Using the HYL ZR Process and Coke Oven Gases for Production of DRI

By
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SYNOPSIS:

Instead of sending excess of coke oven gases (COG), converter gases and/or blast furnace (BF) top gases from integrated steel mills to power stations, as is mainly today's practice, there are technical and feasible possibilities for use of these gases in metallurgical processes, i.e., for direct reduction (DR) of iron ores and crude steel-production.

The additional production of direct reduced iron (DRI) to the hot metal (HM) production, and further use of DRI as metallic charge to BF or in EAF's, allows - without increasing the capacities of the coke oven plant and BF and without changes in the quality of the crude steel – an increase in production of crude steel or alternatively, a significant reduction of fossil fuels specific consumption. In the way the production is increased and the specific consumption of fossil primary energy is lowered.

Processing the DRI in an EAF also enables, by optimising the DRI/scrap ratio with respect to quality and costs, to produce a much wider product range than would be possible by only charging scrap.

An analysis of the most adequate process scheme for an HYL DR plant, using coke oven gases as source of reducing gases, based on the HYL-ZR scheme (Self-reforming), is included.

The economical evaluation is based on the comparison of using excess of COG for producing DRI vs. power generation. The production of DRI, based on COG, is possible at costs that can be below world market prices for DRI/HBI and premium scrap prices. Examples for economical impact are given for use of DRI in BF as well as in EAF.

The optimised utilisation of primary fossil energy also has the effect of significantly reducing the specific CO_2 emissions per ton of crude steel. The specific CO_2 emission via the conventional BF/BOF route is about 1.6 tonnes (t) of CO_2/t crude steel, even on an optimised process route basis. Utilising the DRI -being produced with COG and BF top gas- as metallic charge to BF or in an EAF, allows significant reductions in absolute and/or specific CO_2 emissions.

Keywords: DR, HYL DR Process, DRI, coke oven gas, BF top gas, CO_2 emissions.

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1. Introduction

Increasing prices for energy, mainly for coke, and environmental restrictions related to CO_2 emissions have led to considerations for using available energies from integrated steelworks mainly for steel production and not, as is today's practice, for other uses. Additionally, current increasing prices of metallics and prevailing market fluctuations makes necessary the analysis of alternatives for production of cheaper and on-site available metallic units.

The major gaseous fuel by-products, which are recovered in integrated steel works, are: coke oven gases (COG), blast furnace gases (BFG), and basic oxygen furnace gases (BOFG). The calorific value and composition of these gases have wide ranges.

In any integrated facility producing steel via BF/BOF there is a natural unbalance in energy. The energy contained in the gases generated by the COG, BF, and the BOF is always higher than the energy required as fuel inside the facility. Typically, energy balances of integrated steel works show that most of the excess gaseous energies are mainly used for power generation or even flared. As only a minor part of the electrical power, which could be generated from these gases, can be used in the steelworks for its own requirements, most of the electrical power has to be exported.

An alternative use for the excess of COG is to produce DRI. The DRI produced can be used in several ways such as:

1. Substitute of scrap in the BOF
2. Metallic charge to the BF, to decrease the consumption of coke and/or powdered coal injection (PCI) or, to increase the production of hot metal
3. It can be sold as scrap substitute to other company

2. Basis of the analysis

The selected integrated steel work comprises a coke oven plant/sinter plant, blast furnace for generation of HM and a BOF steel plant with ladle furnace and slab caster for the production of slabs. Figure 1 shows the schematic energy distribution of this facility.

Blast furnace and BFG

The development of the BF process during the last 30 – 40 years has decreased the average coke/coal - consumption to about 470 kg//t HM. Through this development, other fuels like oil or coal have also replaced coke so that a BF nowadays can operate with about 300 kg coke/t HM plus about 170 kg coal (PCI).

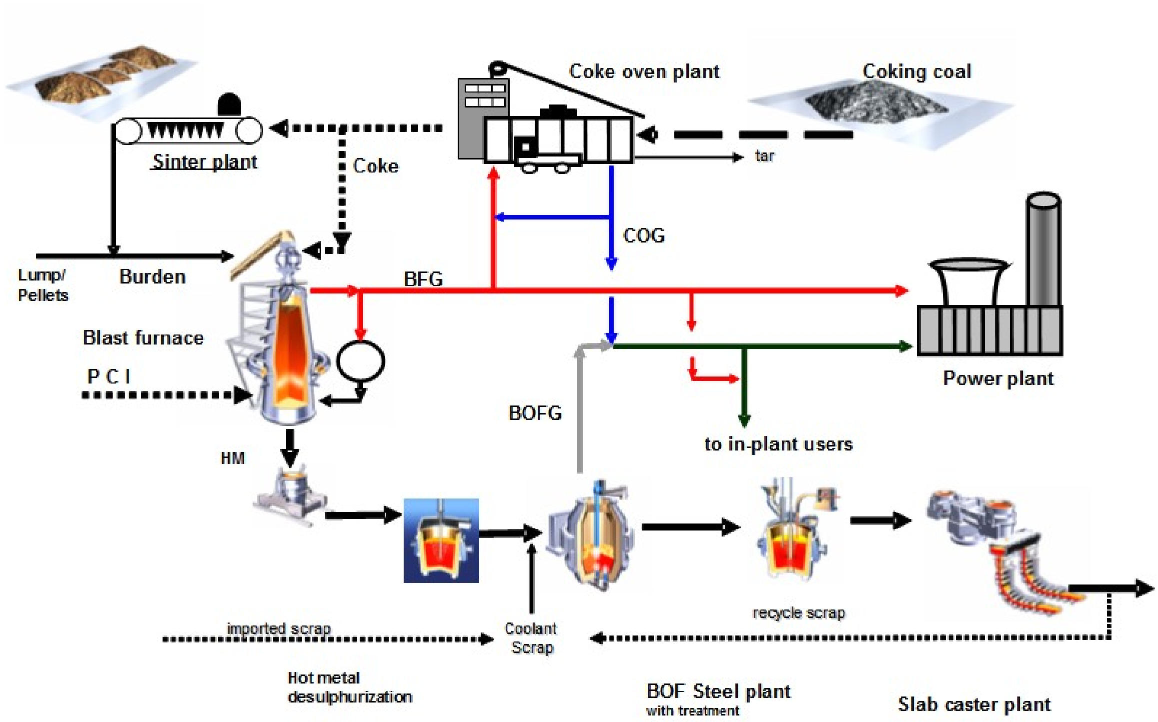
Blast furnace gases are generated by partial combustion of carbon (coke/coal) with air. The percentages of CO and CO_2 in the BFG are directly related to the amount of carbon in the shaft. For many years the use of BFG for purposes other than for the firing of stoves and boilers was not economical. A number of factors have contributed, however, to wider use of BFG. The most important are:

- Increasing fuel cost.
- Technical progress in gas cleaning, in the use of regeneration/recuperation and in mixing gaseous fuels.

Preheated BFG burned with preheated air has also been used successfully in coke oven heating, soaking pits and reheating furnaces.

The analysis and the amount of gases, related to the overall energy balance of a BF typical installation, are shown in Figure 2, with corresponding gas analysis in Table 1.

Figure 1. Energy Distribution in Integrated Steelworks



Coke Oven Gas (COG)

The coke oven plant is a part of the energy network in a modern iron and steel works.

COG is a by-product of coke manufacture. It is produced during the carbonisation or destructive distillation of bituminous coal in the absence of air.

As compared to BFG, the COG has a 5 – 6 times higher calorific value. COG has a more extended use than BFG because of:

- Relatively low distribution costs due to its low specific gravity and high calorific value.
- Its ability to develop extremely high temperatures by combustion.
- The high rate at which it can release heat, thereby eliminating excessively large combustion chambers.

The sulphur (as H_2S) present in untreated (not desulphurized) COG is a distinct disadvantage, particularly when heating certain grades of alloy steel for rolling. Its presence also requires the use of materials resistant to sulphur attack in pipelines, valves and burners.

For the carbonization process the coke oven furnaces require fuel for heating. In this regard, coke oven plants have a high flexibility for use of fuels from different sources, including BFG and their own generated COG.

Between the coke oven plant and the other plant systems of an integrated steel works based on HM and BOF, there is an energetic “interlink“.

The advantage of this interlinking gas system is mainly related to the use of the low calorific BFG as fuel in coke oven furnaces and hot stoves of the BF, while the high calorific coke oven gas can be used for other consumers like rolling mill and power plant.

Production of hot COG is approximately 420 Nm^3/t of coking coal.

Corresponding characteristics of treated COG are indicated in Table 1. It can be observed from the COG analysis that for the purposes of this investigation, a modern integrated steelworks, including COG treatment, has been selected. However, it is important to mention that raw, untreated COG may be used in the HYL-ZR DR technology for production of DRI.

Converter Gas (BOFG)

During blowing time, the amount of BOFG normally generated in a converter is in the range of 0.75 GJ or 80 – 90 Nm^3/t LS. BOFG, mainly made-up of carbon monoxide (CO) and carbon dioxide (CO_2), is collected, cooled and purified. These gases are not allowed to escape to the atmosphere during the oxygen blowing process. The gas is collected in a gasholder, which also fulfils the task of a buffer for further continuous delivery to consumers. Currently, BOFG is mainly flared or used in reheating furnaces.

The composition of that gas is also shown in Table 1.

Application of spent gases in integrated mills

A symptomatic situation for the steel works is that numerous materials and energy flows interlink the metallurgical processes, as is shown in the overall energy balance, presented in Figure 2**.**

Table 1. Mass and Energy Flows of Plants/Systems
In typical Integrated Steel facility

Item	Unit	Blast Furnace	Coke Oven Plant	BOF converter
Main Inputs		Unit/t HM	Unit/t coke	Unit/t LS
Coke	GJ/t	8.99		
	kg/t	300		
PCI	GJ/t	4.72		
	kg/t	168		
Coking coal	GJ/t		39.91	
	t/t		1.22	
Additional fuel/energy	GJ/t	0.02	3.45	
	kWh/t			25
Spent gases				
Flows		Unit/t HM	Unit/t coke	Unit/t LS
Mass flow	Nm^3/t	891.8	418.1	8.690
Energy	GJ/t	3.05	7.27	0.75
Composition				
H_2	Vol. %	3.9	62.3	6.5
CO	Vol. %	23.7	5.9	62.7
CO_2	Vol. %	23.2	1.4	17.0
CH_4	Vol. %	49.2	23.9	13.8
C_nH_m	Vol. %		1.9	
N_2	Vol. %		4.6	
H_2S	g/Nm^3		0.19	
LHV	MJ/Nm^3	3.42	17.39	8.63

Major important applications, where gaseous fuels are used, are the following:

- Coke oven heating
- Blast furnace stoves
- Soaking pits
- Reheating furnaces
- Ladle preheating, etc.

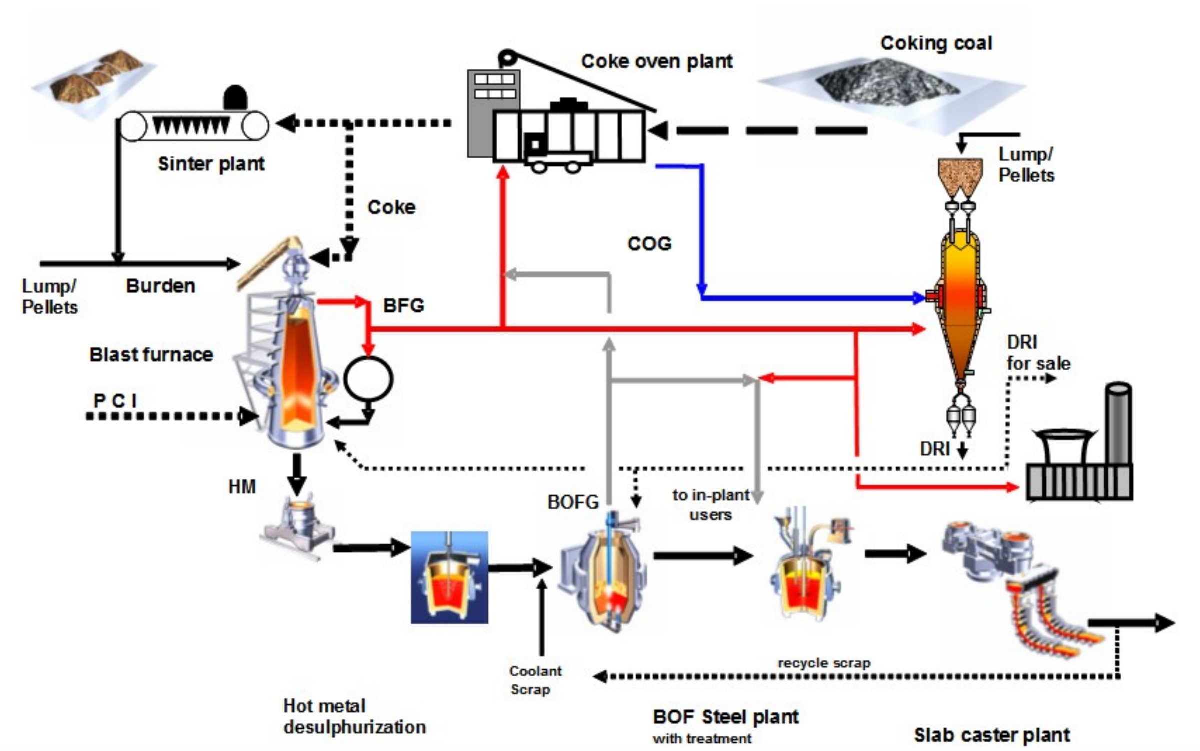
As already mentioned above, the aim of this analysis is to investigate the possibility for using these surplus gases for other than electrical power generation, specifically for production of DRI.

3. Use of surplus gases for production of DRI

In this context, COG and BOFG can be used for the reduction of iron ores, while BFG can be used as fuel for reduction gas heating and for steam/power generation.

Figure 3 presents an overview of this idea, simply replacing the power plant with a direct reduction (DR) plant. For this application, the conventional concept for gases distribution in a typical steel works has to be changed, depending on the internal use of DRI and on the selected DR plant scheme, which could provide some or none of the spent tail gas back to the integrated steel facility.

Figure 2. Incorporation of a DR plant in Integrated Steelworks



The investigation of the use of COG as well as BOFG in a DR plant is based on the HYL-ZR (Self-reforming) 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 alternate reducing gas generation system is not needed.

4. Direct Reduction Process

Among the dominant DR technologies currently available in the market, while others requires major basic-scheme modifications, the HYL-ZR Technology can use COG without any modifications to its process or equipment.

Therefore, the investigation of the use of COG in a direct reduction plant for production of DRI is based on the HYL-ZR technology, with improved reduction efficiency via generation of the reducing gas in the reduction section itself (*in situ* reforming). As a result, an external reformer unit or alternate reducing gas generation system is not needed. Special treatment of the COG is also not required.

The general scheme of the HYL DR- process configuration is shown in Figure 4 [1]. The reactor operates at elevated pressure (4 to 6 bar, absolute), allowing a reactor productivity of about 10 t/h x m^2 and minimum dust losses through top gas carry-over. This is reflected in low iron ore consumption, which allows keeping the operating cost low.

The top gas, leaving the reactor, contains water (H_2O) and carbon dioxide (CO_2) generated from the reduction process. These components will be eliminated through a top gas-scrubbing system (to remove the water) and a CO_2 removal system in the recycle gas circuit. The reducing gas consists of recycled gas to which COG is added as a make up. This gas is reheated to 950°C in the gas heater. A further increase of the temperature to > 1000°C is achieved after injection of oxygen for partial oxidation of the reduction gas.

A DRI plant can be designed for production of cold DRI, hot DRI for direct charging to a melting facility (EAF or BOF) and/or for hot briquetting producing HBI (Hot Briquetted Iron), as per Figure 3.

Besides the use of DRI in the BOF as coolant, it could alternatively be used in the blast furnace to decrease the consumption of coke/PCI, or to increase the production of hot metal.

5. HYL-ZR Process

The HYL-ZR Process (Figure 3) is based on the reduction of iron ores with reducing gases, which are generated from partial combustion and *in situ* reforming of hydrocarbons (NG or in COG) , taking advantage of the catalytic effect of the metallic iron inside the reduction reactor.

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

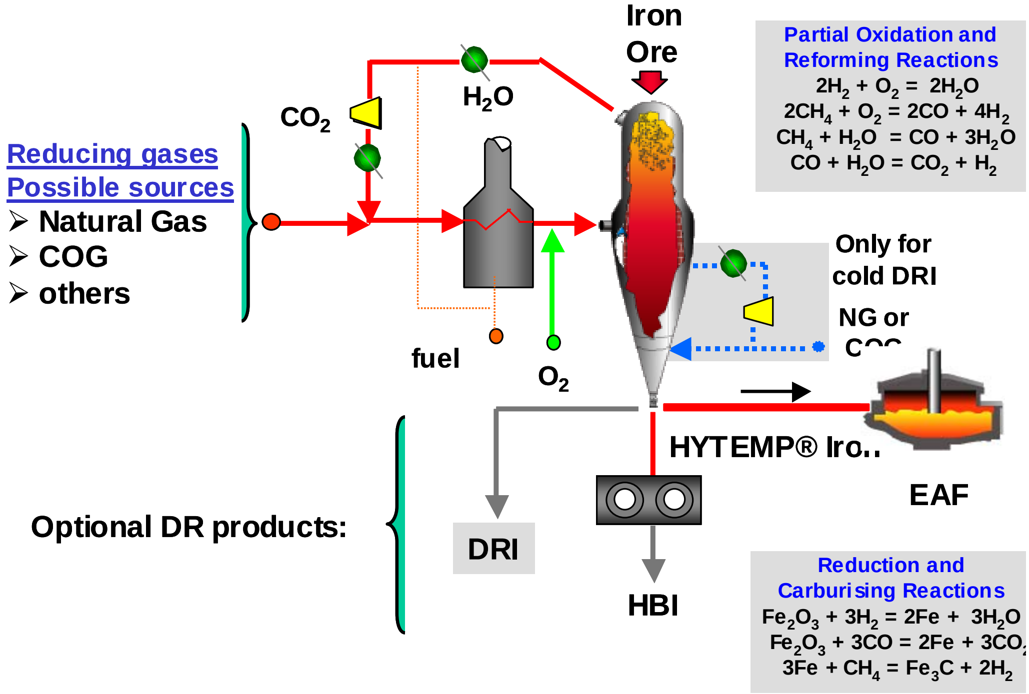
- Partial combustion of the reducing gas: Partial combustion of COG with oxygen (see figures 6a and 6b) before the reactor inlet provides additional energy required for reforming methane *in situ* and for the carburization of the metallic iron. Due to this partial combustion process, the reducing gas temperature at the reactor inlet is very high – above 1000°C. The endothermic behavior of the combined chemical reactions taking place inside the reactor reduce the temperature in the reduction zone to about 820°C , therefore, the iron ore pellets do not get plastic or stick together (cluster formation).

- *In situ* reforming in the lower part of the reactor's reduction zone: Once in contact with the solids inside the reactor, further *in situ* methane reforming takes place due to the catalytic effect of the metallic iron.

- Adjustable composition of the reducing gas: The level of metallization and carbon can be controlled independently by adjusting main process parameters and the gas composition.

The DRI carburization is controlled by adjusting the percentage of oxidants in the gas entering the reactor by controlling the water content in the reduction gas, the oxygen injection in the reduction area, or by the control of CO_2 content of the reduction gas.

Figure 3. HYL-ZR General Process Scheme with Options



For a carbon content of 4% approx. 95% of this carbon is present as Fe_3C. The high percentage of Fe_3C in the DRI makes the material more resistant against re-oxidation. The main characteristics of DR products are shown in Figure 4.

Figure 4. HYL Typical DR products Characteristics

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

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

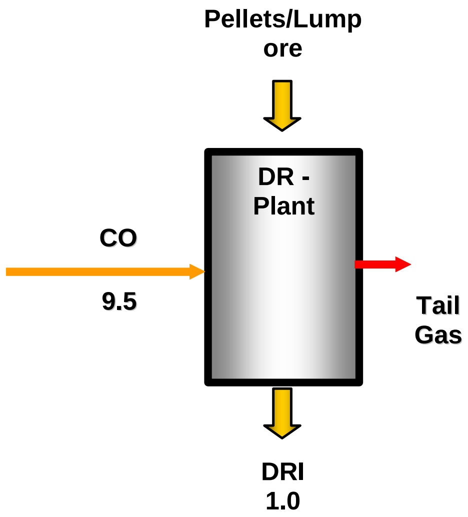
The accumulated production of high carbon DRI in Monterrey, Mexico from 1998 to 2005 is nearly 6 million tonnes.

6. Use of COG in Direct Reduction Plants

In gas-based direct reduction processes, natural gas is reformed into a gas containing as reduction agents hydrogen and carbon monoxide. Depending on the direct reduction process and on the natural gas composition, the ratio of hydrogen to carbon monoxide can vary. Actually, the chemical compositions of COG and natural gas are quite different and there is no industrial plant presently running on COG. However, irrespective of whether the original gas is COG or natural gas, the chemical composition of the reduction gas that goes into the reactor differs only insignificantly (Figure 5). Consequently, the risk of using COG instead of natural gas is negligible for the HYL-ZR direct reducing process. Typical requirement of COG for DRI production, based on the HYL-ZR scheme is about 9.5 GJ/t DRI, for a DRI of 94% metallization and 4.0% carbon.

Figure 5. Comparative Gas Analysis:
COG vs. HYL-ZR (Nat. gas-based) Scheme

Item Vol. %	COG	Nat. gas	COG to Reduction	Reduc. gas in HYL ZR Scheme
H_2	56.5		47.7	50.0
CO	7.5		8.5	15.0
CH_4 + C_nH_m	27.0	97.0	16.8	25.0
CO_2	2.5	2.5	1.5	3.0
H_2O			4.0	4.0
(H2+CO)/ (CO_2+H_2O)			10.2	9.3
N_2	6.5	0.5	21.5	3.0



7. Incorporation of the HYL DR module in integrated steel works

Figure 6 presents a simplified overview of the global energy scheme and CO_2 emission for a typical integrated steelworks for production of slabs. Corresponding figures of this example are presented in Table 2.

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

- An amount of 2.26 Gj of COG/t HM is used as process gas for DRI production.
- Required amount of BFG is used as fuel for reducing gas heating and steam generation, which is needed for CO_2 absorption in the DR plant.

Figure 6. Overall Energy/Carbon Scheme
for Typical Integrated Steelworks-Slab production
Gaseous Energy Streams

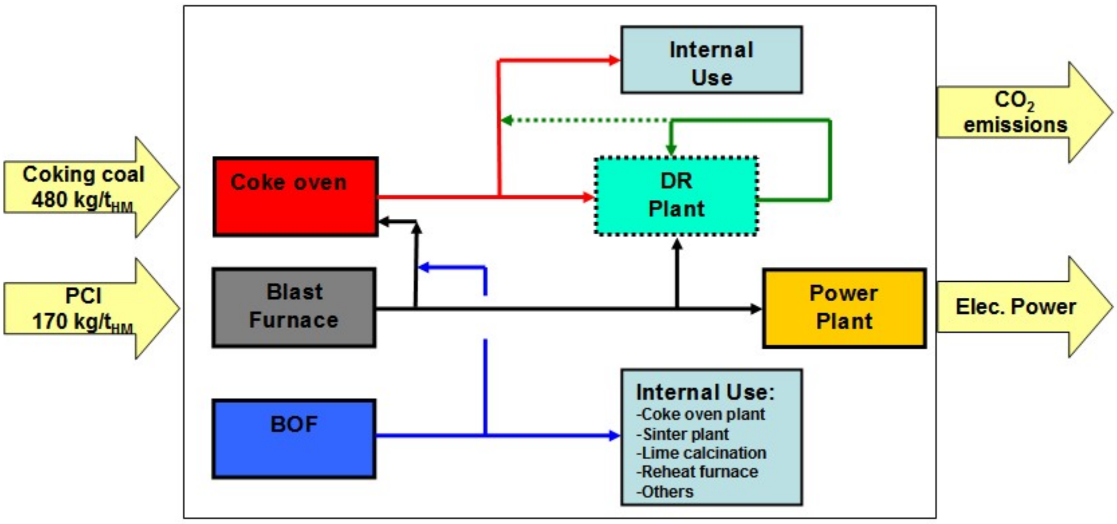


Table 2. Overall Energy/Carbon/DRI Balance
for Typical Integrated Steelworks-Slab production

		Without DR-Plant	With DR-Plant
Power Generation	MW/t_{HM}	375	142
Export Power	MW/t_{HM}	194	0
Import Power	MW/t_{HM}	0	21
Total CO_2 Emission	kg_{CO2}/t_{HM}	1,780	1,780
Range of selective CO_2 removal	kg_{CO2}/t_{HM}	0	30 - 150
DRI Production	kg_{DRI}/t_{HM}	0	227
Note: Maximum potential DRI Production from a balanced/optimised-Integrated Steel Plant (using COG & BOFG for DRI)	kg_{DRI}/t_{HM}		380

For the most optimised DR scheme, there is a surplus of purge gas (tail gas), mainly due to the need of N_2 purge, which is highly concentrated in the BOFG, for the case BOFG is also used for DRI production. Excess of purge gas (tail gas) from the reduction circuit is sent to the steelworks for use in the coke oven plant and/or in the steel mill or other consumers like power generation, sinter plant, lime calcinations, etc. The amount of recycled gas through the CO_2 removal system influences the DRI production rate and consequently the amount of spent tail gas. Depending on the DRI requirements and additional fuel needs for the different facilities in the steel works, the production of DRI can be maximised, for which case surplus of tail gas is minimised or can be controlled in such a way that the required amount of fuel can be balanced by decreasing DRI production.

8. Cases for Analysis

The possible schemes in an integrated steel plant, when producing DRI, are:

a) DRI can be sold as scrap substitute to other company
b) Substitute of scrap by DRI in the BOF
c) Use of DRI as metallic charge to the BF, to decrease the consumption of coke and/or powdered coal injection (PCI) or, to increase the production of hot metal

Basis for this analysis are:

- BF using 300 kg of coke and 170 kg of PCI/t HM.
- DRI production, as per available COG only, is about 230 kg/t HM, with 94% Metallization and 4% Carbon.

a) Use of COG for production and sale of DRI

As commented before, the COG can be used either to generate power or to produce DRI. In order to determine which alternative is more profitable, the following is considered for the present analysis:

Based on the results presented in the overall energy balance (Table 2), it can be observed that, as general rule, the same amount of COG can be used to produce either, 1.0 kg of DRI or 1.0 MW (227 kg DRI/t HM vs. 215 MW/t HM).

A simpler and direct result is also obtained if an efficiency of 35%, based on COG LHV, is considered. For comparison purposes, in both cases the same flow of COG of 38,100 Nm^3/hr is considered, with this flow you can produce either 65 MW or 65 tonnes of DRI in one hour (equivalent to 500,000 t DRI/year).

In both cases no capital cost is considered; only operational cost is used for this comparison.

As basis for calculation of the DRI production cost, the following has been taking into account:

- Imported pellets are used for the DRI production
- power and oxygen necessary for the production of DRI are at market prices

Based on the above, the DRI production cost estimate is presented in Table 3 below. To compare both business alternatives, the following is assumed:

i) The production cost (COG at zero cost) is:
   - For power 0.01 US$/kWh
   - For DRI 125 US$/t

ii) Both, power and DRI are sold externally at market prices; 0.05 US$/kWh and 200 US$/ton of DRI.

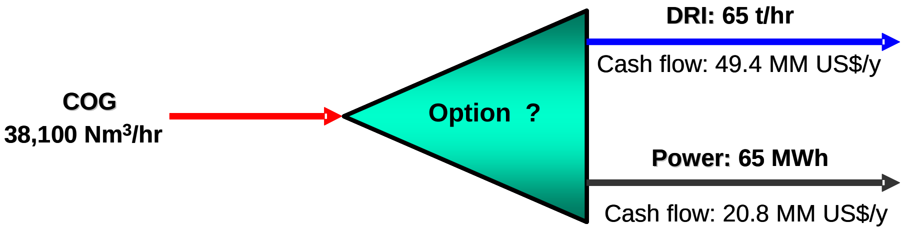
Table 3. DRI production Cost-based on COG

		Unit Cost	HYL MINI-MODULE 70% Pellets/30% Lump ore DRI: 94% Mtz, 4% C	
Concept	unit	US$	consump/t	$US/t
Pellets	t	90.0	0.97	86.94
Lump ore	t	70.0	0.41	28.98
Coke Oven gas	GJ	-	10	-
Electricity	kWh	0.05	80	4.00
Oxygen	Nm3	0.05	11	0.55
Water	m3	0.02	1.3	0.03
Other consumables	$US			0.60
Maintenance	$US			3.01
Personnel	m-h	5.00	0.17	0.85
G&A	$US			1.00
Total DRI Production Cost	**$US**			**125.96**

Based on the above, the economical analysis results are presented in Figure 10.

Figure 10. Comparative analysis of DRI production vs. Power with COG

COG Utilization - Economical Comparison					
DRI cost (w/o COG)	US$/tonne	125.00	Power gen. cost (w/o COG)	US$/kWh	0.01
DRI price	US$/tonne	220.00	Power price	US$/kWh	0.05
DRI profit	US$/tonne	95.00	Power profit	US$/kWh	0.04
DRI Plant production	tonne DRI/hr	65.0	Power generation	kWh/hr	65,000
DRI benefits	**MMUS$/year**	**49.4**	**Power benefits**	**US$/year**	**20.80**

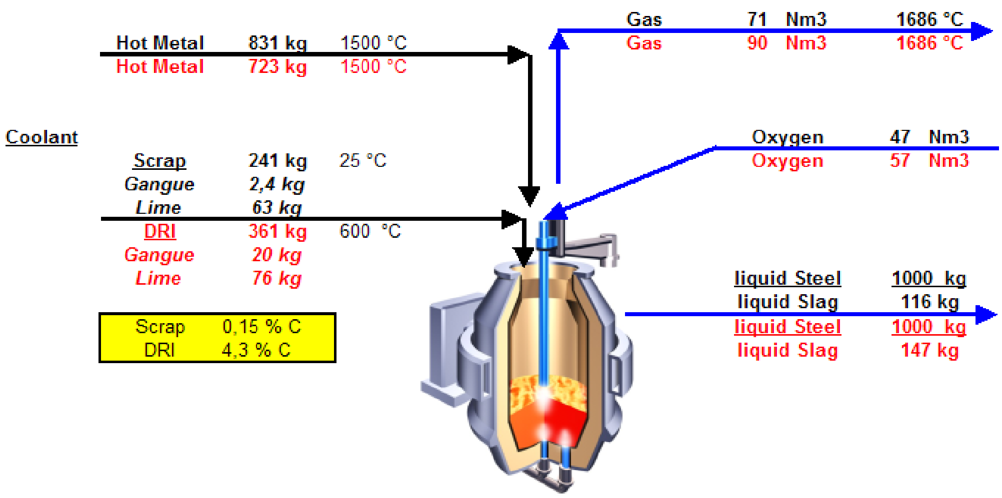


Benefit difference = 28.6 MM US$/y
In favor of DRI production option

b) <u>*Use of DRI as substitute of scrap in the BOF*</u>

The impact of using DRI in the BOF, as compared to scrap feed, is presented in Figure 7. For this case, it is assumed that the DRI is fed hot [6]. Based on this analysis, the steel production is increased in about 15%, when replacing scrap by DRI as coolant.

Figure 7. Influence of DRI Charge to the BOF, as compared to Scrap

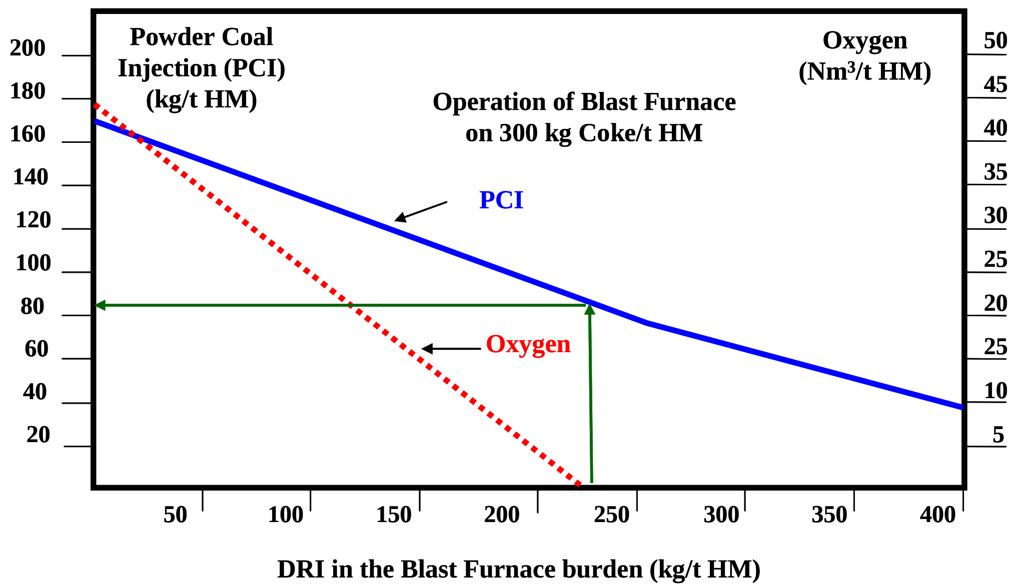


c) <u>*Use of DRI as metallic charge to the BF*</u>

For this case, DRI is fed to the BF. Since the specific consumption of coke is already optimised, there are two possibilities:

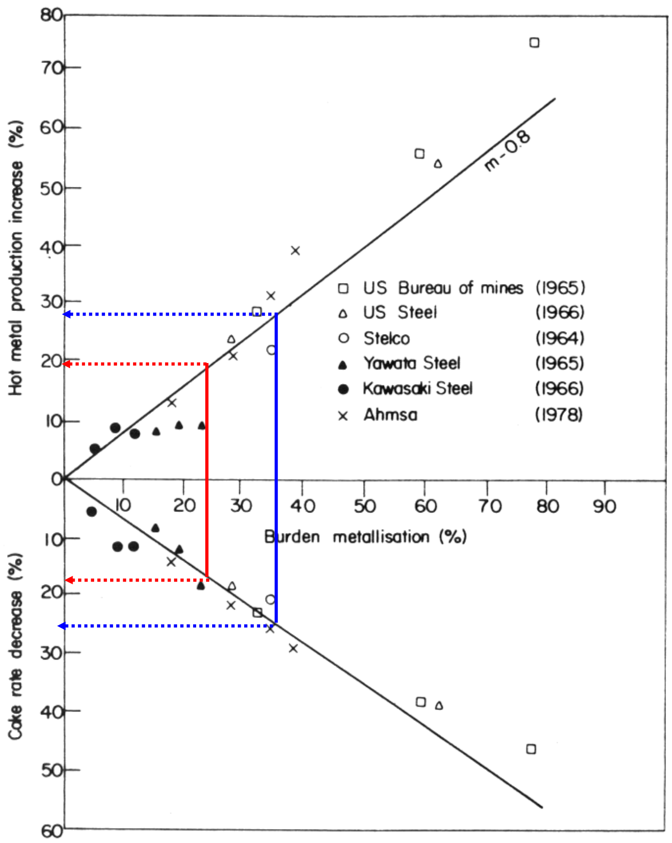
Option 1). - To keep same liquid steel production rate. In this case the main target is reduction of environmental impact due to a decrease of specific coal consumption and CO_2 emissions by lowering PCI consumption. This case has been analysed in previous works [2]. As presented in Figure 8, for constant coke rate to the BF, for 230 kg DRI/t HM, PCI can be reduced to about 90 kg/t HM; a reduction of about 17% of total coke feed.

Figure 8. Influence of DRI Charge on PCI Consumption in BF - Constant Coke rate



Option 2).- To increase HM productivity in the BF, decreasing not only specific consumption figures and CO_2 emissions but also achieving savings in production costs. Influence of DRI/HBI feed to the BF has been reported in previous works performed in various facilities worldwide [3], [4], [5]. The impact on BF productivity is presented in Figure 9.

Figure 9. Influence of DRI Charge on BF Productivity



In summary, based on the above analysis, as general rules;

- Hot Metal (HM) production increase; about 8% per each 10% of burden metallization.
- Lower coke rate; about 7% per each 10% of burden metallization.
- For 23% - 38% DRI charge, production increase is about 20% - 28%, respectively.

Conclusions

The main forthcoming factors of relevant importance for integrated steelworks are:

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

- By keeping the steelworks operating, there are some possibilities to overcome these issues. By modifying the current trend of using spent gases from the integrated facility for power generation, the alternative is to use these gases for more value-added DRI production while reducing fossil fuels consumption and decreasing CO_2 emissions. Potential decrease of non-selective CO_2 emissions is in the order of 23 – 34%.

For the incorporation of a DR plant in an integrated steelworks there are various approaches, depending on the prevailing situation of the integrated mill.

According to general analysis, the main benefits are:

- Potential increase of about 15% of crude steel, when feeding DRI to the BOF, as substitute of scrap.
- Potential increase of about 28% of hot metal when producing and feeding DRI (380 kg DRI/t HM) by using all possible COG/BOFG energy available.
- DRI production is a better choice as compared with power generation, by taking advantage of the COG available.

9. References

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