Technical, economical and ecological aspects for optimised use of fossil primary energies in integrated steel plants for crude steel production

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Summary

Instead of sending excess of coke oven gases (COG), converter gases and 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, 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, based on a simplified Mini-Module concept to be incorporated in integrated steel facilities, is included.

The economical evaluation is based on a typical material and energy balance of an integrated steel mill, including thin slab casting and rolling mill for the production of hot rolled coils. The production of DRI in an integrated steel mill 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.

Reasons of investigation

Increasing prices for energy, mainly for coke, and environmental restrictions, related nowadays 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: blast furnace gases (BFG), coke oven gases (COG) and basic oxygen furnace gases (BOFG). The calorific value and composition of these gases have wide ranges.

Energy balances of integrated steel works show that most of the 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.

The technical viability and possible schemes for using these gases for production of DRI and consequently for production of liquid steel (LS), as well as energy optimisation, are the main objectives of investigation and analysis included in this document.

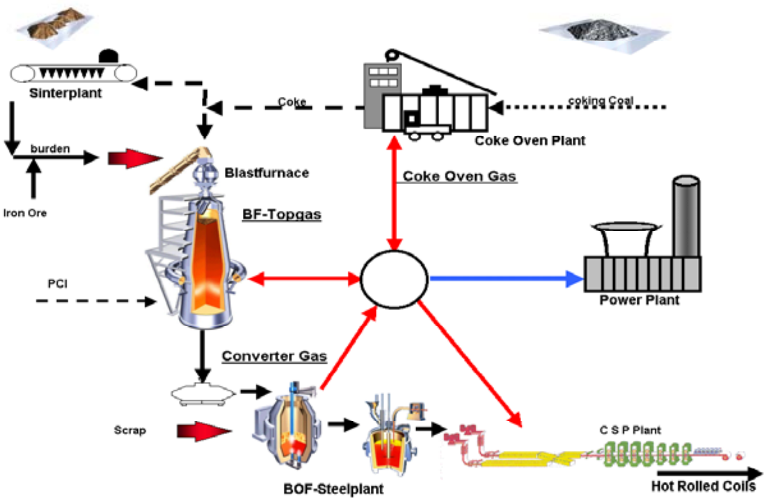
The DRI could be used in the BF to decrease the consumption of coke and/or powdered coal injection (PCI), having the capability to also increase the production of hot metal. An alternate possibility, in case there is an expansion plan for the steel works, is to increase the production of crude steel, melting the DRI with required scrap in an EAF, avoiding in this way an increase in BF and coke oven plant capacity. In the worst case, if there were no possibility for using DRI in the mill, the simplest approach would be to sell it.

Basis of the analysis

The selected integrated steel work comprises a coke oven plant/sinter plant and blast furnace for generation of HM and a BOF steel plant with ladle furnace and thin slab caster or compact strip plant (CSP) for the production of hot rolled coals (HRC).

Figure 1 shows the schematic energy distribution of this facility.

Figure 1. Energy Distribution in Integrated Steelworks



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 energy balance of a BF, as used for this investigation, is included in Figure 2 below. The analysis and the amount of gases are shown in **Table 1**.

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 sulfur (as H_2S) present in untreated (not desulfurised) 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 sulfur attack in pipelines, valves and burners.

For the carbonisation 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.

The energy balance of the coke oven plant of reference is also included in **Figure 2**. 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 DR technology for production of DRI.

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	GJ/t	0,02	3,45	
fuel/energy	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

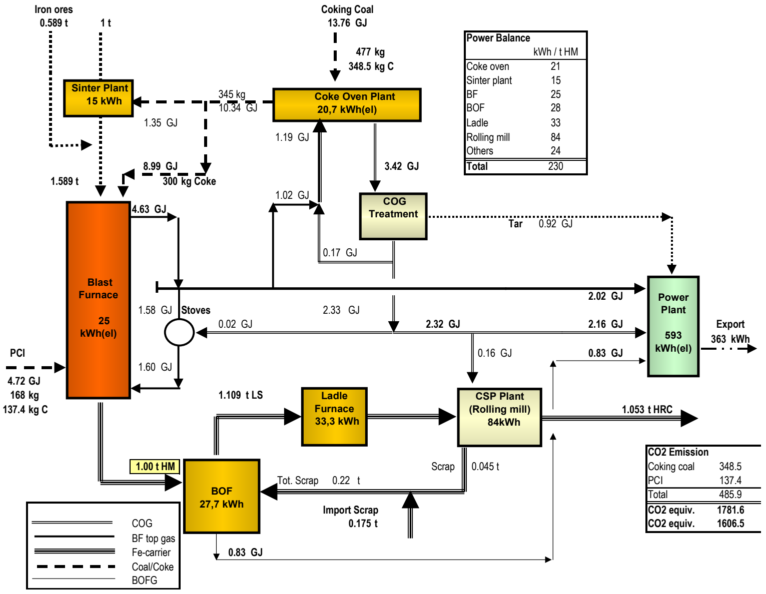
Converter Gas (BOFG)

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.** **Figure 2** includes a corresponding energy-balance of the BOF taken as reference for this analysis.

Application of spent gases in integrated mills

Figure 2. Energy/Mass Balance of conventional Integrated Steelworks



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.**

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

- Coke oven heating (fuel = up to 100% BF-gas)
- Blast furnace stoves (fuel = up to 100 % BF-gas)
- Soaking pits
- Reheating furnaces
- Ladle preheating, etc.

As shown in **Figure 2**, for a balanced conventional integrated steel mill, about 32% of the fossil primary energy is surplus gas, which is mainly used for power generation. The total amount of electric power, which can be produced, assuming 36% efficiency, is in the range of 560 kWh/t HRC. About 220 kWh/t HRC are used for in-plant requirements and the remaining 340 kWh/t HRC has to be exported.

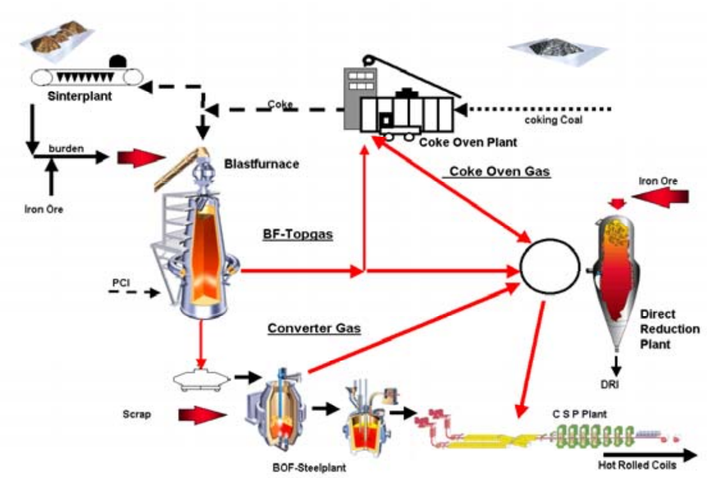
As already mentioned above, the aim of this analysis is to investigate the possibility for using these surplus gases for other than electrical power generation, specifically for production of DRI.

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 3. Incorporation of a DR plant in Integrated Steelworks

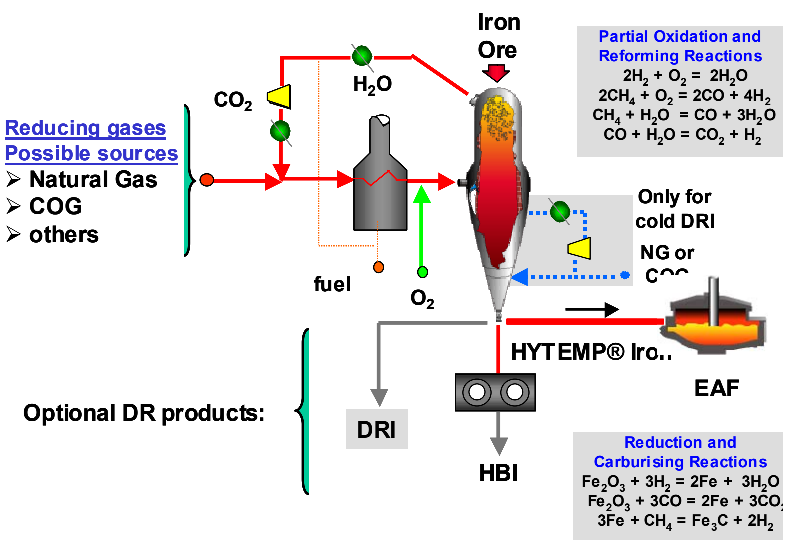


The investigation of the use of COG as well as BOFG in a DR plant is based on the HYL Self-reforming process technology, with optimum reduction efficiency via generation of the reducing gas in the reduction section itself. As a result, an external reformer unit or alternate reducing gas generation system is not needed.

Description of the HYL DR facility

The HYL Self-reforming Process [1] 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 [2], 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 and/or for hot briquetting and production of HBI. The general scheme of the HYL DR process is shown in **Figure 4.**

Figure 4. HYL Self-Reforming Process Scheme



The main characteristics of possible DR products are presented in **Figure 5.**

Figure 5. DR Products Typical Characteristics

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**

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 natural gas/COG 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.

"In-situ" reforming in the lower part of the reactor's reduction zone: Once in contact with the solid inside the reactor, further methane (in 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.

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.

This process scheme is based on the same successfully proven HYL Self-reforming 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 [3]. Similarities between COG and NG-based Self-reforming scheme are shown in **Table 2** [2]. Hence, no technological risks are foreseen by incorporating this DR technology for application in integrated mills.

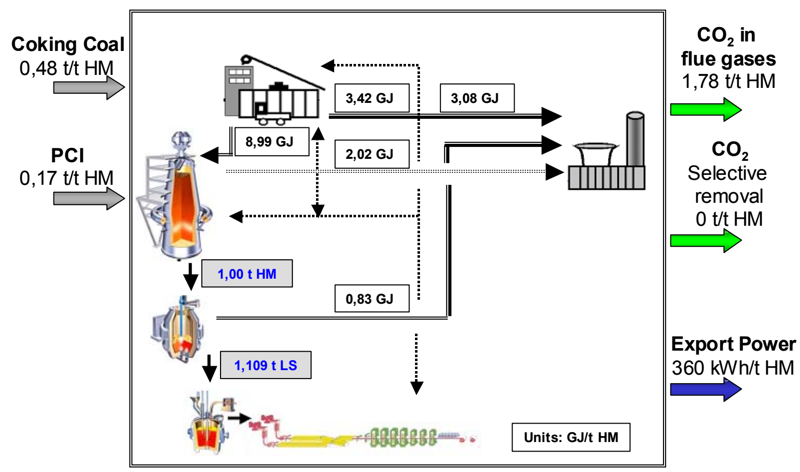
Table 2. Comparative Gas Analysis: COG vs. HYL Self-Reforming Scheme

Item Vol. %	COG	Red. Gases in HYL Self-Reforming Scheme
H_2	60,4	53,9
CO	5,7	11,3
H_2 + CO	66,2	65,2
CO_2	1,4	3,2
CH_4	25,0	22,9
N_2	4,5	5,3
H_2O	3,0	3,4

Incorporation of the HYL DR module in integrated steel works

Figure 6 presents a simplified overview of the global energy balance and CO_2 emission for a typical integrated steelworks.

Figure 6. Overall Energy/Carbon Balance for Typical Integrated Steelworks



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

- Total amount of COG and BOFG, to be 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.

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. 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 rolling mill or other consumers like power generation. 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.

Cases of Analysis

The following cases are analysed for improving overall energy consumption, CO_2 emissions and production costs in typical integrated steel works:

- Base approach: Production of cold DRI to be fed into the BF, to decrease specific coal consumption and CO_2 emissions by either keeping same liquid steel production rate or increasing HM/LS productivity.
- Alternate approach: Production of hot DRI to be fed into an electric arc furnace (EAF), for additional liquid steel production.

Basis for this analysis are:

- BF using 300 kg of coke and 170 kg of PCI/t HM.
- Maximum DRI production, as per available COG and BOFG is about 350 kg/t HM, with 94% Mtz and 4% Carbon.

Base approach: Cold DRI to the BF

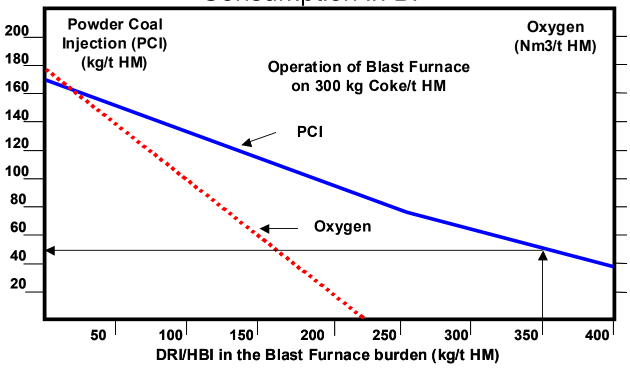
For this case, cold DRI is fed to the BF. As commented before, for the scheme based on the maximum use of COG and BOFG, DRI production rate is about 0,35 t/t HM. Since the specific consumption of coke is already optimised, there are two possibilities:

Case 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.

Case 2. To increase HM productivity in the BF, decreasing not only specific consumption figures and CO2 emissions but also achieving savings in production costs.

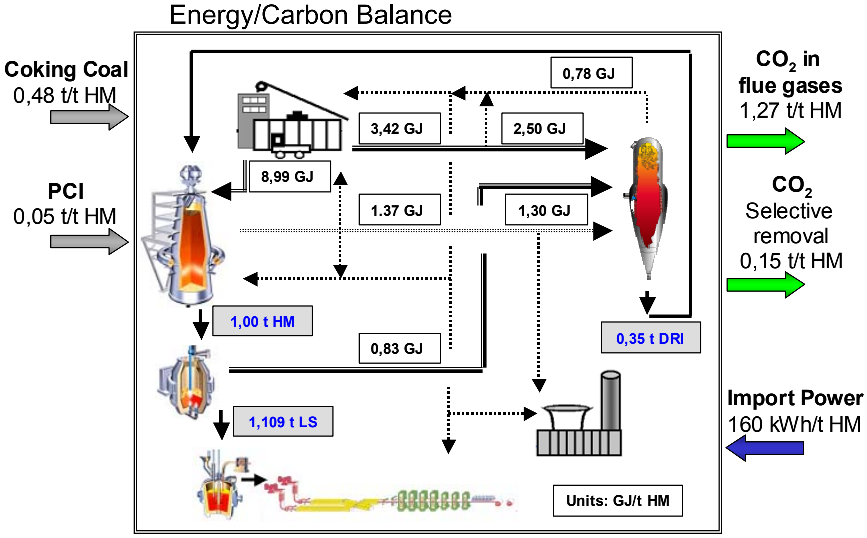
Influence of DRI/HBI feed to the BF has been reported in previous works performed in various facilities worldwide [4], [5], [6]. **Figure 7** shows the influence of DRI feeding into the BF in terms of PCI consumption.

Figure 7. Influence of DRI Charge on PCI Consumption in BF



For Case 1, there is a reduction of 18% of PCI/t HM and a potential decrease of CO_2 emission of about 28% less, considering the selective elimination from the DR plant, which should be delivered/disposed for other purposes than venting. **Figure 8** presents the schematic overall balance of Case 1.

Figure 8. DRI to BF. Same HM production Overall Energy/Carbon Balance



For Case 2, there is an estimated increase of 24% of HM/LS with 0.35 t of DRI/t HM in the BF. Fossil energy decreases in about 13% as PCI/t HM and CO_2 in flue gases is reduced in 23%. The corresponding scheme is presented in **Figure 9.**

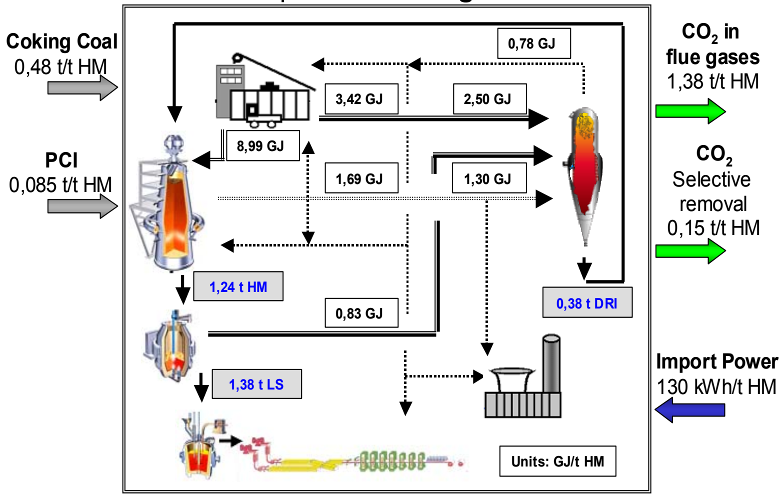


Figure 9. DRI to BF. Increase of HM production Overall Energy/Carbon Balance

Alternate approach: Hot DRI to EAF

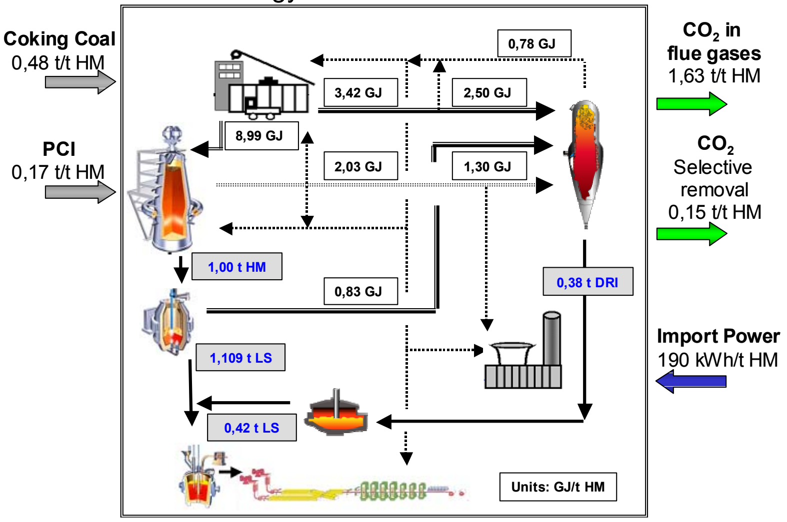
In case there is no further possibility for increasing HM production in an existing BF, an alternate solution for higher liquid steel production is:

Case 3. To feed the DRI, being produced by spent gases from the integrated steelworks, into an EAF.

For this case, hot DRI mixed with scrap is fed to the EAF. The liquid steel from the EAF can be added to the crude steel produced in the BOF. There is maximum crude steel production of about 1,53 t/t HM, as compared to conventional-base case of 1,109 t/t HM. About 0,42 t LS is obtained in the EAF.

While the amount of scrap as coolant added to the BOF is in the range of 200 kg/t LS, the amount of scrap added to the EAF could be nil or in the amount restricted by the grade of steel to be produced. For this example, a mixture of 78% DRI and 22% scrap was selected.

Figure 10. DRI to EAF. Increase of LS production Overall Energy/Carbon Balance



The total increase of steel production, as compared to the conventional scheme, is about 38% more with the same input of fossil energy. The advantage of this concept is that without an increase of the blast furnace/BOF capacity and without an increase of the coke oven capacity, the production of the steel works could be significantly increased. For this case, total CO_2 emissions are decreased by 27.5%. Similarly to above cases, provided that selective CO_2 removal from DR plant is delivered for other than venting purposes, this figure is about 34%.

A summary of specific consumption figures for the various discussed approaches is included in **Table 3.**

Table 3. DR Plant in Integrated Steelworks. Specific Consumption Figures

		Base Case 1,00 t HM	1,109 t LS	CASE 1: DRI to BF 1,00 t HM	1,109 t LS	CASE 2: DRI to BF 1,24 t HM	1,375 t LS	CASE 3: DRI to EAF 1,00 t HM	1,530 t LS
Concept	unit	unit/t HM	unit/t LS	unit/t HM	unit/t LS	unit/t HM	unit/t LS	unit/t HM	unit/t LS
Coke	**kg**	**300,0**	**270,5**	**300,0**	**270,5**	**300,0**	**270,5**	**300,0**	**196,1**
Consump. Decrease	**%**				**0,0%**		**0,0%**		**27,5%**
Raw materials									
Sinter	t	1,00	0,90	1,00	0,90	1,00	0,90	1,00	0,65
Ore BF	t	0,59	0,53	0,08	0,07	0,08	0,07	0,59	0,39
Ore DR	t	-	-	0,51	0,46	0,51	0,46	0,51	0,33
Imp. Scrap	t	0,18	0,16	0,18	0,16	0,18	0,16	0,27	0,18
Total Raw Materials	**t**	**1,77**	**1,59**	**1,76**	**1,59**	**1,76**	**1,59**	**2,37**	**1,55**
Fossil Energy									
Coking coal	GJ	13,76	12,41	13,76	12,41	13,76	12,41	13,76	8,99
PCI	GJ	4,72	4,26	1,39	1,25	2,36	2,13	4,72	3,08
Total Fossil Energy	**GJ**	**18,48**	**16,66**	**15,15**	**13,66**	**16,12**	**14,54**	**18,48**	**12,08**
Consump. Decrease	**%**				**18,0%**		**12,8%**		**27,5%**
Electrical Power									
Import power	kWh	-	-	159	143	127	114	192	125
Export power	kWh	363	328	-	-	-	-	-	-
CO2 in Flue gases	**kg**	**1.782**	**1.607**	**1.274**	**1.148**	**1.379**	**1.243**	**1.627**	**1.064**
Emissions Decrease	**%**				**28,5%**		**22,6%**		**33,8%**

Economical aspects

Energy Cost

The economical investigation for the use of surplus gases from integrated steelworks is based on the price of steam coal for power generation. Electrical power is generated with an efficiency of 33 - 36%. The cost for electrical power has been calculated under German conditions, where the price of steam coal is in the range of 42 US$/t, which is equivalent to 1.3 US$/GJ. With this price, the cost of electrical power is calculated as 0.033 US$/kWh.

Using the spent gases from the integrated steel works, which only can be used in a conventional power plant (no pressure of the gases), with an efficiency of 33%, the equivalent cost for the gas is **0.8 US$ /GJ.**

This figure is used for calculation of DRI production cost, as equivalent energy cost of COG and BF top gases.

DRI Production Cost

DRI production cost estimate, excluding investment and financing cost, is included in **Table 4.** Feedstock is made up of 50% pellets and 50% lump ore. DRI cost is about 75 US$/t.

Table 4. DRI Production Cost

		Unit Cost	HYL DR MINI-MODULE 50% pellet/ 50% lump ore DRI: 94% Mtz, 4% C	
Concept	unit		Unit/t	$US/t
Pellets	t	46.0	0.69	31.74
Lump ore	t	37.0	0.69	25.53
COG	GJ	0.80	7.14	5.71
Fuel (BF/BOF) gas-Net	GJ	0.80	3.86	3.09
Electricity	kWh	0.04	80	3.20
Oxygen	Nm3	0.039	11	0.43
Water	m3	0.050	1.30	0.07
Other consumables	$US			1.15
Variable Cost	**$US**			**70.91**
Maintenance	$US			3.01
Personnel	m-h	7.00	0.17	1.19
G&A	$US			1.00
Fix Cost	**$US**			**5.20**
Total Process Cost	**$US**			**76.11**

Hot Metal and Liquid Steel Production Cost

Estimate of HM and LS production costs for the base-reference case and the above-described approaches are included in **Table 5**. No capital cost for DR plant and EAF (if required) have been included.

Table 5. Hot Metal and Liquid Steel Production Cost

		Unit Cost	Base Case 1.00 t HM	1.109 t LS	CASE 1: DRI to BF 1.00 t HM	1.109 t LS DRI: 94% Mtz, 4% C	CASE 2: DRI to BF 1.24 t HM	1.375 t LS DRI: 94% Mtz, 4% C	CASE 3: DRI to EAF 1.00 t HM	1.530 t LS DRI: 94% Mtz, 4% C
Concept	unit		unit/t HM	$US/t HM	unit/t HM	$US/t HM	unit/t HM	$US/t HM	unit/t HM	$US/t HM
BF Process Cost										
Sinter	t	45.5	1.00	45.50	1.00	45.50	1.00	45.50	1.00	45.50
Pellets	t	46.0	0.42	19.32	-	-	-	-	0.42	19.32
Lump ore	t	33.0	0.17	5.61	0.08	2.64	0.08	2.64	0.17	5.61
DRI	t	76.11	-	-	0.35	26.64	0.35	26.64	-	-
Others	US$			0.14		0.85		0.85		0.14
Total Feedstock	**$US**			**70.57**		**75.63**		**75.63**		**70.57**
Coke	t	137.00	0.300	41.10	0.300	41.10	0.300	41.10	0.300	41.10
PCI	t	63.81	0.170	10.85	0.050	3.19	0.085	5.42	0.170	10.85
Oxygen	Nm3	0.04	44.0	1.76	-	-	44.0	1.76	44.0	1.76
Electric. Power-Net	kWh	0.033	-363	-11.99	131	4.31	99	3.26	27	0.88
Total Energy	**$US**			**41.72**		**48.60**		**51.54**		**54.59**
Total BF	**$US/t HM**			**112.29**		**124.23**		**127.17**		**125.16**
Liquid Steel Processing Cost										
Concept	unit		unit/t LS	$US/t LS	unit/t LS	$US/t LS	unit/t LS	$US/t LS	unit/t LS	$US/t LS
Hot metal	t		0.902	101.25	0.902	112.02	0.902	114.67	0.902	112.86
Scrap	t	120.0	0.162	19.48	0.162	19.48	0.162	19.48	0.198	23.81
BOF Proc. cost	US$			27.00	-	27.00		27.00		27.00
Total BOF LS	US$			147.73		158.50		161.15		163.66
Total EAF LS Cost	US$									132.63
LS increase	%					-		24%		38%
Margin LS surplus						-		24.00		37.96
Total LS	**$US/t LS**			**147.73**		**158.50**		**137.15**		**125.70**

The Case 1 approach is aimed to the main target of environmental impact by reducing CO_2 emissions.

Since there is no additional HM/LS production and there is an import of electrical power instead of export, the production cost is about 10 US$/t LS higher than that of the conventional case. For this approach, the main driving force will be the additional economical benefits due to environmental restrictions. Credit for decrease of CO_2 emissions has not been included and it is expected that this benefit would compensate the production cost increase in some extent.

Case 2 implies the possibility of increasing HM/LS production rate, by feeding DRI to the BF. Main economic benefits can be achieved by selling pig iron surplus or, provided there is enough downstream lines capacity, by increasing liquid steel production. For the latter, estimated reduction of LS production cost is about 10 US$/t LS.

Other possibility for Cases 1 and 2 could be to simply sell the DRI produced.

For Case 3, the cost of LS in the EAF was calculated in about 132 US$/t LS on the basis of 78% hot DRI and 22% scrap. Taking into account surplus production, this approach provides the highest benefits in terms of LS production cost – about 22 US$/t LS less- and CO_2 emissions reduction –about 34%-, although implies the implementation of DR-EAF route for additional steel production.

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.

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:

- Decrease in 13 - 28% of fossil fuel consumption and 23 – 34% of non-selective CO_2 emissions.
- Potential increase of 24% of hot metal by incorporating a DR module and keeping the same production route. Liquid steel production cost can be about 10 US$ /t less.
- Potential increase of about 38% of liquid steel by installing DR-EAF facilities. Cost of crude steel can be reduced in about 22 US$/t.

Main purpose of this work is to present a general and preliminary analysis of the various approaches. A specific and detailed investigation will depend on the particular plant arrangement and economical conditions of existing integrated mills.

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