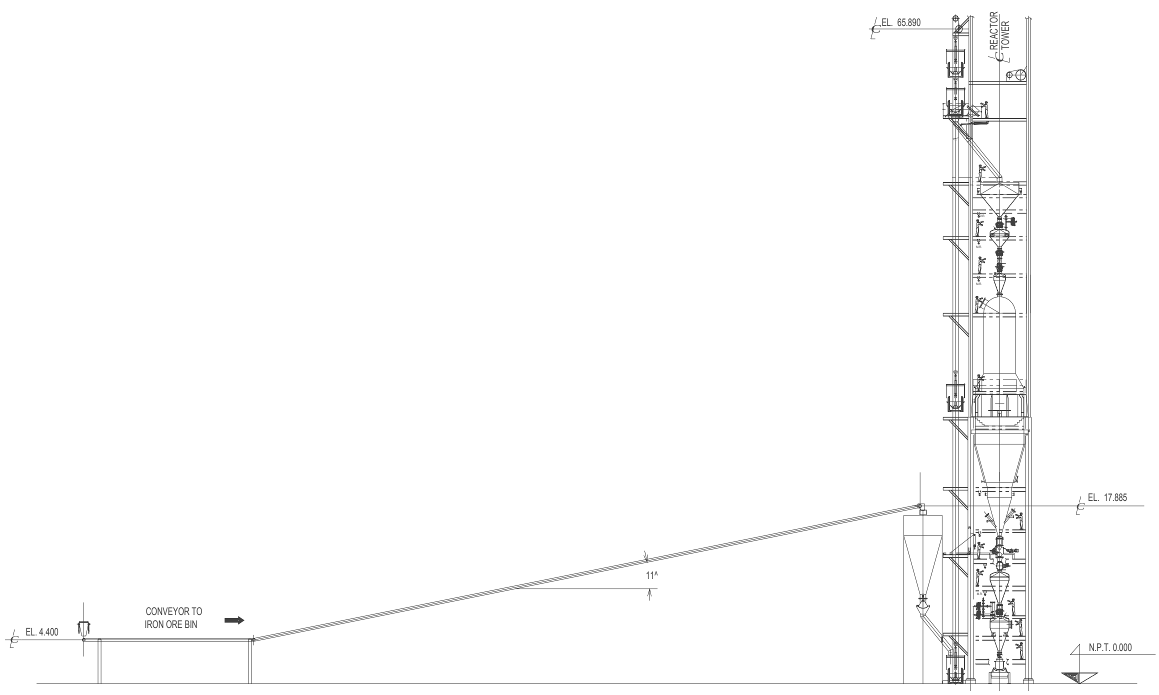
- <u>Optimized process design</u>. Specific optimization of process parameters, as a result of the industrial operation of the Hylsa 4M DR plant, has been incorporated in the design of the HYL Micro-Module.

- <u>Local equipment and materials sourcing</u>. Most of plant equipment and systems to be manufactured in India, to decrease plant cost investment. Also engineering services and local resources for erection have been considered of domestic supply.

- <u>Prefabricated equipment</u> (skid-mounted, modular design). There has always been an economic compromise between prefabricated equipment and erection time. For big plants, to transport prefabricated equipment is not normally the best option. However, for this small plant, there is better economical attractiveness to have most systems and equipment skid-mounted thus, reducing erection time.

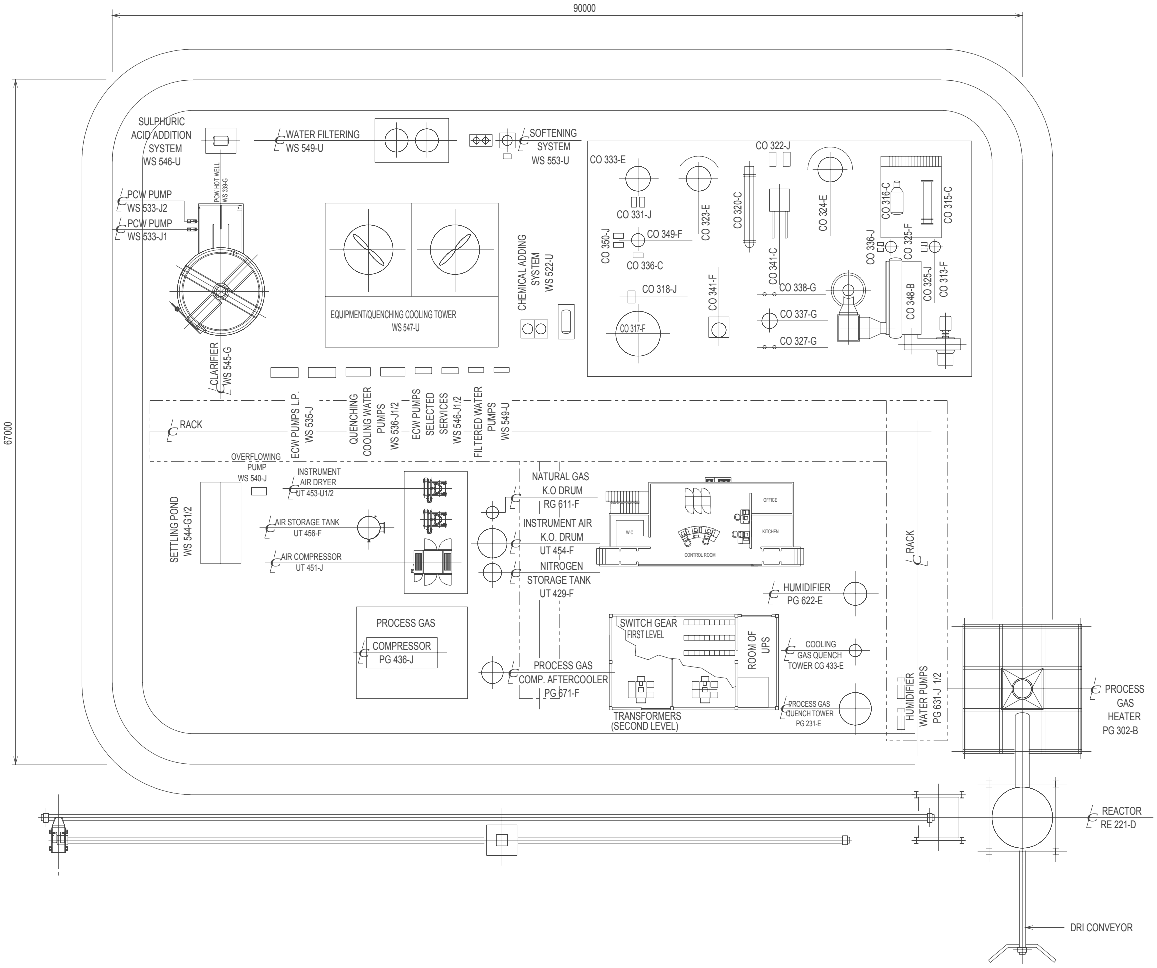
- Short erection time. As mentioned above, this is the result of modular design and prefabrication of most equipment.
- Compact, optimized layout. The required area for a Micro-Module of 0.200 Mtpy (Figures 9 and 10) is only 70m x 90m, which can be easily implemented in existing facilities.
- Synergy by using existing and/or common utilities/services. Most of the existing infrastructure and utilities; i.e. oxygen plant, water systems, etc., can be utilized and/or modified to serve the Micro-Module. In such cases, additional investment can be reduced.

Figure 9
Reactor Charging and Tower Elevation



Other inherent characteristics of the HYL 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.

Figure 10
HYL DR Plant Micro-Module



6.2 Design basis for the HYL Micro-Module

The design of the HYL Micro-Module is based on the HYL ZR Process technology, with optimum reduction efficiency via generation of the reducing gas in the reduction section. As a result, an external reformer is not needed. The Micro-Module is designed for cold DRI production in order to simplify plant design and to reduce additional investment costs due to briquetting or hot charging. The general process scheme is presented in Figure 11.

Simplifications implemented in the HYL Micro-Module are already in place and/or proven in other HYL DR industrial plants in operation. In this regard, there are no technological risks. Equipment in reactor tower has been reduced by incorporating a discharge system in series, similar to Hylsa's 2M5 plant in Monterrey. Due to this arrangement, the reactor tower, as shown in Figure 9, is of about 65 m height with a small reactor of just 2.0 m ID.

Typical expected consumption figures for the Micro-Module are presented in Table 5.

6.3 Optimized Investment Cost

In general, specific investment cost of small DR plants is higher than that of big plants. The main target of the economical investigation has been to decrease the specific investment cost of the small DR plant to a cost level that should be comparable or even lower than the price structure of plants designed for more than 1.0 Mtpy. As the result of such efforts, budgetary figures for a 200,000 t/a HYL Micro-Module are in the range of US$125–150/per annual tonnage capacity, based on mostly Indian supply.

Figure 11
HYL DR Micro-Module Process Scheme

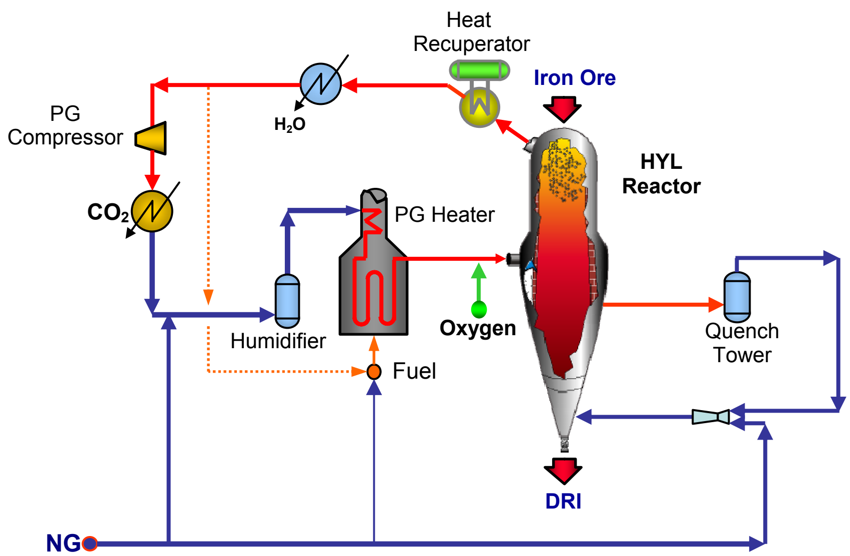


Table 5
HYL DR Micro-Module Expected Consumption Figures

Product Type Cold DRI		
Metallization		**≥ 93%**
Carbon		**3.50%**
Item	unit	**Specific Consumption**
Iron ore	(t/t)	**1.38**
Natural gas	(Gcal/t)	**2.25**
Electricity	(kWh/t)	**90**
Oxygen	(Nm^3/t)	**60**
Water	(m^3/t)	**1.0**
Nitrogen	(Nm^3/t)	**14**
Labour	(m-m/t)	**0.15**
Maintenance & supplies	($US/t)	**3.0**
Others	($US/t)	**0.4**

7 Conclusions

For India, the HYL DR Technology can be adapted to two main routes: 1) Coal gasification for big size DR plants and 2) Micro-Modules for NG-based units.

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.

On the other hand, 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.

The concept of the HYL Micro-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.

8 References:

1. Pablo E. Duarte; Erwin A. Reich; Heinz Smegal. *Direct Reduction Using Coal Gasification*. Asia Steel, 1998. pp 81-87.

2. Pablo E. Duarte; Heinz Smegal. *New HYL Process for Production of Iron Carbide*, Asia Steel, 1999. pp 68-72.

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.