SUSTAINABLE DECREASE OF CO_2 EMISSIONS IN THE STEELMAKING INDUSTRY BY MEANS OF THE ENERGIRON DIRECT REDUCTION TECHNOLOGY

Dario Pauluzzi[1], Alessandro Martinis[1]

[1]Danieli & Officine Meccaniche
Via Nazionale, 41
33042 Buttrio (UD) Italy
Tel (39) 0432.1958111
Fax (39) 0432.1958289
www.danieli.com
Email: d.pauluzzi@danieli.it; a.martinis@danieli.it

KEYWORDS

Direct Reduction, DRI, Energiron, steelmaking, EAF, CO_2 emissions, environmental sustainability, Hydrogen, electrolysis, GHG.

ABSTRACT

Compared to the traditional Blast Furnace– Basic Oxygen Furnace way of producing steel, more than 50% of CO_2 emissions can be saved if steel is produced by means of the Energiron Direct Reduction – Electric Arc Furnace way. This target is achieved partly thanks to the use of reducing sources cleaner than coal, and partly thanks to the selective capture of up to 60% of the CO_2 produced by reduction of iron ores, CO_2 that can be possibly commercialized as a valuable by-product for several different industries. The investment cost of DR-EAF minimills is lower than the BF-BOF configuration; therefore, in principle this is a sustainable solution to decrease CO_2 emissions in the steel industry. Operating costs are competitive, provided that the reducing agent is available at reasonable price: the Energiron process can use either natural gas, syngas and BF off-gas, whichever is locally available at the cheapest price. Further than this, even Hydrogen can be used as reducing gas, without any modification to the original Energiron process scheme. This allows further reductions in CO_2 emissions, as many technologies are being developed to exploit renewable energy sources for production of Hydrogen, which is generally considered to be the fundamental element for the future global energy system.

INTRODUCTION

The performance requirements for modern steelmaking facilities are ever more stringent, as customers and markets are continuously pushing for technologies which allow having high quality steel produced in an economic and sustainable way.

The Blast Furnace (BF)- Basic Oxygen Furnace (BOF), directly using iron ore as raw material for steel production, is for sure the preferred way for producing high grade steel. Nevertheless, using coal as reducing agent, the significant amount of CO_2 emitted in the atmosphere as byproduct of the reduction reactions, combined with the limited energy efficiency of this process, contributes to make this route often incompatible with restrictions imposed by environmental regulations and less competitive in comparison to alternative solutions.

On the contrary, when steel is recycled from scrap via Electric Arc Furnaces (EAF), the environmental parameters are more easily respected but, due to scrap availability and quality (market price fluctuations and several residual elements and nitrogen level), price and grade of the final steel could be not competitive: for this reason, EAF operators intensified the research for alternative iron materials as feed for EAFs. Using Direct Reduced Iron (DRI) or Hot Briquetted Iron (HBI), electric mills can produce the superior steel grades demanded by such users as automotive, special and tool steels that were originally only possible in integrated mills with BF-BOF, maintaining all their typical advantages (i.e. lower CAPEX, flexible operations and lower environmental impact).

DRI and HBI are produced in Direct Reduction Plants (DRP) and, among all the available technologies, Energiron is the one that allows higher energy efficiency levels and lower gaseous emissions, especially in terms of CO_2. The Carbon footprint of a DRP is intrinsically lower than a BF, simply because in the first case the reducing agent is typically Natural Gas (NG), whilst the primary energy source in BFs is coal. Moreover, the basic Energiron process scheme incorporates a CO_2 removal unit, that allows to selectively remove the majority of the CO_2 generated by the reduction of iron ores. Further advantages can be achieved by feeding Energiron plants with Hydrogen: this can be done with no major changes to the proven Zero-Reformer process scheme, and retrofitting of existing plants could be also possible.

So in terms of emissions, the DR-EAF route grants a 40-60% reduction in CO_2 emissions and it's no more limited to producing simply commercial steel grades.

Add to this the ability to now produce DRI in capacities exceeding 2 million tons per year, and coupling this type of plant with a modern EAF meltshop, and a new type of “integrated” mill for the near future is available: a high volume integrated DR-EAF mill, capable of competing with BF-BOF in both quality and cost, but with drastic advantages in terms of environmental sustainability.

1. ENERGIRON ZERO REFORMER PROCESS SCHEME

The ENERGIRON Zero Reformer process allows carrying out the natural gas reforming stage within the reactor without requiring an external reformer, using the DRI itself as reforming catalyst. In this way, the process efficiency is improved to unmatched levels: most of the energy supplied to the process is taken by the product, with minimum energy losses to the environment. As compared to other processes for which the overall efficiency is below 70%, for this scheme the efficiency is above 78% and natural gas consumption is kept as low as 2.35 Gcal/t. A brief summary of the process configuration is illustrated in Fig 1.

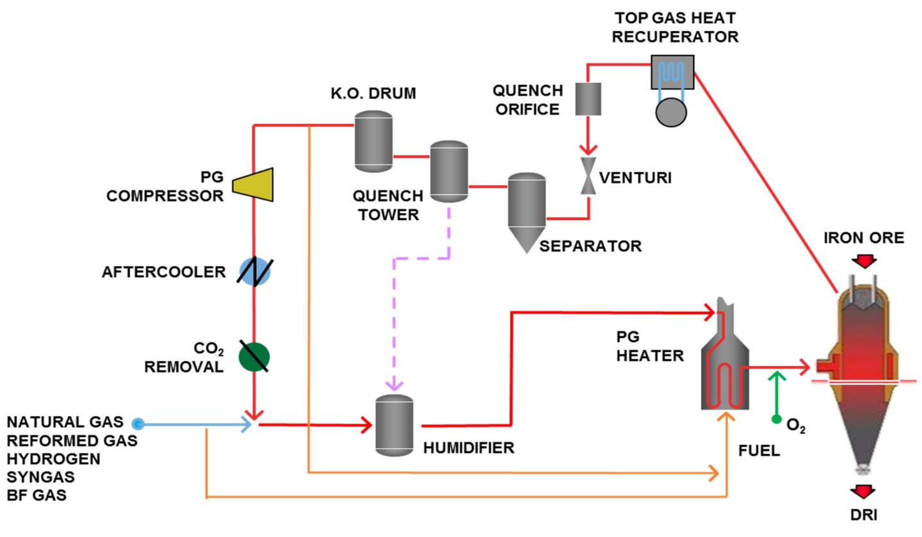


Fig 1. ENERGIRON ZR basic process scheme

After that Oxygen is removed from the iron ore by chemical reactions based on Hydrogen and Carbon Monoxide, the exhaust reducing gas (top gas) leaves the reactor at about 400-450°C and it's subsequently treated in order to be recirculated at the maximum extent possible. To allow this, first of all the gas must be cleaned from dust and oxidant elements (H_2O and CO_2) generated by the reduction reactions. Specifically, the top gas leaving the reactor passes through the top gas heat recuperator (tubes and shell heat exchanger), where its energy is recovered to produce steam, and then it's sent through the quenching/scrubbing system. In these units, water (a byproduct of the reduction reactions) is condensed and easily removed from the gas stream, that is also cleaned out of some dust carried by the gas. Subsequently, after being compressed, the scrubbed gas is treated in the CO_2 removal unit, where CO_2, the other byproduct of reduction reactions, is selectively removed.
From the environmental point of view, the selective elimination of both by-products generated by the reduction process, water and carbon dioxide, is one of the inherent and most important features of the Energiron process.
The upgraded gas is finally mixed with the reducing gas make-up before passing first through a humidifier, where water content in the gas is regulated, and later through the process gas heater for increasing its temperature up to 950°C, thus closing the reducing gas circuit. Direct internal combustion of the reducing gas by means of oxygen injection finally tunes the gas temperature to the desired value at Reactor's inlet.
The continuous gravity flow of the material through the reduction furnace is regulated by a rotary valve located at the bottom of the vessel. Specially designed flow feeders ensure the uniform flow of solids within the shaft. DRI is finally discharged, hot or cold, by automated mechanisms, consisting of pressurized bins and special valves.

2. CO_2 EMISSIONS FOR THE BF-BOF AND DRP-EAF ROUTES

A comparison between the CO_2 emissions generated by the two steelmaking routes BF-BOF and DRP-EAF is hereby presented, based on the following assumptions:

- The production capacity and the type of product of the 2 facilities is assumed to be the same. Final product is Hot Rolled Coil (HRC)
- The scenario for the BF-BOF route comprises the emissions generated by the coke oven plant, as it provides the reducing agent (coke) for the blast furnace;
- The DRP is assumed to be fed by Natural Gas;
- The emissions of CO_2 related to the electrical energy requirements of the 2 facilities are evaluated in grams of CO_2 per kWh equivalent. Usually the BF-BOF is a producer of electrical energy, therefore a CO_2 credit will be accounted equivalent to the kWh exported. On the contrary, the DRP-EAF is typically a consumer of electrical energy, therefore the correspondent CO_2 will be added to the facility's emissions.

The CO_2 generated to produce electrical energy strongly depends on the location of the steel plant. Each Nation has its own composite sourcing of natural gas, coal, hydraulic, eolic, nuclear, biomass for electrical power generation, and this mixture can strongly change from case to case. In figure 2, the equivalent CO_2 emissions for production of 1 kWh are shown (LCA method). For the purposes of this study case, it is assumed that the electrical energy is produced from the combustion of Natural Gas, therefore 500g of CO_2 are accounted for each kWh distributed on the local network. This choice has been made based on the assumption that the DRP is fed by NG, therefore it's reasonable to suppose that it's available in good quantities and at a competitive price.

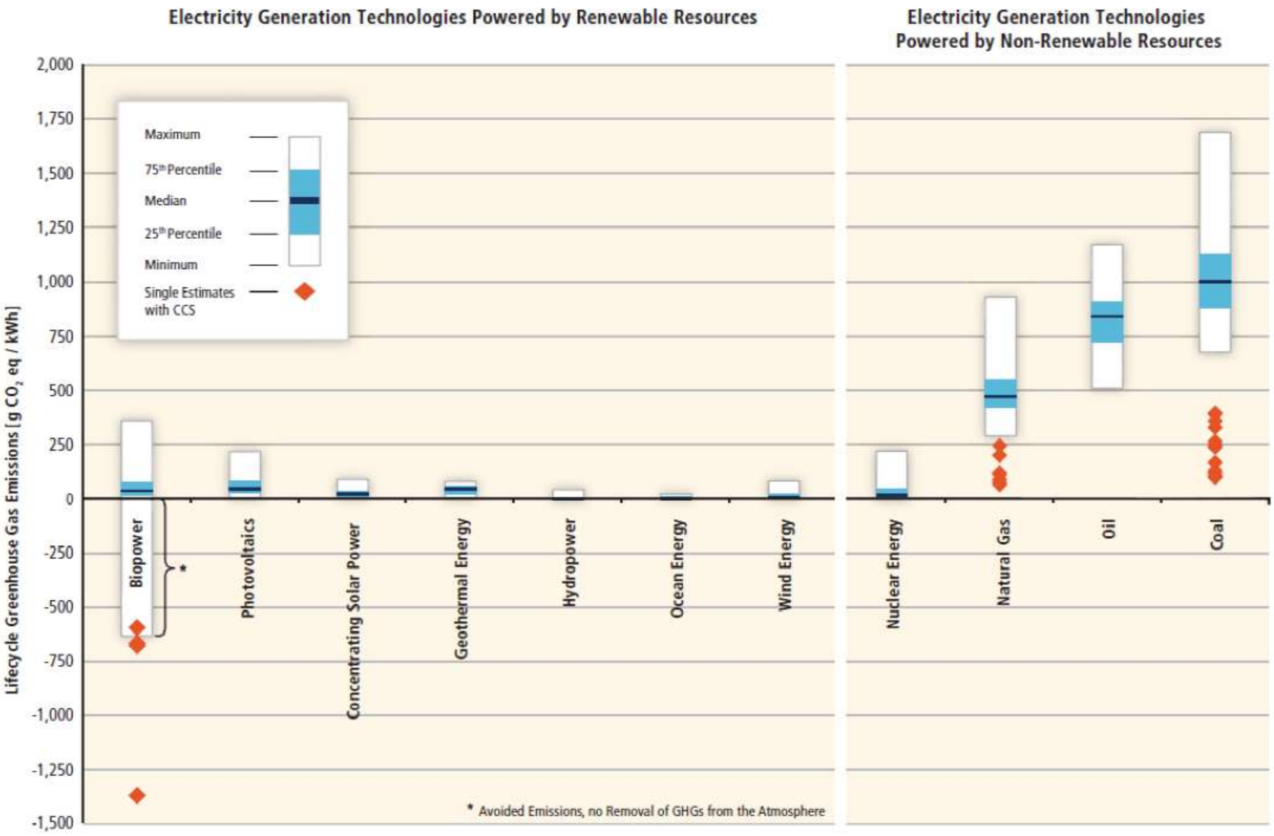
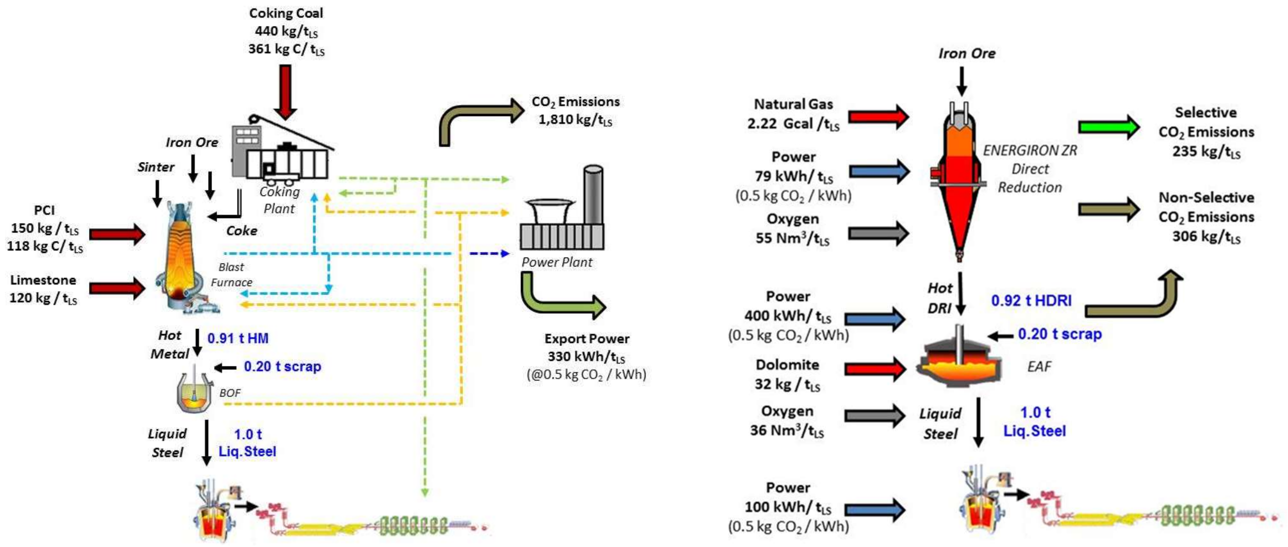


Fig 2. Equivalent CO_2 emissions per kWh produced by different energy sources [1]

The BF generates a significant amount of fuel by-products, blast furnace gases (BFG), coke oven gases (COG) and basic oxygen furnace gases (BOFG), in excess to what can be completely recirculated in the steelworks. Therefore, portion of this energy is used for power generation or, in some cases, is even wasted. Since only a minor part of the electrical power that could be generated from these gases can be used in the steelworks for its own requirements, typically most of the electrical power is exported.

For the selected integrated BF-BOF mill, the specific CO_2 emissions, inclusive of coke oven plant, sinter plant, BF and BOF, are approx. 1810 kg of CO_2/t of liquid steel (LS). The exported power of the facility is approx 330 kWh/t_{LS}, therefore the facility is credited with 165 kg CO_2/t_{LS} of equivalent emissions "saved". The CO2 emissions balance of the BF-BOF mill is shown in fig. 3, for a net CO_2 emission of 1615 kg CO_2/t_{LS}.

On the contrary, a DR/EAF mill is able to recover the majority of the spent gas' energy, but it's a net electrical energy importer: the balance is also schematically shown in Fig. 3. The DRP considered in this case is based on the ENERGIRON ZR process scheme and it's assumed to produce high-C DRI (94% Mtz and 4%C), which provides additional energy for secondary reduction of FeO, as 80% feed to the EAF.



Typical BF-BOF steelworks				Typical DR-EAF mill			
Input	Unit	Consumption (kg/tLS)	CO_2 emissions (kg CO_2/tLS)	Input	Unit	Consumption (Unit/tLS)	CO_2 emissions (kg CO_2/tLS)
Coking coal (dry)	Kg/tLS	440	1324	Natural gas	Gcal/tLS	2.22	526
PCI (dry)	Kg/tLS	150	433	Dolomite	Kg/tLS	32	15
Limestone to BF/Sinter	Kg/tLS	120	53			Total	541
		Total	1810				
Credit for Export Power				Import Power (incl. O_2)			
		330 kWh/tLS	-165			630 kWh/tLS	+315
		Total	1645			Total	856

Fig 3. Energy, mass and emissions balances for a BF-BOF and DR-EAF integrated mill [2]

The comparative analysis shows that the carbon footprint of a BF-BOF mill is approx. double than for a modern DRP-EAF mill, and further improvements in emissions and energy efficiency can be achieved when the DRP is based on the Energiron ZR process.

3. ENERGIRON ZR: MINIMUM ENERGY REQUEST, MINIMUM EMISSIONS

As a matter of fact, the ENERGIRON ZR technology further improves the overall energy efficiency of a DRP. Since the reducing gases are generated inside the reactor, most of the energy supplied to the process is taken by the product, with minimum energy losses to the environment: as compared to other processes for which the overall efficiency is below 70%, for this scheme the efficiency is above 78% [3]. This arrangement ultimately turns into very low natural gas consumption, even lower than 2.35 Gcal/t. The higher operating pressure of the Energiron plants (~8 barg vs ~atmospheric pressure of other DR technologies) allows to decrease also the power consumptions. In fact, being the recirculating gas compressor the main electrical energy consumer, the power consumption is proportional to the ratio of discharge to suction pressure: for the same Δp, the higher suction pressure results in a lower power consumption.

Moreover, Energiron includes in its basic process a CO_2 capture system, as previously discussed and shown in Fig. 1. This allows to further decrease the DRP emissions by approx. 60%, leading to a Carbon footprint of just 156 kg CO2/t_{DRI}. The selectively removed CO_2 can be used then by several other industries, for production of soft drinks, dry ice, construction conglomerates or for enhanced oil recovery (EOR).

		ENERGIRON ZR	OTHER TECHNOLOGIES
SELECTIVE CO_2 EMISSIONS Captured and sold as by-product	Kg_{CO2} / t_{DRI}	256	0
NON-SELECTIVE CO_2 EMISSIONS Released to atmosphere	Kg_{CO2} / t_{DRI}	159	~ 500

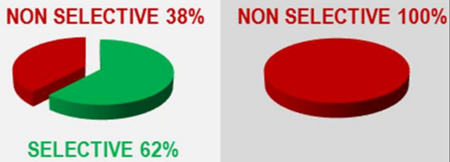
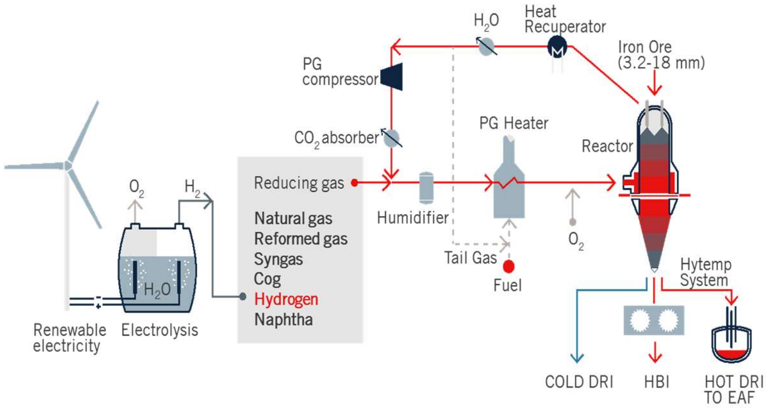


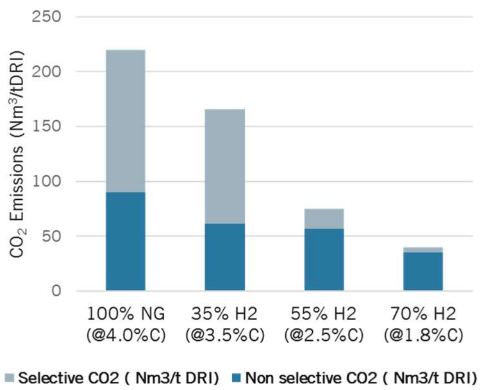
Fig 4. Reduction of CO2 emissions for the Energiron ZR DRP

4. USING HYDROGEN TO FEED ENERGIRON PLANTS

Hydrogen can be used as reducing gas, without any modification to the original Energiron process scheme. In fact, Energiron plants are typically working with a H_2/CO ratio in the range of 3÷5, therefore they are designed since the beginning to work with high H_2 content. As a matter of fact, Hydrogen has always been the main reductant agent for this technology. Historically, the available reducing sources have been gases with variable amount of Hydrogen (Reformed gas, Syngas, BOF, COG), pure hydrogen is seldom available in good quantity and at competitive price. Anyhow, nowadays new technologies (such as electrolyzes) are being developed to exploit renewable energy sources for production of Hydrogen, which is generally considered to be the fundamental element for the future global energy system. Renewable energy such as solar energy and wind energy combined with water electrolysis is a sustainable method for hydrogen production due to high purity, simple and green process. Therefore, Energiron is already fitted to use this promising energy vector, since reduction with H_2 in Energiron reactors is more efficient and faster from the kinetics point of view: about 5 times as compared to that based on CO. Further to take chance of an additional reducing agent, this solution allows also to minimize the CO_2 emissions, depending at which extent Hydrogen is used in place of CO. Using as make-up for the Energiron plant a gas mixture composed by 70% H_2 and 30% Natural Gas, CO_2 emissions from the direct reduction plant can be decreased by -80% in comparison to the same plant fed with Natural Gas only. In fact, the by-product of iron ore reduction by CO is CO_2, whilst the by-product of reduction by H_2 is water.

Finally, thanks to the Energiron technology, it's now possible to produce high grade steel in an economic and sustainable way.





(a) (b)

Fig.5 Energiron ZR using H2 as reducing agent: process scheme (5a) and CO_2 emissions (5b)

REFERENCES

[1] W. Moomaw, P. Burgherr, G. Heat, M. Lenzen, J. Nyboer e A. Verbgruggen, «Annex II: Methodology. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation,» Cambridge (UK) and New York (USA), Cambridge University Press, 2011.
[2] P. Duarte, J. Martinez, «By-Products, CO2 Emissions and Hydrogen use in an ENERGIRON DRI Plant»
[3] D. Pauluzzi, B. Franco, A. Martinis, A. Piccoli, «Analysis on Operating Results of ENERGIRON Plants and Focus on the Emirates Steel case», AISTech 2018.