Technical and economic aspects of production and use of DRI in integrated steel works

The use of surplus energy from integrated steel works for the on-site production and use of DRI in blast furnaces and BOF plants has been shown to be economically viable. It is capable of increasing output and reducing CO_2 emissions through a reduction in BF fuel requirement.

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Increasing prices for energy (mainly coke) and environmental restrictions related to CO_2 emissions, have led to considerations for using surplus energy from integrated steel works for steel production, rather than for export, power generation or flaring. Since only a minor part of the electrical power that could be generated from these gases can be used in the steel works for its own requirements, most of this electric power has to be exported.

Additionally, increasing prices of metallics and general market fluctuations makes it necessary to investigate alternatives for production using cheaper and on-site available metallic units. The technical viability of using the gases from integrated steel works for production of direct reduced iron (DRI) and consequently for the production of liquid steel, as well as energy optimisation, are the main objectives of the investigation described in this article.

The DRI could be used in the BF to decrease the consumption of coke and/or powdered coal injection (PCI) as well as increase the production of hot metal. An alternative is to use DRI as coolant in the BOF either to replace scrap or increase the production of crude steel, without necessitating an increase in BF and coke oven capacity. In the worst case, if there were no possibility for using DRI produced on an integrated plant then it could be sold to EAF steel plants.

Energy distribution in integrated steel works

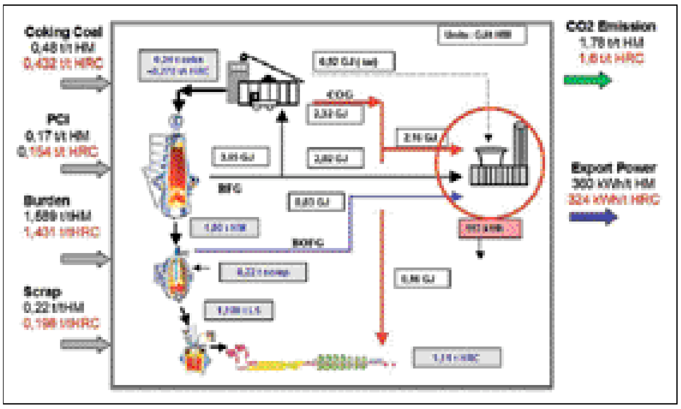
The major gaseous fuel by-products that are recovered in integrated steel works are blast furnace gas (BFG), coke oven gas (COG) and basic oxygen furnace gas (BOFG). The calorific value and composition of these gases have wide ranges. BFG is generated by partial combustion of carbon (coke/coal) with air, the percentages of CO and CO_2 in the BFG being directly related to the amount of carbon in the shaft. COG is a by-product of coke manufacture, produced during the carbonisation or destructive distillation of bituminous coal in the absence of air, and has a calorific value 5 to 6 times higher than BFG. BOFG is generated during blowing of the converter and is typically of the order of 0.75GJ/tls or 80–90Nm^3/tls.

		Blast Furnace	Coke oven Plant	BOF converter
	Unit	Unit / t HM	Unit / t coke	Unit / t LS
Main inputs				
coke	GJ	8,99		
	kg	360		
PCI	GJ	4,72		
	kg	168		
Coking coal	GJ		39,91	
	t		1,22	
Additional fuel / energy	GJ	0,02	3,45	
Spent gases				
Mass flow	Nm3	891,8	418,1	86,9
Energy	GJ	3,06	7,27	0,76
Composition				
H2	Vol %	3,6	62,3	6,5
CO	Vol %	23,7	6,9	62,7
CO2	Vol %	23,2	1,4	17
CH4	Vol %		23,9	
CmHn	Vol %		1,9	
N2	Vol %	49,2	4,6	13,8
H2S	g / Nm3		0,19	
LHV	MJ / Nm3	3,42	17,39	8,63

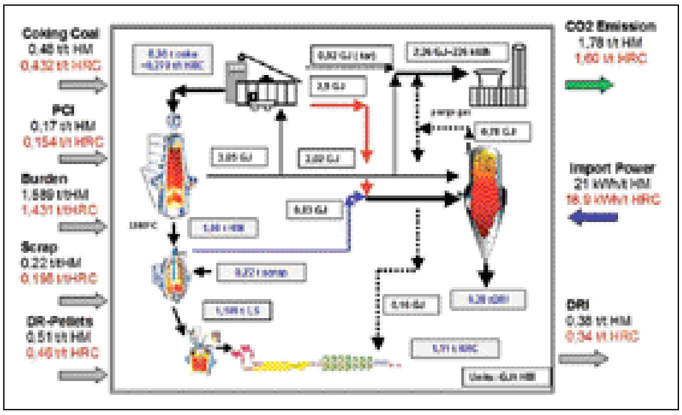
● **Table 1** ***Gases from integrated steel works as basis for investigation***

The analysis, quantities and input conditions are shown in *Table 1* and are the basis for the calculations in the following investigation. The selected integrated steel works comprises a coke oven plant, sinter plant, blast furnace, a BOF steel plant with ladle furnace and thin slab caster or compact strip plant (CSP) for the production of hot rolled coils (HRC).

Figure 1 shows the energy distribution and energy balance of the steel works. Between the coke oven plant and the other plant systems is an energy 'interlink'. For the carbonisation process the coke ovens require fuel for heating and have a high flexibility regarding the fuels used, including BFG and their own generated COG. The development of the BF during the past 30–40 years has decreased the average coke/coal consumption to about 470kg/tHM and other fuels like oil or coal have replaced coke so that today a BF can operate with about 300kg coke/tHM plus about



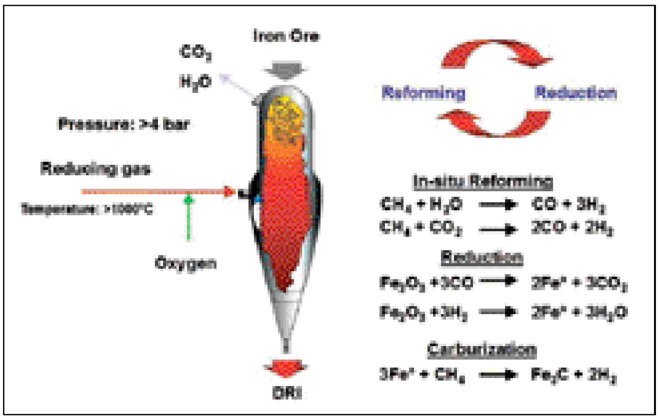
● **Figure 1** ***Overall balance for integrated steel works based on HRC production***



● **Figure 2** ***Overall balance with integrated DRI plant***

170kg/tHM powdered coal. From the BOF plant the BOFG is cooled and purified and collected in a gasholder, which also fulfils the task of a buffer for further continuous delivery to consumers.

The major steel works applications where gaseous fuels are used are:



● **Figure 3** ***HYL Zero reformer process***

- Coke oven heating
- Blast furnace stoves
- Soaking pits
- Reheating furnaces
- Ladle/tundish preheating and so on

As shown in *Figure 1*, for a balanced conventional integrated steel mill of the type described, about 32% of the fossil primary energy is surplus gas, which is used mainly for power generation. The total amount of electric power that can be produced (assuming 36% efficiency), is approximately 560kWh/t HRC. About 220kWh/t HRC is used for in-plant requirements and the remaining 340kWh/t HRC has to be exported.

Incorporation of a DRI plant in an integrated steel works

Figure 2 gives an overview of this idea by simply replacing the power plant in *Figure 1* with a DRI plant. The figure shows DRI production, energy balance and CO_2 emissions. The maximum production of DRI in this steel works is ~380kg/tls.

For this application, spent gases from the integrated steel mill are sent to the DRI plant and split as follows:

- COG and BOFG are totally used as process gas for DRI production
- Required amount of BFG is used as fuel for reducing gas heating and steam generation

As can be seen from *Figure 2* there is a surplus of purge gas (tail gas), mainly due to the need for N_2 purging, which is mainly concentrated in the BOFG. Excess tail gas from the reduction circuit is sent to the steel works for use in the coke oven plant and/or in the rolling mill, or other consumers.

The investigation of the use of COG as well as BOFG in a DRI plant is based on the HYL Self-reforming or ZR process technology, with optimum reduction efficiency via generation of the reducing gas in the reduction section itself. As a result, an external reformer unit or alternative reducing gas generation system is not needed and no special treatment of the gases is required.

HYL ZR – DR process

This process (see *Figure 3*) is based on the reduction of iron ores with reducing gases, which are generated from partial combustion and in-situ reforming of natural gas or COG, taking advantage of the catalytic effect of the metallic iron inside the reduction reactor. [*Duarte P, Knop K, and Masloch P, The HYL mini-module concept: The optimum integration of a DR plant in minimills, MPT International, pp74–81, April, 2002.*]

Item/use	DRI on-site consumption	HYTEMP® Iron direct feed to EAF	HBI overseas export
Metallisation	92–95	92–95	92–95
Carbon	1.5-5.5	1.5-5.5	1.5-2.5
Temperature (°C)	40	> 600	40
Bulk density (t/m³)	1.6	1.6	2.5
App. density (t/m³)	3.2	3.2	5.0
Nominal size (mm)	6–13	6–13	110x60x30

● **Table 2** ***DRI product characteristics***

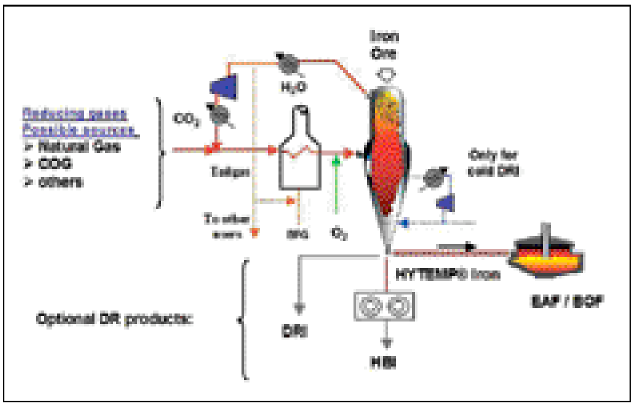
Because of partial combustion, the reducing gas temperature at the reactor inlet is very high – above 1,000°C, but due to the endothermic behaviour of the combined chemical reactions taking place inside the reactor, the resulting temperature at the reduction zone is below the potential condition for material cluster formation.

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

- **Partial combustion of the reducing gas** Partial combustion of COG/BOFG with oxygen before the reactor inlet provides the additional energy, which is required for methane-reforming in situ, and for the carburisation of the metallic iron
- **In-situ reforming in the lower part of the reactor reduction zone** Once in contact with the solids inside the reactor, further methane (from the COG) reforming in situ takes place due to the catalytic effect of the metallic iron
- **Adjustable composition of the reducing gas** The level of metallisation and carbon can be controlled independently by adjusting main process parameters and the gas composition

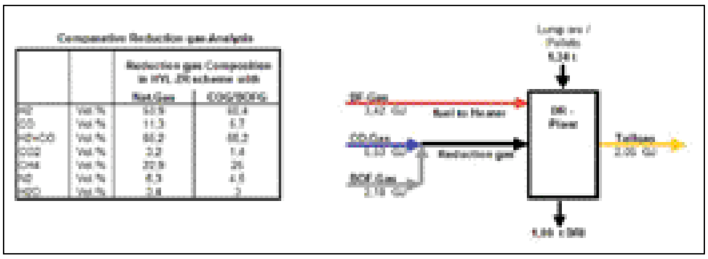
A schematic of the Hyl ZR process is shown in *Figure 4*.

The reactor operates at elevated pressure (4–6 bar, absolute), allowing a high reactor productivity of about 10t/h/m^2 and minimum dust losses through top gas carry-over. This is reflected in low iron ore consumption, which helps keep operating cost low. The top gas leaving the reactor contains H_2O and CO_2 generated from the reduction process. These components are eliminated through a top gas scrubbing system to remove the water and, optionally, a CO_2-removal system in the recycle gas.



● **Figure 4** ***Principles of HYL III – process schematic***

The reducing gas, made up of recycled gas and COG/BOFG, is reheated to 930°C in the gas heater and the tail gas from the reduction circuit is send to



● **Figure 5** ***Energy/mass – Balance of HYL-ZR- process on basis of gases from integrated steel works***

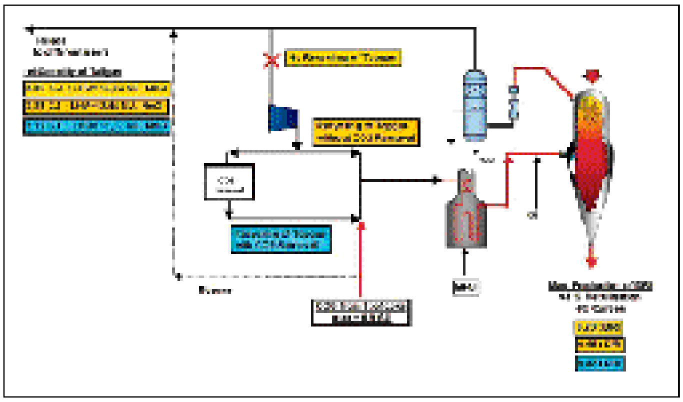
consumers in the steel works or optionally to the heater. The plant can be designed for production of cold DRI or hot DRI for direct charging to a melting facility and/or for hot briquetting and production of HBI. The main characteristics of possible DR products are shown in *Table 2*.

The process scheme is based on the same successfully proven Hyl ZR technology, that has been in operation at industrial scale in the '4M' plant since 1998, and which was recently incorporated in the '3M5' plant, both at Hylsa facilities in Monterrey, Mexico.

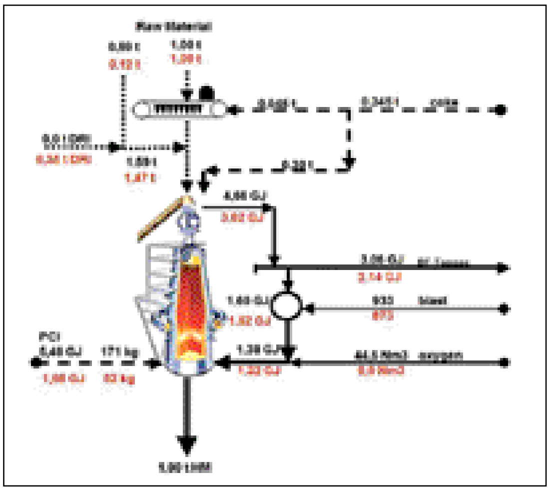
Integration of the DRI plant

The calculation of the reduction gas composition, using either natural gas or a mixture of COG and BOFG in the Hyl ZR process is shown in *Figure 5*. As the COG/BOFG and natural gas-based ZR schemes are similar, no technological risks are foreseen by incorporating this DRI technology into integrated mills. It is important to note that untreated COG may also be used in the Hyl technology for production of DRI.

Figure 6 shows possibilities for operation of the plant. The DRI production rate and consequently the



● Figure 6 *Integration of DRI plant with use of different process schemes*



● Figure 7 *Example of charging DRI to blast furnace*

amount of spent tail gas can be adjusted. Depending on the DRI requirements and additional fuel needs for the different facilities in the steel works, the production of DRI can be optimised. This means surplus tail gas is minimised or can be controlled in such a way that the required amount of fuel can be balanced by increasing or decreasing DRI production.

Use of DRI in integrated steel works

DRI can be used either in the BF or in the BOF.

Case 1: Charging cold DRI to the BF

[Becerra J, and Yañez D, Why DRI has become an attractive alternative to blast furnace operators, Iron and Steel International, pp43–49, February 1980]

The basis for this analysis is:

- BF using 300kg of coke and 170kg of PCI/t HM.
- DRI production using COG and BOFG is about 350kg/t HM
- 94% metallisation and 4% carbon

Figure 7 presents the schematic balance in more detail for the BF with (coloured red), and without (coloured black) charging DRI. The same liquid steel production rate has been kept.

The main influenced parameters are:

- PCI consumption
- Oxygen consumption
- Amount of top gas
- Burden

In this case, the main target is reduction of the environmental impact due to a decrease in CO_2 emissions by lowering PCI consumption. There is a reduction of about 70% of PCI/tHM and a potential decrease of CO_2 emission of about 28%, considering the selective elimination from the DRI plant, which should be delivered/disposed of for other purposes than venting.

The influence of DRI/HBI feed to the BF has been reported at many facilities worldwide. In general, most of the studies agree to an increase of 6–7% in production with 100kg DRI/t HM, keeping the same consumption in coke and PCI. *[Kercsmar D, Yamauchi Y, Dibert W, and Kleather J, Sustained production in excess of 9 tons per day/100cu. ft. W.V. at Middletown No. 3 blast furnace, Ironmaking Conference Proceedings, pp443–450, 1994]*

Case 2: Hot charging DRI to BOF

An alternate possibility for higher liquid steel production is to feed the DRI into a BOF (*Figure 8*). For this case, only hot DRI is fed to the BOF and the

t ore / t DRI 1,34 Prod. Mio t/a 0,4	unit	US$ / unit	unit / t	US$ / t
Metallisation	%		94	
carbon	%		4	
temperature DRI	°C		25	
Pellets (incl transport)	t	46	0,67	30,82
lumpore (incl transport)	t	33	0,67	22,11
Total			1,34	52,93
Process-Gas (COG/BOFG)	GJ	1,5	6,6	9,9
fuel (BFG)	GJ	0,5	3,43	1,715
Energy total			10,03	11,615
power	kWh	0,04	70	2,8
Oxygen	Nm3	0,039	22	0,858
Water	m3	0,5	0,9	0,45
nitrogen	m3	0,03	12	0,36
DMDS	kg	1,8	0	0
MDEA	lt	1,8	0	0
Coating	kg	0,08	5	0,4
Chemiecals	kg	3	0	0
maintanance				3
Personal	1 / m*a	40000	20	2,00
others		1	1	1
Int. Transport	t	1	1	1
Total processing				11,9
Total				76,4

● Table 3 *Production costs for DRI*

temperature of the HM was assumed as 1,500°C. There is a maximum possible crude steel production of about 1.4t/tHM, compared to a conventional scrap based case of 1.2t/tHM. The production increase is about 15.3%.

Economics

Energy cost The cost of surplus gas from integrated steel works (used for electrical power generation) has to be based on the price of steam coal for power generation. In this situation, the cost for electrical power has been calculated under German conditions as 1.5US$/GJ and is used for calculation of the DRI production cost, as the equivalent energy cost of COG/BOFG. BF top gas is assumed as 0.5US$/GJ.

Production cost for DRI/tls A DRI production cost estimation, excluding the investment and financing cost (which depends strongly on the concept and degree of integration of the DRI plant), is included in *Table 3*. The feedstock is made up of 50% pellets and 50% lump ore, with a calculated DRI cost of about 77US$/t, or about half the price of scrap. It is expected that there would be a decrease in the production cost of HM and liquid steel to some extent.

Table 4 shows a comparison between a scrap-based and hot DRI-based production of liquid steel. The difference of about 21US$/tls is mainly related to the scrap price, which is assumed to be about 150US$/t. To compete with the price for steel made out of DRI, the scrap price has to be as low as about 60US$/t.

Conclusions

The main issues facing integrated steel works are:

- Limited supply and increasing prices of coke and scrap
- Environmental restrictions related to CO_2 emissions, which could be of economic importance due to regulations/trading aspects envisioned in the Kyoto protocol

By modifying the current trend of using spent gases from the integrated facility for power generation, these issues can be overcome by using them for more value-added DRI production while reducing fossil fuel consumption and decreasing CO_2 emissions.

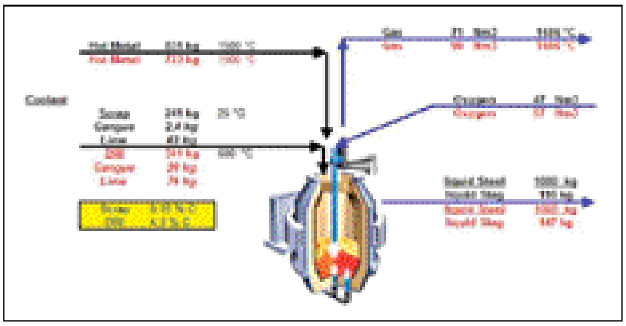


Figure 8 ***Comparison of charging scrap/DRI to a BOF***

Processing in BOF	unit	US$ / unit	Scrap as coolant: unit / t LSt	Scrap as coolant: US$ / t LSt	Hot DRI as Coolant: unit / t LSt	Hot DRI as Coolant: US$ / t LSt
Metallic Input						
Hot Metal	t	137,0	0,83	113,8	0,72	99,1
own scrap	t	150,0	0,00	0,0	0,00	0,0
import scrap	t	150,0	0,24	36,2	0,00	0,0
DRI (without capital cost)	t	77,0	0,00	0,0	0,36	27,8
Total metallic Input			1,07	150,0	1,08	126,8
melting processing						
alloys	kg	0,960	7,0	6,7	7,0	6,7
lime	kg	0,075	63,0	4,7	76,0	5,7
oxygen	Nm3	0,039	47,0	1,8	57,0	2,2
el power	kWh	0,0400	70,0	2,8	70,0	2,8
others processing				5,0		5,0
Slag-handling	kg	0,015	116,0	1,7	147,0	2,2
Total melting				22,7		24,6
bonus for BOFG	GJ	1,5000	0,65	-0,98	0,83	-1,25
Total liquid steel cost				171,8		150,2

Table 4 ***Comparison of costs for liquid steel***

This work has presented a preliminary analysis of the various approaches for incorporation of a DRI plant into an integrated steel works. A detailed investigation will depend on the particular plant arrangement and economic conditions of a specific plant.

According to the general analysis, the main benefits are:

- Decrease of fossil fuel consumption for HM production and CO_2 emissions
- Potential for increase up to 21% of hot metal production
- Increase of BOF liquid steel production by about 15% using hot DRI as coolant
- Potential increase of about 38% of liquid steel by installing DRI with EAF facilities

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