ENERGIRON Direct Reduction Technology - Economical, Flexible, Environmentally Friendly

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Summary

For more than 50 years, HYL (now Tenova HYL) has developed technologies designed to improve steelmaking competitiveness and productivity for steel facilities. The HYL direct reduction (DR) technology, while perhaps the best known, is accompanied by other technologies designed for making steel in more efficient, cost-effective ways. The HYL Process has been improved over generations and the current status of the technology, the HYL ZR (or Self-reforming) Process, was developed to allow reduction of iron ores in a shaft furnace without external gas reforming equipment. This process scheme has the ability to produce High Carbon DRI, which allows producers to obtain maximum benefits of carbon in the steel making process, while for merchant sale of the product, eliminating the need for costly briquetting equipment thanks to its highly improved stability.

The recent alliance between Tenova HYL, Techint and Danieli brings a new brand - ENERGIRON - to the forefront of the direct reduction industry. Current environmental regulations worldwide bring more stringent demands to the design of industrial plant operations of all types. ENERGIRON technology is characterized by its flexible process configuration which is able to satisfy and exceed these requirements. In regions where either the high cost or low availability of natural gas work against this traditional energy source, the process is easily configured to operate using coke oven gas, syngas from coal gasifiers and other hydrocarbon sources. More importantly, the air and water effluents of the process are not only low but easily controlled. Incorporation of selective carbon dioxide (CO_2) removal systems has been a key factor over the past decade in reducing significantly the emissions levels, providing an additional source of revenue for the plant operator via the captured CO_2. The high pressure operation and closed system of an ENERGIRON plant combined with the HYTEMP Pneumatic Transport System reduces dust emissions to both air and settling tanks, making the process more economical and environmentally friendly. This paper will review the design configuration and economic impact of these green technologies.

1. The ENERGIRON Process

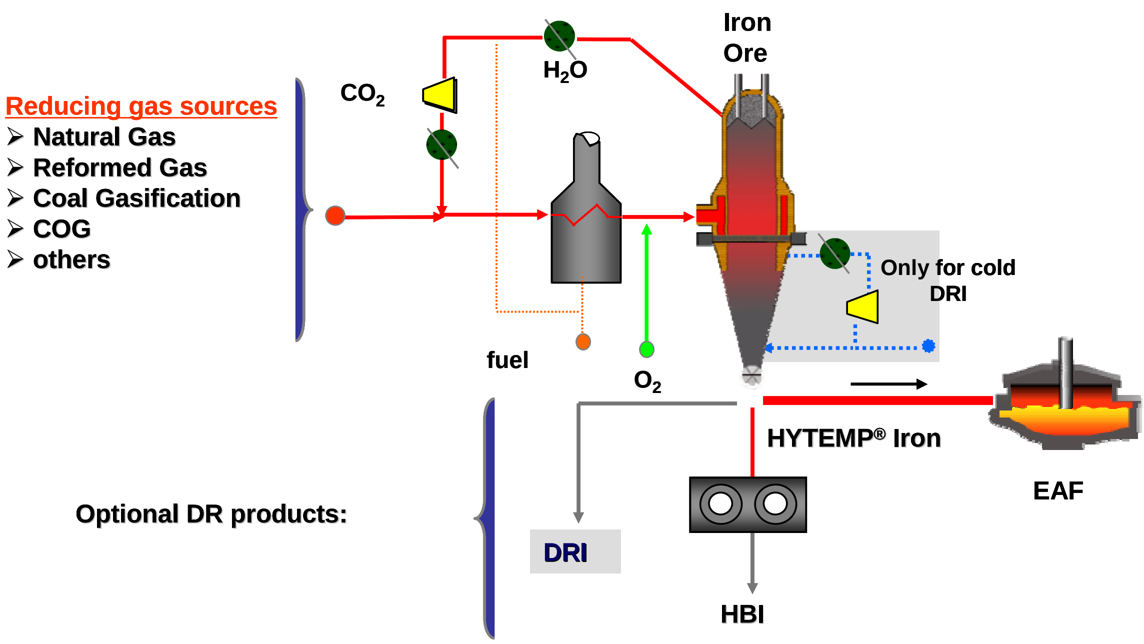
The ENERGIRON Process (Figure 1), based on the ZR scheme, is a major step in reducing the size and improving the efficiency of direct reduction plants. Reducing gases are generated by in-situ in the reduction reactor, feeding natural gas as make-up to the reducing gas circuit and injecting oxygen at the inlet of the reactor.

Since all reducing gases are generated in the reduction section, taking advantage of the catalytic effect of the metallic iron inside the shaft furnace, optimum reduction efficiency is attained, and thus an external reducing gas reformer is not required. Compared to a conventional DR plant including reformer, in addition to lower operating/maintenance costs and higher DRI quality, the total investment for a ZR plant is also lower.

The basic ENERGIRON scheme permits the direct utilization of natural gas. Of course, ENERGIRON plants can also use the conventional steam-natural gas reforming equipment, which has long characterized the process. Other reducing agents such as hydrogen, gases from gasification of coal, petcoke and similar fossil fuels and coke-oven gas, among others, are also potential sources of reducing gas depending on the particular situation and availability.

Additionally, the DR plant can be designed to produce High-carbon DRI, hot DRI, which can be directly fed to adjacent EAF through the HYTEMP System or to briquetting units to produced HBI or any combination of these products.

Figure 1. ENERGIRON Process Diagram



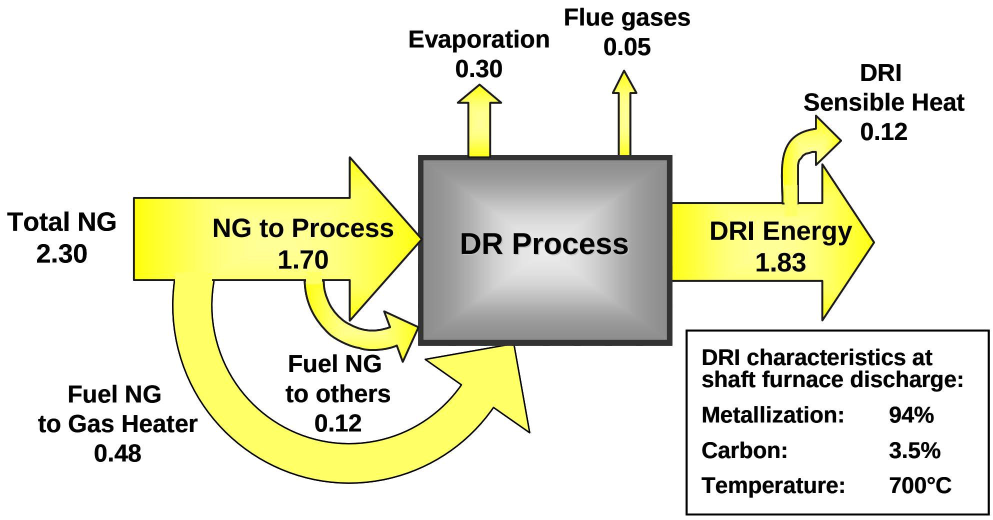
The overall energy efficiency of the ZR process is optimized by the integration of high reduction temperature (above 1050°C), "in-situ" reforming inside the shaft furnace, as well as by a lower utilization of thermal equipment in the plant. Therefore, the product takes most of the energy supplied to the process, with minimum energy losses to the environment. One of the inherent characteristics of the process scheme and of high importance for this application is the selective elimination of both by-products generated from the reduction process; water (H_2O) and specifically carbon dioxide (CO_2), which are eliminated through top gas scrubbing and CO_2 removal systems, respectively.

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

A remarkable advantage of this process scheme is the wider flexibility for DRI carburization, which allows attaining carbon levels up to 5.5%, due to the improved carburizing potential of the gases inside the reactor, which allow for the production primarily of iron carbide.

For the production of high quality DRI, i.e. 94% metallization, 3.5% carbon and discharged at 700°C, the thermal energy consumption is only 2.30 Gcal/t DRI as natural gas and just 60 to 80 kWh/ton DRI as electricity, with a remarkable low iron ore consumption of 1.35 to 1.40 t/t DRI, mainly due to high operating pressure. This makes the ENERGIRON plant, based on the ZR scheme, the most efficient direct reduction method in the field. Figure 2 presents the overall thermal energy distribution for the plant based on High-carbon, hot DRI. This plant configuration has been successfully operated since 1998 with the HYL DR 4M plant and was also incorporated (in 2001) in the 3M5 plant, both at Ternium-Hylsa in Monterrey.

Figure 2. Energy Balance



The impact of eliminating the external gas reformer on plant size is significant. For example, a plant of 1.6-million t/year capacity requires only 60% of the area needed by other process plants for the same capacity.

2. DRI quality –High Carbon DRI

In the ENERGIRON process, carbon in the DRI, mostly as iron carbide (Fe_3C), is derived mainly from methane (CH_4) and in less extent from carbon monoxide (CO). The level of carbon is adjusted by controlling the reducing gas composition and/or oxygen injection. Most of the carbon in DRI (more than 90% for carbon levels of 4%) currently being produced in the ZR scheme is in the form of iron carbide (Fe_3C). The high percentage of Fe_3C in the DRI makes the product very stable and presents a unique option related to storage, shipping and handling.

HYL ran extensive tests to determine whether the combined carbon in DRI was a factor in improving product stability over that of conventional DRI, whether produced by HYL plants or other process technologies. This has been proven through industrial operations and by specific own and independent laboratory tests

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

To the end of December 2006, the accumulated production of high-carbon DRI (94% metallization, carbon range from 3.5 - 4.2%) from both Monterrey HYL Process plants was:

3M5 (since July 2001)	2,698,993 MT
4M (since April 1998)	6,772,760 MT
Total Accumulated Production:	9,471,753 MT

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Benefits of high-carbon hot DRI in meltshop operations has been demonstrated in Ternium-Hylsa's meltshop while feeding up to 100% of hot DRI with about 94% metallization and 4% carbon.

In general, carbon in the DRI in EAF provides:

- Chemical energy contribution; the dissociation of cementite is an exothermic reaction ($Fe_3C \rightarrow 3Fe + C + \Delta E$ -0.4 kWh/kg C), which improves the thermal efficiency in the EAF thus decreasing electric power requirements. Besides, EAF's quality carbon is normally available at higher cost than the carbon obtained from natural gas in DRI
- Efficient use of carbon; as compared to other sources of carbon injection, while minimizing external carbon (graphite) additions, cementite in DRI is characterized by a higher recovery yield in the EAF.
- Easy foamy slag generation; as high carbon DRI enters in contact with free or combined oxygen.
- The same system controls the feeding rate of metallic charge and carbon additions.

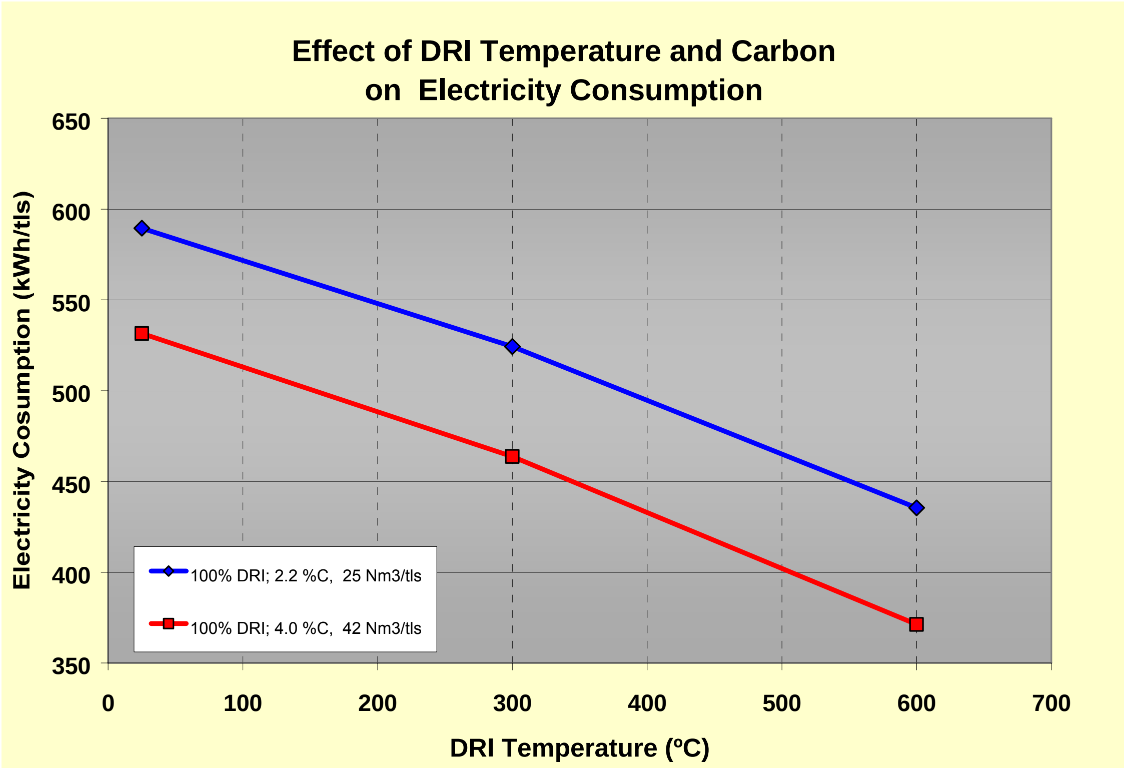
Impact of DRI carbon in the EAF is presented in Figure 3. Graphite injection is about 12 kg/tLS for DRI with 2.2% carbon and 0.5 kg/tLS for DRI with 4.0% carbon. For these operating conditions, the change from 2.2% to 4% carbon in cold DRI represents a decrease of 11-kg graphite and 58-kWh/tLS. This power saving is a result of the replacement of graphite by cementite related to yield and heat reaction.

On the other hand, hot DRI feed provides additional sensible heat to the EAF, reducing power consumption and tap-to-tap time, which is additionally reflected in productivity increase. The overall effect of:

- high-efficiency ZR scheme with minimum thermal and electricity consumption figures, and
- use of hot and/or cold High-Carbon DRI in EAF,

have an important impact on the overall energy demand for steel production, decreasing overall plant emissions and particularly CO_2 release to atmosphere.

Figure 3: EAF Performance with High-Carbon DRI at different feeding Temperatures



3. DR Plant Emissions

For a DR plant, main gas and solids emissions are related to:

- Iron ore particulates from material handling
- Iron ore and DRI particulates as sludge from process water system
- Gaseous effluents from thermal equipment and degassing stacks of water systems

Emissions from gaseous and aqueous effluents from a DR plant can be categorized in two main groups:

a) Pollutants, such as: NOx, SOx, VOC, particulates, etc., which limits are defined by the environmental regulations of local Governments.

b) Global Warming-Greenhouse emissions (GHG), which refer to gaseous compounds from natural and anthropogenic sources that absorb and re-emit infrared radiation, enhancing the greenhouse effect. GHG comprises: CO_2, CH_4, N_2O and HFCs, PFCs, SF_6.

Compliance with the pollutants indicated in a) is mandatory to obtain governmental permits for the installation of the DR facility.

On the other hand, for those countries under the Kyoto Protocol, there is a commitment to decrease the GHG emissions by 5.2% from the 1990 level by the period 2008-2012.

3.1 *Pollutants from the DR plant*

An ENERGIRON plant complies with the strictest environmental regulations worldwide without the need of specific process requirements and/or additional equipment for treatment of heavy hydrocarbons in natural gas, sulfur in iron ore and/or de-NOx systems.

An ENERGIRON plant for hot DRI charging to adjacent EAF is normally designed for about 95% hot DRI production for direct charging to the EAF, pneumatically transported by the HYTEMP system, and about 5% of cold DRI, which is produced whenever the EAF is not receiving hot DRI.

Typical environmental data for such plant are included in Table 1.

Table 1: Typical Emissions figures of an ENERGIRON DR plant

1. Emissions factors of gaseous streams from DR Plant:
Unit: kg/ton of DRI:

Gaseous pollutant	Source		
	Process gas heater	Incinerator of CO_2 effluent	Package boiler
CO	0.0299	0.0010	0.0032
NOx	0.0985	0.0081	0.0107
SOx	0.0027	0.1036	0.0000
TSP	0.0000	0.0000	0.0000

Gaseous pollutant	Blow down stack (QCW)	Blow down degasifier (PCW)
CO	0.0118	0.0017

Gaseous pollutant	Source			
	Uncontrolled Emissions		With controlled emissions	
	Iron ore/pellet	Coating area	Iron ore/pellet	Coating area
TSP	2.75	0.00159	0.0027	0.00001

2. Emissions factors of aqueous streams from DR Plant:
Unit: kg/ton of DRI:

Aqueous pollutant	Source	
	Settling Ponds	CO_2 Scrubbing
Solids fines	19.5	0.1

From these data, the following can be observed:

- The amount of solids wastes is small because of the low gas velocities inside the shaft furnace due to the high operation pressure, which is reflected in low amount of carry-over particles in the gases.
- A nowadays critical pollutant, NOx emission in flue gases, is a result of high flame temperatures at the fuel combustion system. For the ENERGIRON plant, the NOx is below environmental limits due to the overall energy integration of the ZR DR plant, which is possible without the need of huge air preheating for energy recovery.

As example of specific compliance with strict environmental regulations, actual data are indicated in Table 2. It can be noted that no particular methods and/or additional equipment is necessary to fulfill the local regulations.

Table 2: Specific Environmental requirements as compared with emissions of the ENERGIRON DR plant

Gaseous Pollutants	Minnesota Environmental regulation	Achieved value in ENERGIRON plant	Specific Method
Particulate	0.014 grains/dscf	0.01 grains/dscf	None
SO_2	15 lb/hr, 24-hour average.	14.1 lb/hr	None
NOx	96 ppmv @ 3% O_2 152 lb/hr, 24-hour average	85 ppmv (maximum) 75 lb/hr	Just use of low NOx burners.
CO	32 lb/hr, 24-hour average.	16.6 lb/hr	None
VOC	2 lb/hr, 24-hour average	0	None

3.2 GHG from the DR plant

For the GHG, as per the Kyoto Protocol, the rules enters into force if the parties to the United Nations Framework Convention on Climate Change (UNFCCC) ratify or approve, accept or accede to the Protocol including parties accounting for at least 55% of the 1990 CO_2 emissions. There are two ways to achieving the GHG emissions levels:

- National reduction measures in the various sectors of energy, industrial, transport, agriculture, etc, or
- Through mechanism consisting of: i) Emissions Trading, ii) Joint Implementation (JI) and/or iii) Clean Development Mechanism (CDM).

It is not the purpose of this paper to go into details of such mechanisms but the objective is to emphasize the importance of reducing the GHG emissions basically because of compliance with the targets of the Kyoto Protocol, if applicable; because there are mechanisms which may be reflected in economical benefits and as responsibility of the industry to reduce the impact of the GHG effect for the future generations.

Among the industrial sector, the steel industry represents about 13% of total energy consumption, which is reflected in approximately 8% of the world anthropogenic GHG emissions.

For the analysis of CO_2 emissions, the first scenario is to compare the ENERGIRON ZR based scheme for high-carbon DRI to conventional DRI for steel production.

For calculation of CO_2 emissions, the following was considered:

- Typical consumption figures for iron ore, natural gas, electricity, oxygen and miscellaneous for the ZR plant producing DRI with 94% metallization, 3.7% carbon and for a DR plant producing DRI with 94% metallization and 1.5%C (hot DRI) and 2%C (cold DRI).

- Location in a country with 0,74 kg CO_2/kWh for electricity (and oxygen) required for pellets production, DR plant consumption and EAF operations.

Results of the analysis are presented in Table 3.

Table 3: CO_2 Emissions for Liquid Steel production through ENERGIRON ZR plant vs. typical DRI

CO_2 Emissions / tonne of Liquid Steel				
Scenario	**DR-EAF: ZR High Carbon DRI vs. conventional DRI**			
Location:	Power generation: 0,74 kg CO_2/kWh			
Scheme	**typical Cold DRI** 94% Mtz.; 2% C	**ZR Cold High-C DRI** 94% Mtz.; 3.7% C	**typical Hot DRI** 94% Mtz.; 1.5% C	**ZR Hot High-C DRI** 94% Mtz.; 3.7% C
Item/unit	**kg CO_2/t LS**	**kg CO_2/t LS**	**kg CO_2/t LS**	**kg CO_2/t LS**
Iron ore (production)	132	129	132	129
CO_2 in flue gases + removal system	447	455	455	461
Electricity & O_2 to DR plant	90	80	98	86
Subtotal DR Plant	**669**	**664**	**684**	**676**
Power & O_2 requirements	443	415	339	305
Carbon addition	35	3	59	3
Subtotal EAF	**478**	**419**	**399**	**308**
Total DR-EAF route	**1147**	**1082**	**1082**	**984**
As %	-6%		-10%	

The ENERGIRON ZR-based scheme reduces overall CO_2 emissions in 6% to 10% for cold and hot DRI, respectively, for liquid steel production.

Besides environmental benefits, the overall steel production is also reduced by processing high-Carbon DRI in the EAF, as indicated in the comparative cost analysis of Table 4.

Table 4: CO_2 Comparative Cost Analysis for Liquid Steel production through ENERGIRON ZR plant vs. typical DRI

Comparative Cost Analysis				
Scenario	**DR-EAF: ZR High Carbon DRI vs. conventional DRI**			
Scheme	**typical Cold DRI** 94% Mtz.; 2% C	**ZR Cold High-C DRI** 94% Mtz.; 3.7% C	**typical Hot DRI** 94% Mtz.; 1.5% C	**ZR Hot High-C DRI** 94% Mtz.; 3.7% C
Production cost estimate/t LS	106.9%	103.6%	103.6%	100%
Additional Operating cost for 1.2 m tpy LS million $US/y	19.3	9.9	10.1	Base: 225 $/t LS 0
Comparative EAF Productivity	75.8%	80.4%	91.6%	100%

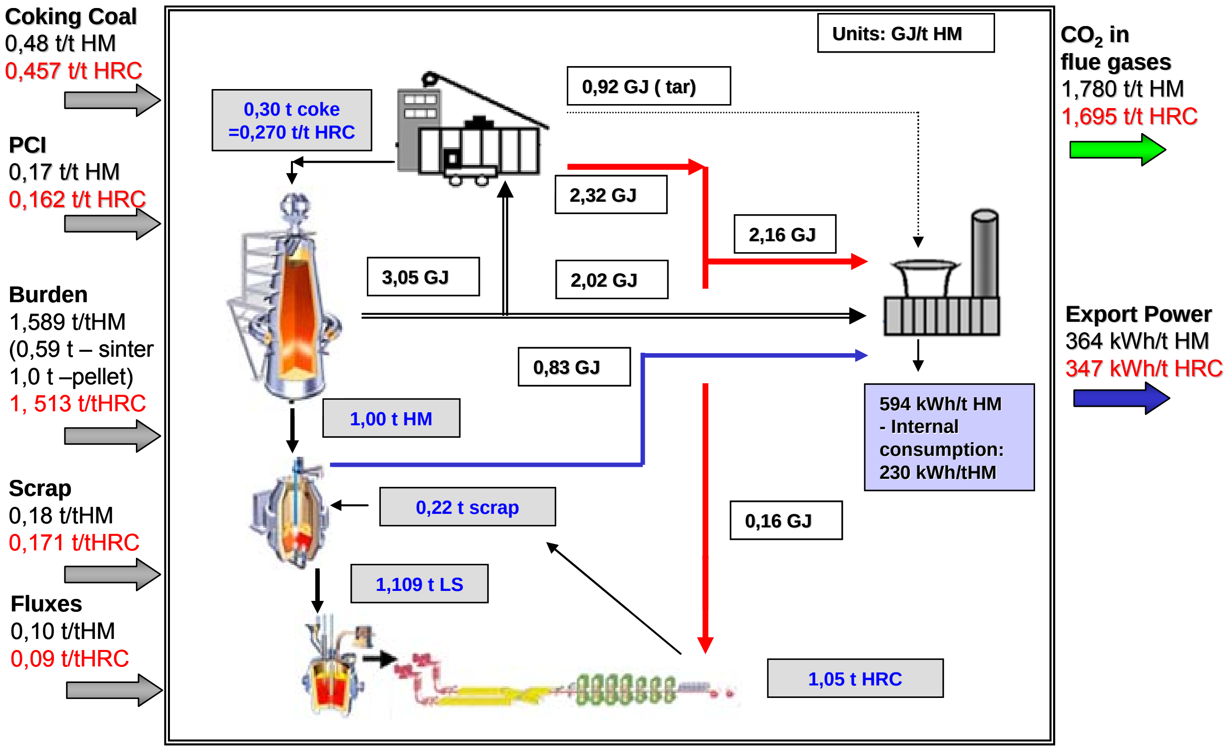
For the above analysis, the following reference prices for raw materials and energy were considered for: pellets100$/t; natural gas 9.92 $/Gcal; electricity 0.045 $/kWh; oxygen 0.06 $/$Nm^3$, and C addition to EAF 0.14 $/kg.

Based on the benefits when using the high-C DRI, as compared to other DRI qualities/schemes, for a steel facility of 1,2 million tpy, savings can be as high as 10 million $/year.

The second scenario is to compare the DR-EAF route to the BF-BOF route for manufacturing of Hot Roll Coils (HRC).

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 4 shows the schematic energy distribution of this facility.

Figure 4: Energy Distribution in Integrated Steelworks



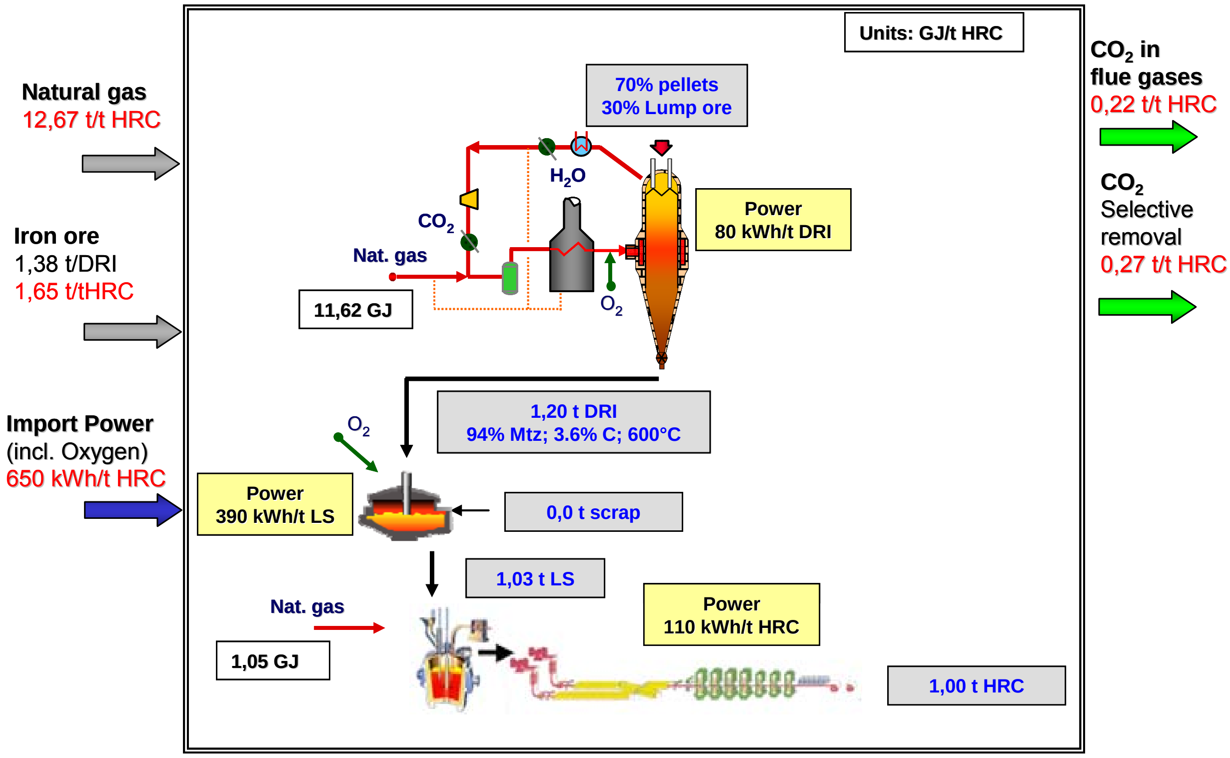
The major gaseous fuel by-products, which are recovered in integrated steel works, are: blast furnace gases (BFG), coke oven gases (COG) and basic oxygen furnace gases (BOFG). Energy balances of integrated steel works show that most of the gaseous energies are mainly used for power generation or even 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. As it can be noted, the optimized utilization of primary fossil energy also has the effect of significantly reducing the specific CO_2 emissions per tonne of HRC. For this optimized scheme, the specific CO_2 emission in flue gases via the conventional BF/BOF route is about 1.6 tonnes of CO_2/t HRC.

On the other hand, the DR-EAF route is presented in Figure 5. The ENERGIRON ZR-based DR plant was selected for high-C DRI production as 100% feed to the EAF.

Main observations are related to the fact that the while the integrated steel plant is a net exporter of electricity, the DR-EAF mill is importer. By using the ZR scheme, more than half of the gaseous CO_2 is selectively removed; this is a strong potential for alternate disposal of this CO_2, reducing significantly the GHG emissions.

Electricity generation has an impact on CO_2 emissions, depending on the location of the steel plant. Electricity generation is a composite of sourcing from natural gas, coal, hydraulic, eolic, nuclear, biomass, and depending on the particular location, the CO_2 emission is a reflection of the overall combination. There are countries like Venezuela where the power generation is based on 0,3 kg CO_2/kWh and others like India, where it is of 0,9 kg CO_2/kWh.

Figure 5: Energy Distribution in DR-EAF mill route



On the other hand, a steel plant based on DR-EAF using basically natural gas for DRI production is unlikely to be located in countries characterized by coal as main energy source, as an integrated steel plant is unlikely to be located in countries with significant natural gas resources. However, there are countries which actually are using both energy sources for steel production.

Based on the above, the comparative analysis for CO_2 emissions is made for the following scenarios:

1. A DR-EAF steel plant for electricity of 0,3 kg CO_2/kWh vs. a BF-BOF steel facility for electricity of 0,9 kg CO_2/kWh.

2. Both, DR-EAF and BF-BOF steel plants located in a country of 0,74 kg CO_2/kWh for power generation.

Results of both scenarios are presented in Tables 5 and 6, respectively.

Table 5: CO_2 Emissions: DR-EAF vs. BF-BOF comparative analysis (Power: 0,3 & 0.9 kg CO_2/kWh)

Comparative Analysis: CO_2 Emissions / tonne of HRC		
Scenario 1:	**DR-EAF route (location: Venezuela) vs. BF-BOF route (location: India)**	
Electricity source	Power gen. 0,3 kg CO_2/kWh	Power gen. 0,9 kg CO_2/kWh
Route	**DR ZR Plant-EAF kg CO_2/t HRC**	**BF-BOF kg CO_2/t HRC**
Iron ore (production) + fluxes	72	129
CO_2 in flue gases + removal system	490	1695
Subtotal	**562**	**1824**
Power requirements	196	-312
Total	**758**	**1511**
If disposal of selective CO_2 removal (ZR scheme)	488	1511

Table 5: CO_2 Emissions: DR-EAF vs. BF-BOF comparative analysis (Power: 0,74 kg CO_2/kWh)

Comparative Analysis: CO_2 Emissions / tonne of HRC		
Scenario 2:	**DR-EAF route vs. BF-BOF route (location: Argentina)**	
Electricity source	Power gen. 0,74 kg CO_2/kWh	Power gen. 0,74 kg CO_2/kWh
Route	**DR ZR Plant-EAF kg CO_2/t HRC**	**BF-BOF kg CO_2/t HRC**
Iron ore (production) + fluxes	111	119
CO_2 in flue gases + removal system	490	1695
Subtotal	**601**	**1814**
Power requirements	479	-257
Total	**1080**	**1557**
If disposal of selective CO_2 removal (ZR scheme)	810	1557

As observed from the above comparative analysis, the following can be summarized:

- By logic principle, the conversion of $CH_4 \rightarrow CO + 2H_2$ for reduction of ores, drastically reduces CO_2 emissions as compared to coal, for which case, all reductants are coming from C.

- Even though the credit from power export in the BF-BOF route, electricity sourcing has a significant impact on CO_2 emissions as noted in Table 5, where two completely different scenarios are compared.

- On a location where both routes are viable, there is a decrease of about 40% less CO_2 emissions through the DR-EAF route.

- In any case, due to the implicit characteristic of the ENERGIRON ZR-based scheme, by the selective elimination of CO_2 to optimize reuse of reducing gases, there is an important potential for further CO_2 emissions reduction of additional 30%.

4. References

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