Energiron direct reduction technology: ecological and economic green steel solutions

The steel industry is integral to the global circular economy and thus to the successful delivery and maintenance of a sustainable future. Steel really is a 'green' material, since it is infinitely recyclable and its byproducts and waste energy are valuable resources. Yet, steelmaking today contributes 7% of the world's carbon dioxide emissions and on average for the last decade 1.83t of CO_2 have been emitted for every ton of steel produced. A sustainable world needs steel and lots of it. Developed economies have an ongoing demand for steel and about three-quarters of the world is still developing, so demand forecasts suggests that annual steel consumption will be in the region of 2.6Bnt by 2050. Despite recycling, or reusing existing stock the environmental impact of new steel production must be addressed.

Today's technology enables steel plants to have very high energy efficiency, supporting the objective of the Paris Agreement to limit global temperature rise to less than 2°C above pre-industrial levels. To make further steps towards CO_2 emissions reduction, a drastic paradigm shift is required in primary steelmaking. The European Commission has published a roadmap that postulates a reduction in CO_2 emissions of 80-95% by 2050, as compared with 1990, for European industry. Europe already taxes CO_2 emissions at the rate of approximately 70€/t CO_2, with provision for a steady increase in the coming years. This will impact on overall operating expenditure and competitiveness of all plants.

Within this environment, Energiron stands as the reference technology for direct reduction plants and for plant owners that want to produce high steel grades without losing quality, while at the same time significantly reducing emissions. Energiron has been jointly developed by Tenova and Danieli.

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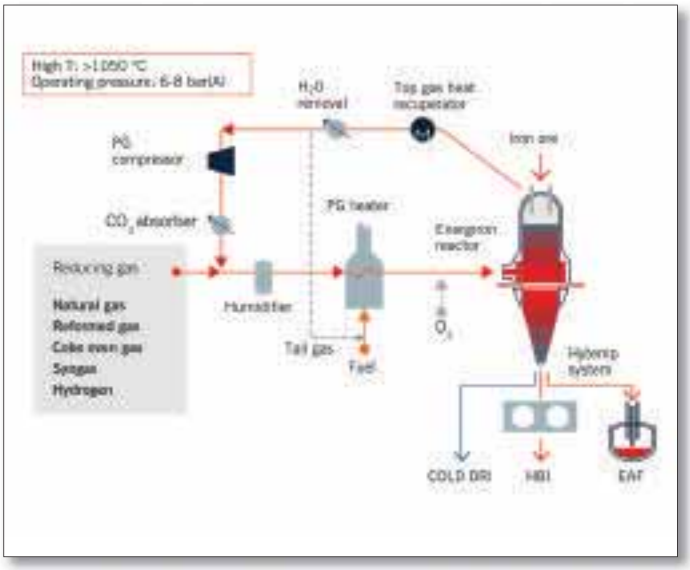

Fig 1 **Energiron ZR basic process scheme**

ENERGIRON TECHNOLOGY

The Energiron ZR process scheme (*Figure 1*) is a major step forward in reducing the size and improving the efficiency of direct reduction plants. Reducing gases are generated by in-situ reforming within the reduction reactor, feeding natural gas as make-up to the reductant circuit and injecting oxygen at the inlet of the reactor. The ZR process scheme is the only one that allows the direct use of natural gas inside the reactor, where it is converted into reformed gas simply by exploiting the catalytic power of Directly Reduced Iron (DRI). Oxygen is therefore removed from the iron ore by chemical reactions based on hydrogen (H_2) and carbon monoxide (CO) for the production of highly metallized DRI. Energiron plants can also use conventional steam methane reforming equipment as an external source of the gaseous reductant, which is a well-established process. Other reducing agents such as hydrogen, syngas from coal gasification, coke oven gas and similar fossil fuels, are potential sources of gaseous reductant, depending on the particular situation and availability. In any case, the same basic process scheme is used, regardless of the source of the reductant.

The current configuration of this technology is based on a continuous process, such that the solid material continuously flows through the shaft furnace reactor, with benefits to both product quality and process efficiency, which have been significantly optimized over the years. Energiron ZR technology is characterized by its uniquely simple process configuration and is currently the most flexible option for producing DRI. It allows for wide flexibility of different energy sources and available raw materials.

The Fe formed in the process acts itself as the necessary, renewable and continuous catalyst for the reduction process. During start-up, the process gas is first heated by the process gas heater, H_2 and CO are generated by partial combustion with oxygen injection and thus the reduction of the iron ore starts. Operating conditions of the ZR process are characterized by a high temperature in the range of 1,080°C. Pressure is also high at between 6barg and 8barg at the top gas. The elevated pressure allows high productivity, of about 10t/h/m and reducing gas velocities are low at about 2m/s, as compared with processes using a lower operating pressure, for which the gas velocities are >5m/s. This minimizes dust losses through top gas carry-over, lowering overall iron ore consumption and in turn lowering operating costs.

A distinct advantage of this process scheme, without an integrated reformer, is the wide flexibility for DRI carburization. DRI carbon levels of up to 5% can be obtained, due to the prevailing conditions of high methane concentration in the process gas and the high bed temperature, in excess of 860°C, which favours the diffusion of carbon into the iron matrix and the precipitation of iron carbide, Fe_3C. A unique characteristic of this process is the selective removal of H_2O and CO_2, both by-products of the reduction process, thus significantly increasing process control and efficiency.

Hytemp® is a patented pneumatic transport system that has been used for more than 20 years to connect a HYL/Energiron direct reduction plant and steelmaking plants up to 500m distance, with 99% availability and minimum maintenance requirements (*Figure 2*). The Hytemp® system is capable of delivering hot DRI at temperatures above 600°C, resulting in remarkable savings in EAF operational expenditure. When a DRI plant is located inside an integrated steel plant, the ideal condition is to not cool the DRI, but to feed it hot to the EAF. The sensible heat of DRI at 600°C (with respect to 25°C) is 362.625MJ/t. Depending on the characteristics of the EAF, operational practices and DRI composition, this represents a saving of 20 to 25kWh/tls, per 100°C of DRI temperature.

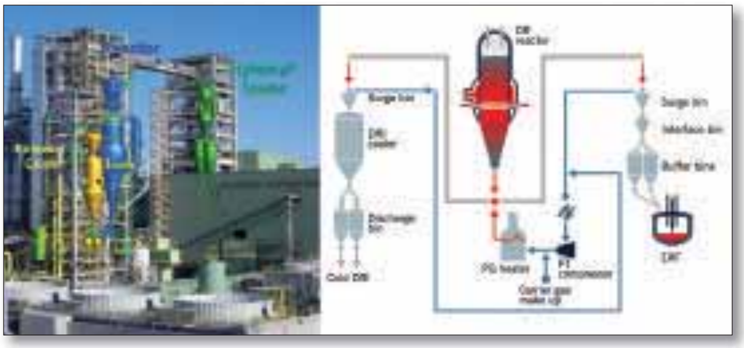

Fig 2 **The Hytemp system arrangement (R) and installation (L)**

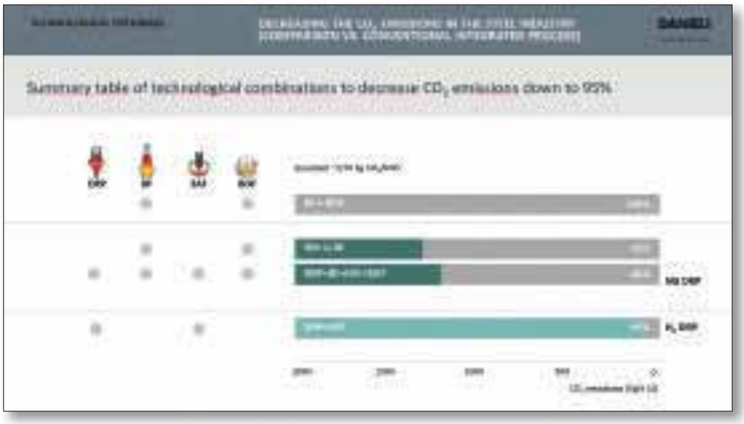

Fig 3 **CO_2 emissions reduction for alternative ironmaking routes**

ENVIRONMENTAL COMPLIANCE

CO_2 emissions in BF-BOF vs DR-EAF

The pressure to reduce environmental impact has pushed most owners of integrated steelworks to consider the DRI-EAF route, as a replacement for the traditional BF-BOF. The overall impact of the steel industry on global CO_2 emissions is estimated to be in the order of 7%. If only the industrial sector is considered, the steel industry is responsible for 25% of emissions.

A comparison of CO_2 emissions from an integrated plant comprising BF and BOF, with CO_2 emissions from a mini-mill comprising the Energiron DR plant and EAF is shown in *Figure 3*. The calculation was made for a location where CO_2 emissions from electricity generation are 0.5kg/kWh. The transition to coal free technology reduces CO_2 emissions by approximately 50%. If it is possible to dispose of, or utilise the captured carbon dioxide, as is done by many of Energiron customers, a significant reduction in emissions can be achieved of up to 67% of the original configuration.

By increasing the hydrogen rate to 70% in the reductant gas stream, the Energiron plant can achieve a more than ▷

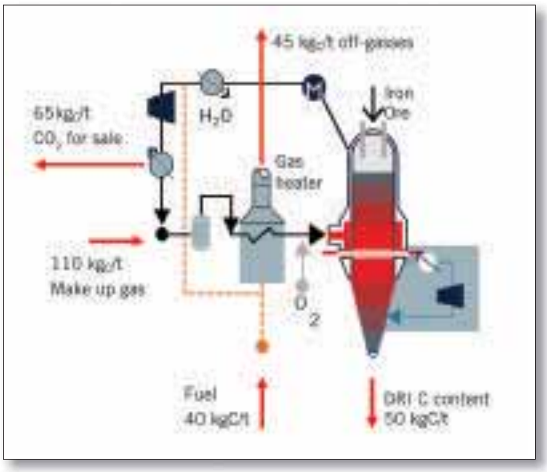

Fig 4 **Carbon mass balance for Energiron technology**

	Energiron kgC/t	Competitor kgC/t
Input	150	150
Outputs:		
Capture	65	0
DRI	40	25
Fuel gas	45	125
Total emitted	45	125

Table 1 **Carbon mass balance comparing Energiron with competing technologies**

80% reduction in CO_2 emissions. The average emissions of CO_2 generated by BF-BOF installations range from 1,800 to 2,100kg CO_2 per ton of steel. A natural gas based Energiron Direct Reduction plant, equipped with CO_2 capture and coupled with a Danieli Digital Melter, a well-referenced and standard plant combination, emits only around 800kg CO_2 per ton of steel. This satisfies the required targets of the European Commission for 2030.

CO_2 emissions and application in an Energiron plant

Greenhouse gas emissions may be found to be significantly different comparing the two leading technologies for production of DRI. The use of natural gas, syngas from coal gasifiers, or coke oven gas, in the reductant gases of a direct reduction plant, means that carbon is present in the form of hydrocarbons, or carbonaceous compounds, such as CO and CO_2. Regardless of the configuration of the direct reduction process, only 1.5-5% of the total input carbon ends up in the direct reduced iron product. The precise amount being dependent on the carbon content in the DRI. By the principle of conservation of mass, as shown in *Figure 4*, the balance of the carbon must exit the process as CO_2.

The Energiron ZR process takes advantage of the catalytic effect of metallic Fe in the DRI, combining carbon in the form of Fe_3C and so higher levels of carbon are included in the product and thus less carbon is released in the form of CO_2. This higher carbon level in the DRI, as has been well been proven in practice and documented in various papers, is beneficial to the steelmaking process by providing chemical energy to the furnace, and for making the steelmaking process more efficient. Additionally, a distinctive feature of this technology is the selective removal of CO_2. In the other DR technology, with an integrated reformer, all carbon entering the process, except for that leaving the system as part of the DRI, is purged through the flue gases of the reformer, to preserve the overall carbon balance. Hence, for the principle of the mass conservation, the total carbon used in the Energiron process ends up as captured CO_2 emissions, carbon in the DRI/HBI product, with Energiron capable of producing up to 5%, high carbon DRI and CO_2 emission to the atmosphere. This is shown in *Table 1*.

Captured CO_2 is a valuable product for plant owners, creating value out of waste from the sale of CO_2 for different applications, as shown in *Figure 5*.

HYDROGEN READY ENERGIRON TECHNOLOGY

Experience in hydrogen utilization

Hydrogen is not a new aspect for Energiron and the technology is ready and available to use 100% hydrogen. High concentrations of hydrogen from the reforming of natural gas have already been widely used (*Figure 6*).

In the early 1990s a pilot plant operated with more than 90% hydrogen (*Figure 7*). The plant had a production rate of 36t of DRI per day. It provides a reference for the process and design parameters that relate DRI quality, in terms of metallization and carbon content, to gas flow and temperature. The tests were aimed at determining if the process and equipment were suitable for production of both cold and hot DRI using hydrogen and the results were very satisfactory.

The use of hydrogen in Energiron plants is a well understood practice and does not present any technological risk or require a demonstration period. All Energiron reference plants are already operating with high percentages of hydrogen. That is why CO_2 emissions can be reduced so drastically, positioning Energiron technology to be the best choice for those clients willing to abate emissions and produce green steel.

Hydrogen as the most efficient energy vector for reduction

Whatever direct reduction technology is used, hydrogen has some evident advantages as compared with CO. H_2 reduction is endothermic, while CO reduction is exothermic. Thus, H_2 reduction cools the bed, reducing the risk of sticking and issues with the flow of solids. H_2 reduction does not cause pellet swelling, which is peculiar to CO reduction. It is also to be expected that fewer fines will be generated in the reactor.

Irrespective of energy requirements, both reduction routes demand high working temperatures in excess of 900°C, to achieve reasonably fast kinetics. By looking at the thermodynamics, it is evident that at high temperatures, iron production demands less H_2 than CO. For instance, at 1,000°C in a reducing gas mixture of H_2 and H_2O, the minimum H_2 requirement is 58%, while in the same H_2 and H_2O mixture the minimum CO requirement is 72%. At higher working temperatures the H_2 requirement reduces, but the CO requirement increases. Consequently, exploiting very fast kinetics at high working temperatures increases the risk associated with CO, as the exothermic nature of the reaction further increases the temperature. For H_2 however, safety is increased, due to the cooling nature of the endothermic reaction. It can be seen from *Figure 8* that reduction kinetics are faster with hydrogen, making it possible to achieve very high metallization levels.

Hydrogen demonstration projects

For many years, Energiron has demonstrated its unique capabilities and strengths using H_2 and for these reasons it has been selected by major steelmakers to be part of their vision for decarbonizing the steel industry. In 2016, HYBRIT was established as joint venture between SSAB, LKAB and Vattenfalls, with the aim of replacing coking coal, traditionally needed for ore based steelmaking, with hydrogen. HYBRIT set specific targets for the construction and operation of a pilot plant with the aim of testing hydrogen as a reductant in the production of DRI and Energiron was selected as the best available technology on which to base the decarbonization of its steel production. SSAB is now considering the installation of an EAF based steel production facility that would also utilize H_2 based DRI, based on the HYBRIT scheme with Energiron technology.

More projects have been launched, such as H_2-GreenSteel, that are also focused on achieving CO_2 free steelmaking. In Germany, Salzgitter Flachstahl GmbH, the largest steel subsidiary in the Salzgitter Group, selected Energiron for the construction of 'µdral', a demonstration plant for the production of DRI using up to 100% hydrogen as reductant. Salzgitter have launched the SALCOS program, aiming to decarbonize their integrated steel mill by a gradual transition to cleaner DRI technology. For this transition Energiron has already been selected as the best available technology for the direct reduction installations. Other projects are on their way and important companies such as Thyssenkrupp, ArcelorMittal and Liberty Steel are actively investigating the most feasible way to convert their production sites.

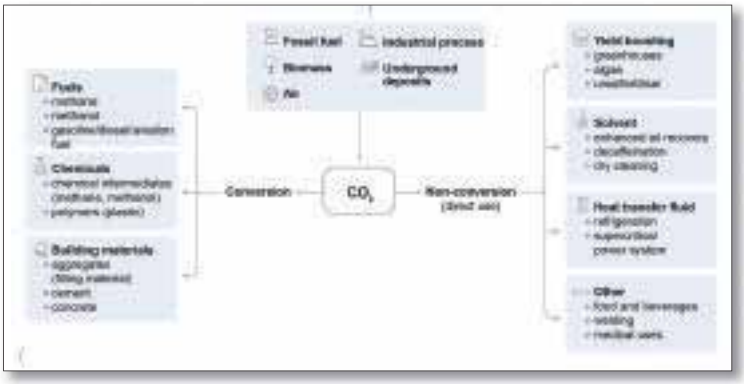

Fig 5 **Simple classification of pathways for CO_2 use (*Source: IEA 2019*)**

Description	Reformed Gas	
Results	Total	100
	LHV	2632,925
	MW	9,900
	GY	0.3441
Component	C	0.1
H2	73.19	
CO	14.67	
CO2	8.66	
CH4	3.44	
N2	0	
C2H6	0	
C3H8	0.04	
H:M	13:36	

Fig 6 **Mass spectrometer reading in the reformer of an Energiron III plant**

NEW ENERGIRON STEEL PROJECTS

First gas based direct reduction plant in China

HBIS, one of the world's largest steelmakers, recently announced the first gas based direct reduction plant in China, to be installed at its facilities in the Hebei province. For this breakthrough project, HBIS selected Energiron direct reduction technology. This will be the world's first DRI production plant powered by hydrogen enriched gas, which will make use of the most advanced, competitive, ▷

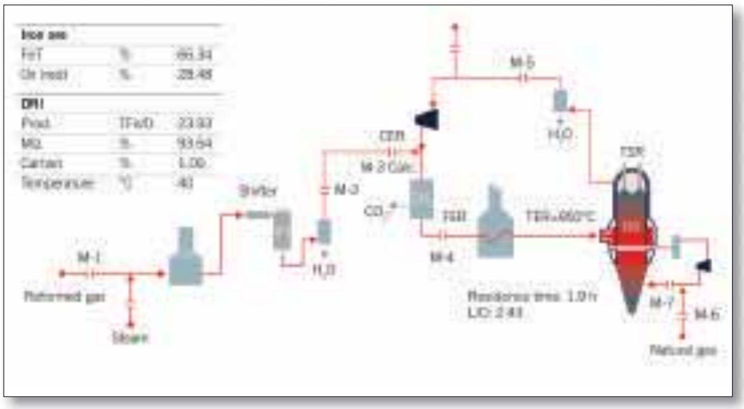

Fig 7 **Process flow diagram of 90% H_2 reduction pilot plant**

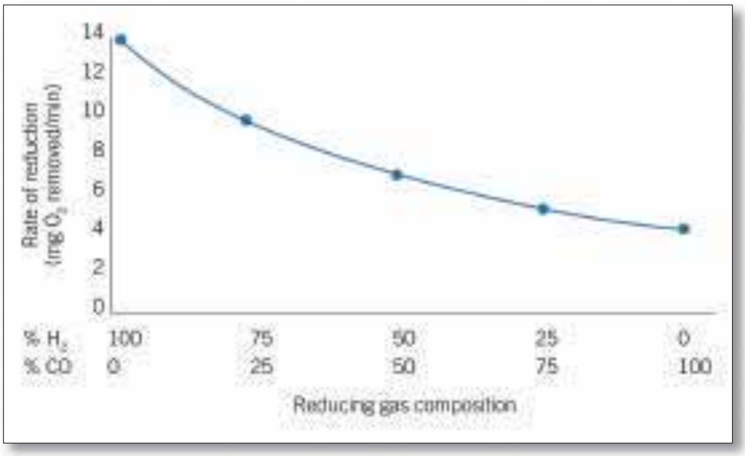

Fig 8 **Rate of reduction with different percentages of H_2**

eco-friendly and reliable technology of the Tenova and Danieli process, which including advanced digital models for equipment and metallurgical behavior prediction. This is also an important breakthrough for the Chinese steel industry, as it will be the first gas based DRI plant in China.

The HBIS DRI plant will use make-up gas with approximately 70% hydrogen concentration. Due to the high amount of H_2, the HBIS plant will be the greenest DRI plant in the world, producing only 250kg of CO_2 per ton of DRI. The carbon dioxide will be selectively recovered and part of it will be reutilized in downstream processes, with a final net emission of just 125kg of CO_2 per ton. The plant is currently under construction.

The greenest direct reduction plant in Russia

At the end of September 2020, Danieli was awarded an important contract for a new steelmaking complex to produce slabs, seamless pipe, and rail wheels by the Russian steelmaker OMK, through its affiliate company Ecolant. The new facility will be installed at Vyksa Steel Works in Vyksa city and will feature an Energiron direct reduction plant and a Danieli electric arc furnace. The Energiron unit will have an installed capacity 2.5mtpa and as such will be largest single-module direct reduction plant in Russia.

The OMK DRI plant is carbon capture ready and compared with a traditional mill, the carbon dioxide emissions will be reduced by 64%, while other pollutants such as dioxin, PAH, are almost negligible. As with all Energiron DRI plants, this one allows for the total, or partial of hydrogen instead of natural gas. The installation will also include HYTEMP®, feeding the EAF continuously with hot DRI at 600°C.

These projects are examples of the best available green technology, which will further develop the steel industry and improve environmental quality in industrial regions. MS

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