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ENERGY SAVING AND CO_2 REDUCTION IN ENERGIRON DRI PRODUCTION[1]

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Abstract

Danieli's Energiron DRI (Direct Reduced Iron) technology coupled with hot transport of DRI to the EAF (Electric Arc Furnace) is aimed to produce high carbon DRI at lower energy and reduced CO_2 emission. Conventional blast furnace route of iron making is characterized by intensive use of coal and therefore, is emission intensive. Gas based DRI uses natural gas, which is cleaner than coking coal: and hence, 40-60% less emission intensive than blast furnace. But, due to unavailability of low cost natural gas in all parts of the world, Energiron ZR (Zero Reforming) route is designed that allows the flexibility to use gas from a variety of sources such as natural gas, gas from blast furnace, coke oven, and basic oxygen furnace, syngas, and coal bed methane. This route is therefore useful for coal-rich countries as well such as India, China, Russia, and Ukraine etc. Energiron ZR scheme capitalises on generation of reducing gas in-situ inside the reactor, and thereby eliminate the need for external reformer, resulting maximum utilization of supplied heat with minimum energy loss to atmosphere. Energiron ZR scheme produces high quality hot and cold DRI (94% metallization, 3.7 % carbon). This needs energy consumption of 2.25-2.30 GCal/t DRI and 60-80 kWh/t DRI as electrical power with iron ore consumption of 1.35-1.40 t/t DRI. The energy saving from hot charging (600 ºC) of 100% DRI in EAF at Emirates Steel, Abu Dhabi, reaches the new world benchmark of 131 KWh/t liquid steel. The Energiron ZR process 60% of CO_2 from the exhaust stream is selectively removed. To reduce emission even further, a new process called 'Energiron ZR (Minimum Emission)' is designed and patented, wherein 90% of CO_2 is selectively removed from the exhaust stream using physical adsorption system (PSA type). This gives nearly carbon free emission from the ENERGIRON ZR plant, and provides further scope of sequestered CO_2 to store as a by-product for commercial sale to food processing industry. This paper discusses on energy and emission aspects of the Energiron DRI technology.

Key words: Iron making; DRI; Energiron; Energy efficiency; Emission reduction.

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1 INTRODUCTION

Energy constitutes 20-40% of the cost of steel production, based on the plant location, and availability of nature of fuel. Efficient use of energy may reduce the production cost and increase competitiveness. Regarding emission, the steel industry is accountable for 5% of the world's total CO_2 emission, and 3% of GHG emissions. The emission intensity varies from one plant to another depending on the process route adopted. Fig. 1 shows the different process routes used for production of steel. Coal-based DRI production, though emission intensive, is not produced in volumes. Out of these process routes BF-BOF, DRI-EAF and scrap-EAF routes are mostly followed (97% of the world steel production). The EAF (scrap) route provides the least and BF-BOF route provides the most carbon emissions. Traditional gas based DRI uses natural gas as energy input. On the other hand, BF-BOF route uses coal/coke as the primary energy source. Natural gas, being cleaner energy than coal, DRI-EAF route inherently less emission intensive compared to BF-EAF route. The DRI(gas)-EAF route emits about 40-60% less CO_2 than that of BF-BOF route.

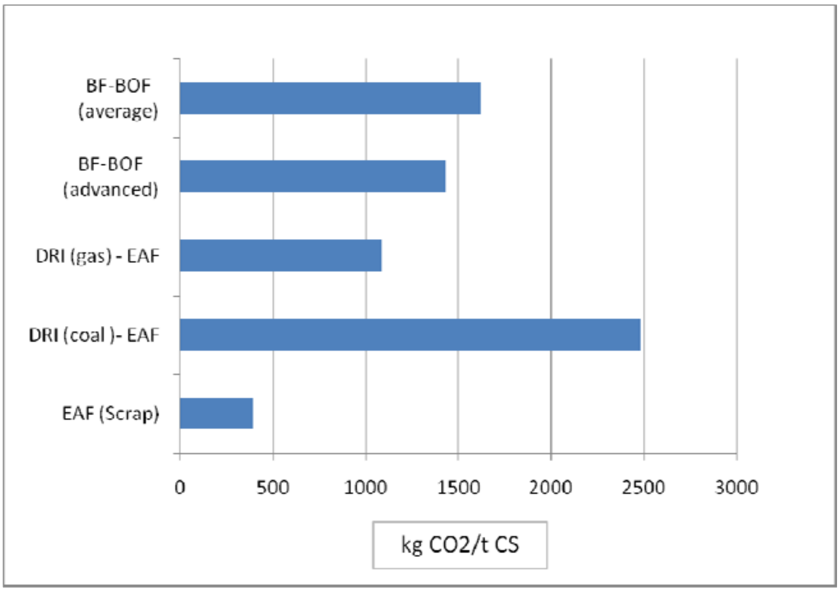

Figure 1: Emission intensities of different process routes. [1]

The energy requirements of BF-BOF, EAF (scrap) and DRI (gas)-EAF routes are given in Table 1. BF-BOF route uses most of fuel, and EAF(scrap) requires most of electricity. Therefore, regarding CO_2 emission, BF-BOF route emits the most and EAF(scrap) route emits the least. But, the scrap-based EAF steel production is limited by availability of scrap.

Table 1: Energy intensities of different process routes

	BF-BOF	DRI(gas)-EAF	EAF (scrap)
Fuel (GJ/tcs)	15.7	10.6	0.9
Electricity (kWh/tcs)	151.5	480.0	564.8

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The DRI (gas)-EAF route has potential to reduce CO_2 emissions, but is limited to low-cost natural gas supply, which is available only in certain parts of the world. The process uses the mixture of CO and H_2 as the reducing gas that is produced in the external reformer. Recognizing the difficulty of using only the natural gas, the Energiron (HYL DRI technology jointly developed by Tenova and Danieli) technology, which is external reformer based, has been extended to Energiron Zero Reforming (ZR) technology, where the same reducing gas can be produced inside the shaft furnace (reactor). Moreover, the process can take reducing gas from a number of different sources such as natural gas, coke-oven gas (COG), syngas (from coal gasification), and coal bed methane (CBM) etc. Energiron (ZR) - EAF route has thus lower carbon emission intensity compared to external reformer based other DRI(gas)-EAF route. A break-up of emission sources in Energiron (ZR)-EAF process is compared with other gas-based DRI-EAF process (Fig. 2).

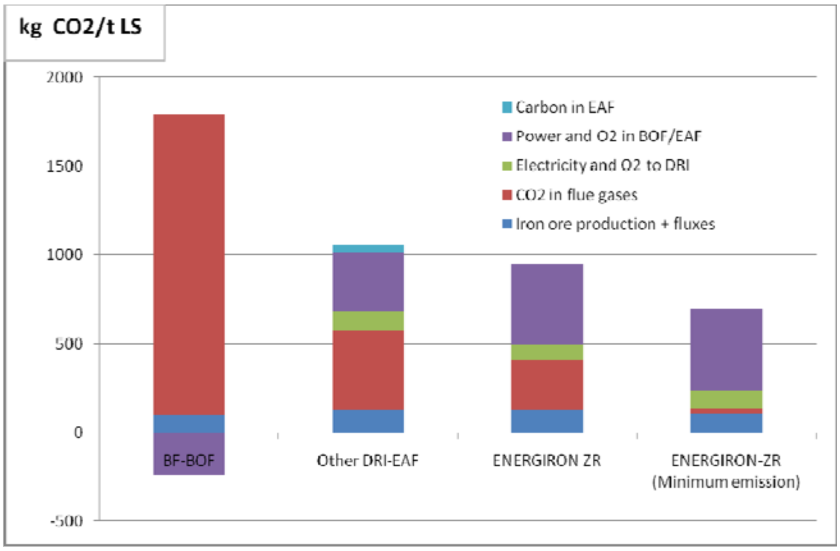

Figure 2 : Contribution to emission intensities from different sources (location : 0.74 kg CO_2/kWh).[2]

Following Kyoto Protocol (1997/2005) and Copenhagen Conference (2009), nearly all countries have formulated their National Policies on mitigation of GHG emissions. Though the protocol aims at reducing GHG emissions by 15-20% (of 1990 level) by 2020, the total CO_2 emissions already increased by 40% (since 1990) to 31.3 BT (billion tonnes). To improve energy efficiency and reduce carbon emissions, a new technology is designed to emit minimum carbon dioxide to atmosphere. The technology is patented as ‘ENERGIRON ZR (minimum emission)’. In this scheme 90% of CO_2 from the exhaust gas stream is selectively extracted to 60% in ZR scheme (Table 2).

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Table 2: Comparison of different process routes in terms of energy and CO_2 removal

	Other DRI-EAF	ENERGIRON ZR	ENERGIRON ZR (Minimum emission)
Fuel (GJ/t)	9.7	9.7	9.7
Electricity + O_2 injection (kWh/t)	100	65	100
Efficiency (%)	80	86	86
CO_2 selective removal	-	60%	90%

2 ENERGIRON (*with* external reformer)

Figure 3 shows the process flow diagram of Energiron technology for DRI production. The process uses a steam reformer that produces the reducing agents of a mixture of hydrogen (H_2) and carbon-monoxide (CO) required for reduction of iron-oxide inside the reactor. The wet reformer gas is dried in a quench tower and then mixed with the process gas (PG) coming out from the top of the reactor. The mixed gas is heated in the process heater before sent to the distribution ring of the reactor. The gas is enriched with oxygen in between the heater and the reactor in order to increase the gas carburization potential when high percentage of carbon (>2.5%) is demanded by the meltshop. In order to prevent the escape of reducing gas from top and bottom ends of the furnace, a seal with an inert gas is provided at a pressure little higher than top and cooling gases. The top gas is passed through the recuperator (where some heat is recovered and delivered to PG heater) before it is sent to the scrubbing and quenching system to get rid of water vapour (H_2O) and carbon-dioxide (CO_2). The clean outcoming gas leaves at a temperature of 30 ºC. The gas is then compressed in the compressor and is sent to the CO_2 absorber where CO_2 is eliminated by means contact between the gas and an amine-based liquid solution. The gas leaving the absorber is free of oxidants and its reducing potential is fully recovered to join the reformed gas, and passes again through process gas heater, thus closing the process loop. The CO_2 absorber strips H_2S as well, and thereby provides the sulphur-free process gas. The cold DRI is stored in bins and is fed to the meltshop by means of belt conveyors. The hot DRI (650-700 ºC) is conveyed to the meltshop using pneumatic transport system through HYTEMP tower. Hot DRI charging reduces electricity consumption and tap-to-tap time.

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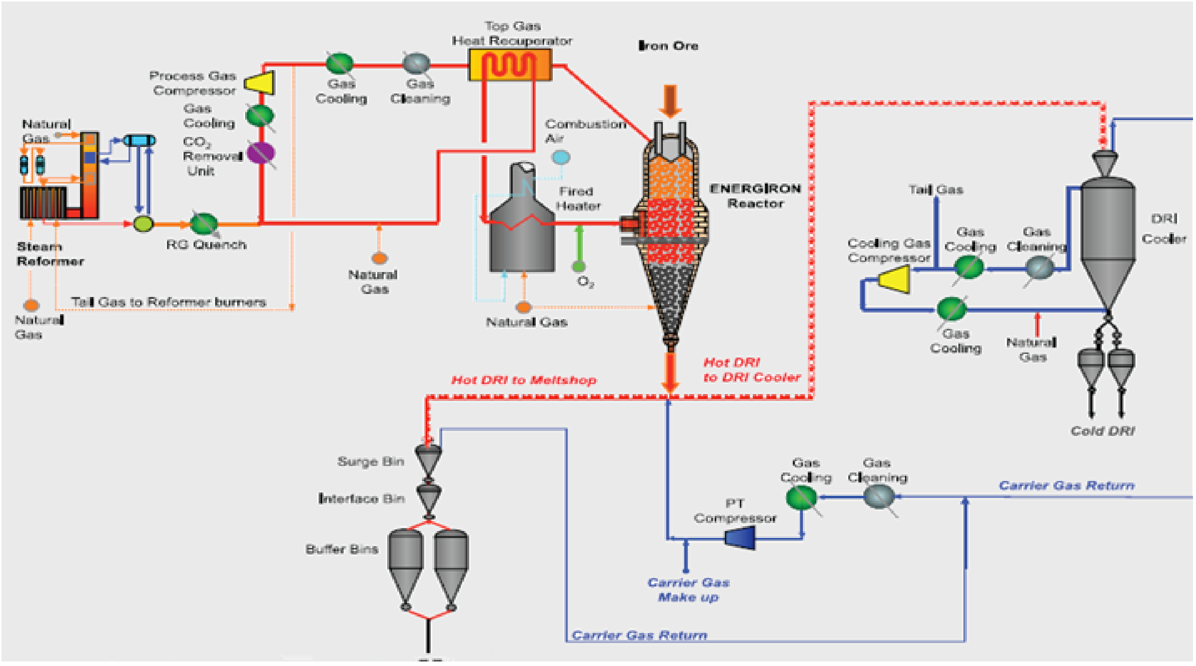

Figure 3: Energiron (with external reformer) Process Flow.

A DRI plant consists of two basic circuits – the iron making circuit (right) and the reducing gas reforming circuit (left) (Fig. 4). The iron ore, in the form of pellet or lump, is charged into the reactor from the top. It descends due to gravity and interacts with the upcoming reducing gas which is mainly CO and H_2. The top gas, that leaves the reactor top, is rich in CO_2 and H_2O (water vapour). The reduced material is DRI and is taken out of the reactor through the bottom valve. Inside the reactor it is very important to control the process gas temperature, gas composition, and the contact time with iron oxide.

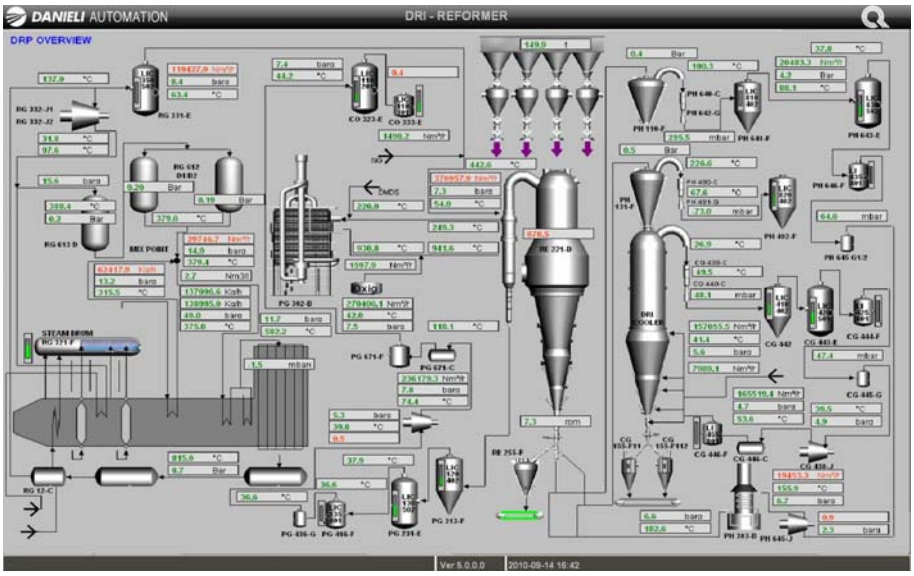

Figure 4: Two basic circuits – iron making (right) and gas reforming (left) for ENERGIRON process at Emirates Steel, Abu Dhabi, UAE

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The reformer furnace is a combustion furnace which is fed with two different kind of gases – top gas and natural gas. The top gas is used as fuel during steady state operation. This ensures minimum energy consumption in the entire process. The natural gas is used during start-up and also as compensating fuel in case the top gas is not sufficient. It is important to have a correct air-fuel ratio in order to avoid incomplete combustion or excess of air, which means excessive energy consumption. Since the calorific value of top gas changes during process and the natural gas and top gas do not have the same properties the air-fuel ratio varies during the process.

The oxygen content is maintained in the combustion exhaust gas to ensure good combustion. The air-fuel ratio is corrected if a difference between desired and actual oxygen content exists. After reforming process the reformed gas leaves the furnace. The quality of reforming reaction is judged through the amount of CO_2 present in the reducing gas. The purpose of this is to maintain CO_2 at a constant level. The amount of methane that is required to be added with the process gas at the inlet of reformer furnace can then be controlled. The amount of natural gas addition also depends on process gas flow. Thus a main loop controls the percentage of CO_2, while a feed-forward loop compensate for process flow variations.

Among recent installations of Energiron, the largest single reactor (module) plant with external reformer was in Emirates Steel, Abu Dhabi, UAE in 2009 for the capacity of 1.6 MTPA (achievable up to 2 MTPA).

3 ENERGIRON ZR (*without* external reforming)

Another scheme of ENERGIRON is called ENERGIRON ZR process, which does not use an external reformer. In ENERGIRON ZR process, reducing gases are generated in the reduction section of the shaft furnace through catalytic effect of metallic iron inside the shaft furnace. Natural gas is used as a feed for make-up to reducing gas circuit. The O_2 is injected at the entry to the reactor (Fig. 5). Thus optimum reduction efficiency is obtained.

The chemical reactions involving in reforming, reduction and carburization stages are given below [3].

In-situ reforming :

$$CH_4 + H_2O \rightarrow CO + 3H_2$$
$$CH_4 + CO_2 \rightarrow 2CO + 2H_2 \quad (1)$$

Reduction :

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$
$$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O \quad (2)$$

Carburization :

$$3Fe + CH_4 \rightarrow Fe_3C + 2H_2 \quad (3)$$

Energiron ZR process is independent of reducing gas source. There is no need for recirculation of gases back to the reformer to complete the process chemistry route. The absence of external reformer means the plant area is only 60% of the plant the uses external reformer. This reduces total investment cost. It also

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increases efficiency of DR process. Thus compared to conventional DRI plant (with reformer) ZR scheme has lower operating and maintenance cost.

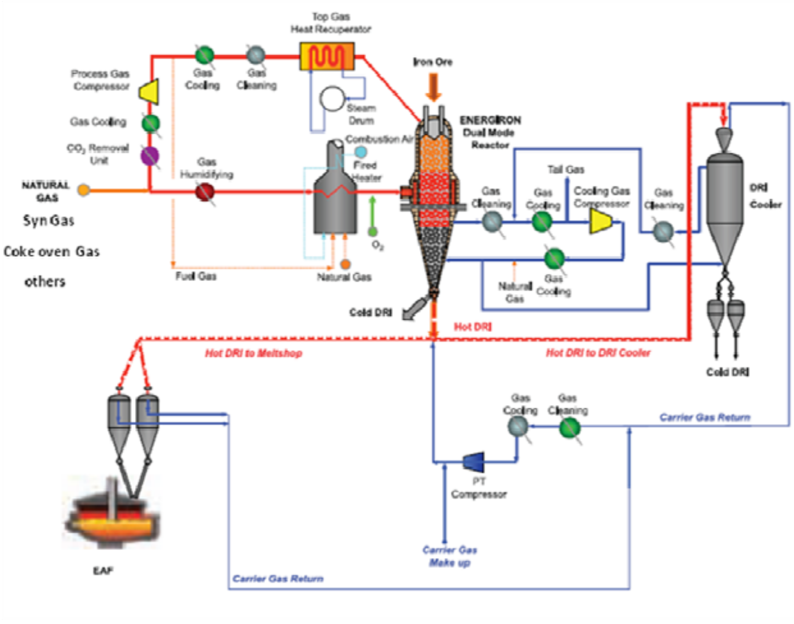

Figure 5: Energiron ZR process flow showing reformer-less production with a wide choice of energy source.

Energy efficiency of ZR process is obtained through high operating pressure (6-8 bar) and high reduction temperature (> 1050 ºC), "in-situ" reforming inside shaft furnace and lower utilization of thermal equipment of plant. Higher operating temperature and pressure result in high productivity 10 t/hr-m^2. It reduces dust loss through carry-over top gas. The result is reflected in low iron ore consumption and low operating cost. This is shown in Table 3.

Table 3: Cost comparison between ENERGIRON ZR and other processes[4]

	Cold DRI		Hot DRI	
	Other DRI-EAF	ENERGIRON-ZR	Other DRI-EAF	ENERGIRON-ZR
	2% C	3.7% C	1.5% C	3.7% C
Comparative Production Cost (Index)	106.9	103.6	103.6	100
Comparative Operating Cost (Index)	122.5	111.6	111.8	100
Note : Other DRI (with reformer)				

Since most carbon is taken up by the product high product quality with wide range of carbon (1.5-5.5%) is obtained in the product due to high degree of carburization potential of gases inside reactor (Table 4). This gives product primarily (more than 90% for 4% C) of iron carbide (Fe_3C). This significantly increases DRI stability and supply of energy for melting.

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Table 4: Comparison of product quality in DRI production[5]

			Other DRI Technology	ENERGIRON ZR	ENERGIRON ZR (Minimum emission)
Product Quality	Metallization	(%)	93	94	94
	Carbon	(%)	2.0	3.5	3.5

Under HYL ZR process scheme Ternium-Hylsa Monterrey (3M5 plant for cold DRI, operating since 2001) and Ternium-Hylsa Monterrey (4M plant for hot DRI, operating since 1998) were built. They produce high-C DRI (3.5 – 4.2%) with 94% metallization. The recent plant on this scheme is Suez Steel, Ain Soukhna, Egypt of 1.9 MT from single module.

Figure 6 shows the energy balance of the DR 4M plant at Ternium-Hylsa in Monterrey, Mexico.

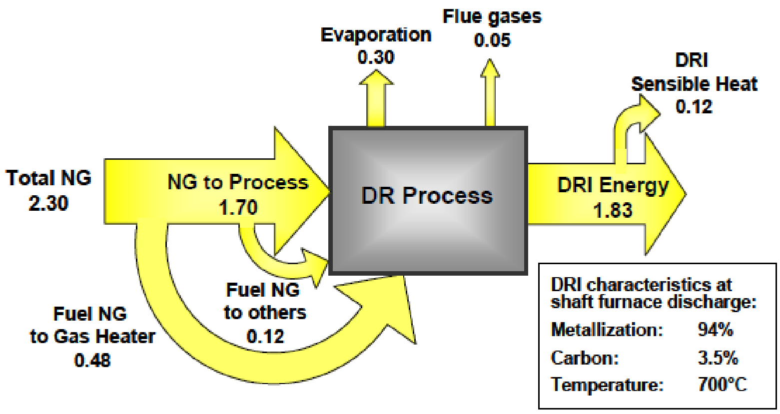

Figure 6: Energy Balance for ENERGIRON Plant at Monterrey, Mexico[4]

For production of high quality DRI of 94% metallization, 3.5% carbon at 700 ºC, the energy consumption is 2.30 Gcal/t DRI as natural gas, and 60-80 kWh/t DRI as electricity with low iron ore consumption rate of 1.35 – 1.40 t/t DRI.

Table 5 shows the benchmarking of ZR process of CO_2 emissions with that of other gas based DRI technologies in market. It shows that there is 10% and 6% less CO_2 emissions between ENERGIRON ZR and other available processes for hot and cold DRI production respectively.[5]

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Table 5: Comparison of emission intensities between ENERGIRON ZR and other processes for production of hot and cold DRI (location of power generation : 0.74 kg CO_2/kWh)

	Cold DRI		Hot DRI	
	Other DRI-EAF	ENERGIRON-ZR	Other DRI-EAF	ENERGIRON-ZR
	2% C	3.7% C	1.5% C	3.7% C
	(kg CO_2/tls)	*(kg CO_2/tls)*	*(kg CO_2/tls)*	*(kg CO_2/tls)*
DRI				
Iron ore (production)	132	129	132	129
CO_2 in flue gas + removal system	447	455	455	461
Electricity & O_2 to DR plant	90	80	98	86
Total DRI	669	664	684	676
EAF				
Power & O_2 requirements	443	415	339	305
Carbon addition	35	3	59	3
Total EAF	478	418	399	308
Note : Other DRI (with reformer)				
Total DRI + EAF route	1147	1082	1083	984

4 **ENERGIRON ZR** (Minimum Emission)

There has been a recent development of Energiron ZR process, wherein potential exists to remove 80% of total carbon input from the recycling gas (after CO_2 absorption). This is done through PSA-type physical adsorption system. This technology is called 'Energiron ZR (minimum emission)', and is patented.

In Energiron plant, emission sources are the absorber of CO_2 removal plant (selective emission) and process gas heater stack (non-selective emission). In case of external reforming, further non-selective emission comes from the reformer stack. Reduced carbon emission is achieved through a new chemical absorption system to extract the CO_2 stream from the exhaust gas out of reactor, heater, and reformer (if applicable). A new addition to this basic Energiron system is the introduction of physical adsorption system (PSA-type), with which hydrogen is recovered from the gas stream previously purified by CO_2 absorption plant. Thus heater burners (and reformer burners) can be mainly fed with H_2 and not carbonaceous fuel.[6] Incorporation of this PSA system is useful for plants that already has CO_2 absorption system and runs at high pressure (8 bar). This is to take advantage of available pressure that is required to separate hydrogen without any additional external power requirement. Only a compressor of small power is required to recycle gas from PSA back to the circuit.

Based on this scheme there has been a recent proposed project in Europe for production of 1.6 MTPA. Here, while conventional scheme (without PSA) vents out 30% non-selective carbon emission to atmosphere, ZR (minimum emission) would release about 19%.[2]

5 **CO_2 - A BYPRODUCT**

Since 1998, CO_2 gas from the CO_2 absorption system of HYL/ENERGIRON plants has been commercialized as a byproduct. Depending on iron ore composition, gas composition and absorbent used the CO_2 stream may contain trace of sulphur. [3] When amine based solution is used small sulphur in the order of ppm may exist. Hot

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carbonate based solution do not allow any contaminated CO_2. Different HYL/ENERGIRON users sequester CO_2 and sell it for different commercial use (Table 6).

Table 6: Use of CO_2 as by-product for commercialization

	Customer for CO_2	Use of CO_2 in industry
Ternium 4M, Monterrey, Mexico	Praxair	Food and Beverage
Ternium 2P, Puebla, Mexico	Infra	Beverage
PTKS, Indonesia	Janitor	Food
PSSB, Malaysia	Air Liquide/MOQ	Food
Welspun Maxsteel, India	Air Liquide	Dry ice
Emirates Steel, UAE		Oil production

6 ENERGY SAVINGS IN MELTING

Melting of high carbon (> 3.5%) DRI in EAF is an exothermic reaction generating heat. This increases thermal efficiency.

$$Fe_3C \rightarrow 3\,Fe + C + \Delta E \quad - 0.4\ \text{kWh/kg C}$$

$$2C + O_2 \rightarrow CO + \Delta E \qquad (4)$$

When hot DRI is directly discharged in EAF, significant savings is achieved in electrical power consumption due to ease of melting and reduction of power-on time. Fig. 7 shows the results of benchmarking for electrical power savings in Emirates Steel against the other DRI-EAF users.

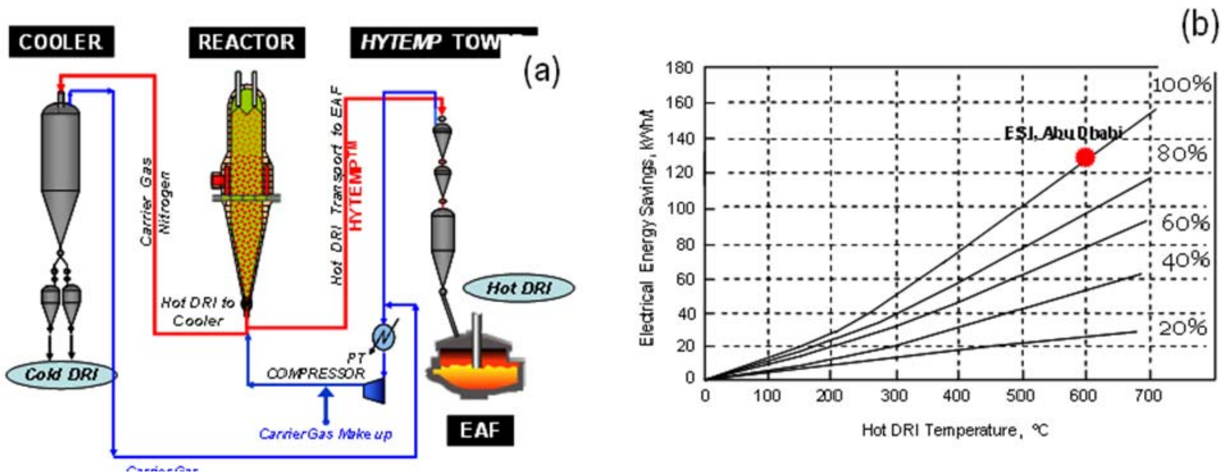

Figure 7: (a) Schematic of HYTEMP 100% Hot DRI charging, (b) Benchmarking of energy savings[9]

The figure shows the electrical power savings at different DRI temperature and % of feed, as reported in the literature for other DRI-EAF plants. [7] The solid circle shows the energy savings of 131 kWh/t of liquid steel in ESI plant for 100% DRI charging at 600 ºC.[8] This is so far the highest energy savings ever achieved.

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5 CONCLUSION

EAF steelmaking is least emission intensive, but suffers from scrap availability. Gas based DRI production is limited by availability of cheap natural gas. Energiron ZR (without external reformer) process accepts gas from many resources. Absence of external reformer saves energy and emission. Further, Energiron ZR (minimum emission) technology has potential to remove 90% CO_2 from exhaust stream as against 60% for Energiron ZR. Additionally, Energiron ZR combined with hot charging of DRI in EAF gives lowest energy consumption and CO_2 reduction.

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