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# TENOVA IBLUE® INTEGRATION OF OPEN SLAG BATH FURNACE WITH GAS BASED DIRECT REDUCTION FOR NEW-GENERATION STEELMAKING – TENOVA IBLUE®

**ENERGIRON, the technology of choice for Hydrogen-based steelmaking projects**



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## ABSTRACT

*The present paper illustrates an innovative steel processing route developed by employing hydrogen direct reduced pellets and an open slag bath furnace. The paper illustrates the direct reduction reactor employing hydrogen as reductant on an industrial scale. The solution allows for the production of steel from blast furnace grade pellets transformed in the direct reduction reactor. The reduced pellets are then melted in open slag bath furnaces, allowing carburization for further refining. The proposed solution is clean for the decarbonization of the steel industry. The kinetic, chemical and thermodynamic issues are detailed with particular attention paid to the slag conditions. The proposed solution is also supported by the economic evaluation compared to traditional routes.*

*There are various technological trends to decrease the carbon footprint in the steelmaking industry. Some pathways are related to CCU (Carbon Capture and Use) /CCS (Carbon Capture and Storage), circular economy, and others to CDA (Carbon Direct Avoidance).*

*For CDA approach, the basic configuration starts with the NG-based DRI ironmaking scheme in combination with EAF or OSBF, with the progressive use of Green-H2 as replacement of or integration in existing BF-BOF installations.*

### *DRP-OSBF (iBLUE®)-BOF*

*The scheme consisting of ENERGIRON plant for DRI feeding the OSBF (Tenova iBLUE® scheme), combines production of DRI using NG and H2, and low- grade iron ore pellets with electric arc melter (OSBF) to produce HM and granulated slag, as a proven technology to substitute the BF, while significantly reducing CO2 emissions and keeping existing BOF's in operation. While the EAF operates under oxidising condition, in the OSBF the DRI is melted in a reducing environment, which allows to modify the slag chemistry, to be suitable for granulation for being used as a by-product in the cement industry.*

## INTRODUCTION

Among the various technological trends to decrease the carbon footprint in the steelmaking industry, there are two mainpathways; one related to CCU (Carbon Capture and Use) /CCS (Carbon Capture and Storage), circular economy, and the other to CDA (Carbon Direct Avoidance). There are otheremerging technologies like plasma direct steel production and electrolytic processes (molten iron electrolysis and electrowinning), which are still under development,with small size pilot plant and laboratory scale testing, and which will take decades for industrial implementation, in any.

For CDA approach, the basic configuration starts with the NG-based DRI ironmaking scheme in combination with EAF or melter (OSBF), with the progressive use of Green-$H_2$ as replacement of or integration in existing BF-BOF installations. Challenges of these schemes are mainly related to availability of high-grade ores for EAF and Green-$H_2$supply at required amounts and cost, depending on the electricity levelized price.

## ENERGIRON® DR PROCESS

ENERGIRON (the DRI technology jointly developed by Tenova and Danieli) DR process is the most flexible scheme in terms of using different reducing gases with the same configuration, process efficiency and CCU system as part of the scheme and simplicity (Fig.1). It is the most adequate scheme for the sustainable production of suitable DRI quality for steel production via EAF or Hot Metal (HM) via melter (OSBF),using NG and/or $H_2$ as energy replacement of coal. Among technological features fitted for these purposes:

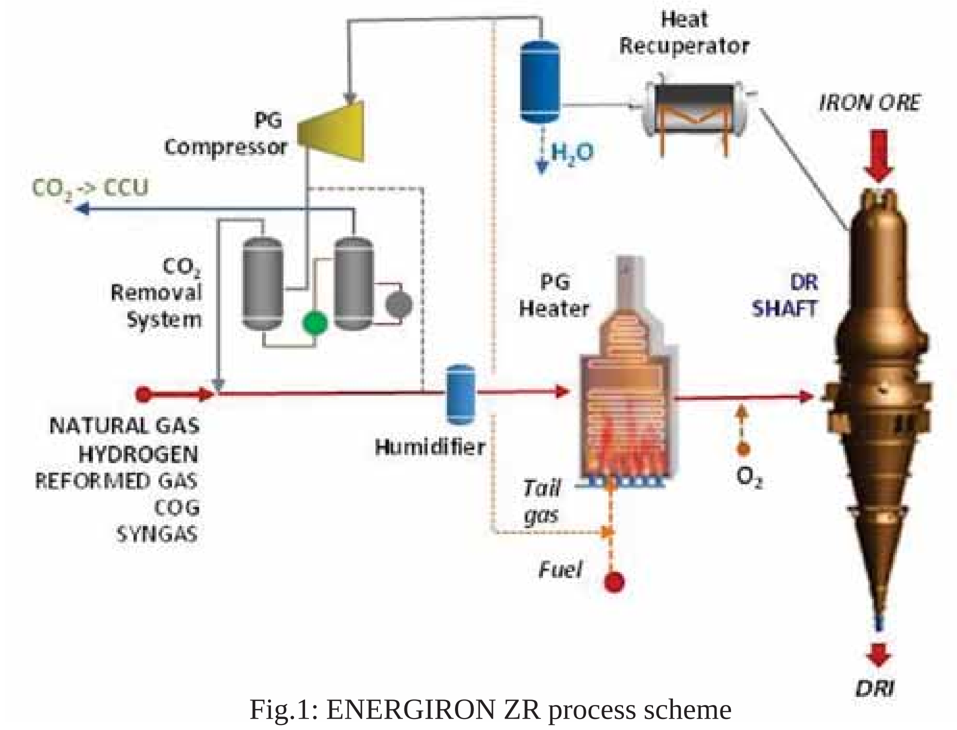


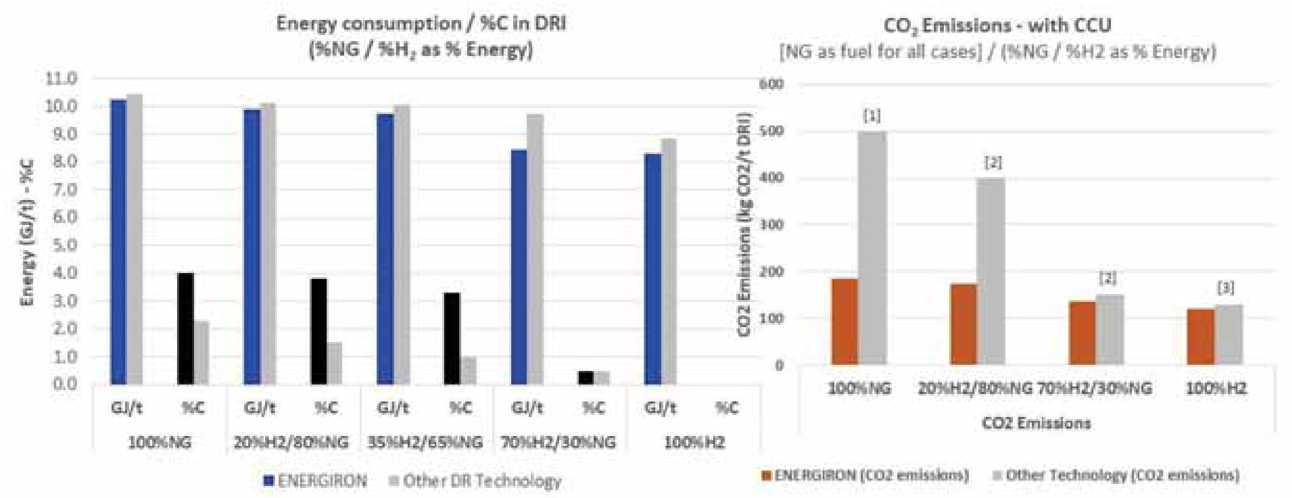

Fig.1: ENERGIRON ZR process scheme

- Unlike other DR technologies for which there are different schemes depending on the reducing gases source, the ENERGIRON® process scheme has the flexibility of direct replacement of NG with $H_2$ in any proportion and in reversible operating mode, with the same configuration and plant equipment, with just minor provisions in some equipment specifications. Comparatively, as shown in Fig.2, it has the lowest $CO_2$ emissionsnot only due to higher efficiency but also due to inherent CCU possibility.
- ENERGIRON has a long-lasting experience for using $H_2$ in ~70% vol. in industrial operating plants, enhanced by demonstration plant campaigns since the 1990´s while processing e”90% vol. of $H_2$.
- The high pressure (6-8 barA), high temperature (950°-1050°C) and mechanical sealing of the reactor charge/discharge systems, provide unique conditions for intensive use of $H_2$ in terms of optimised equipment design, process efficiency ( ˜Process: ~ 93%; ˜Overall: e” 80%;) and safety.
- The energy consumption of the ENERGIRON process with 100% $H_2$ is as low as 6,6 GJ/$t_{DRI}$ as $H_2$ for process plus 1,6 GJ/$t_{DRI}$ of fuel and about 25 kWh/$t_{DRI}$ for the core plant. This exceptionally low electricity consumption is not only because of the $H_2$ use but also due to the high operation pressure of the system (e”6 barA @ top gas).
- ENERGIRON is the only available DR technology capable of producing hot/cold DRI (HDRI/CDRI) with >4%C when using 100% NG. This unique high-C DRI has advantages in terms of reduced power consumption in the EAF and as tailor made material for production of HM in the OSBF.

## $H_2$-BASED IRONMAKING/STEELMAKING SCHEMES FOR REDUCING CARBON FOOTPRINT

### DRP-EAF

EAF's operations to melt DRI are based on %Mtz, %C and gangue for reducing remaining FeO and promoting foaming slag. The optimum %C in DRI (*DRI Value*) dependson the amount of DRI in the mix feedstock for certain steel quality and specific cost scenario, among others.In this regard, the use of High-C DRI lowers electricity consumption and reduces the tap-to-tap time due to the additional chemical energy input to the furnace. Due to the use of DRI as metallic charge in the EAF, high-grade iron ores are processed to optimise the operating cost




For Other DR technology: calculations for different schemes based on published information (*MIDREX $H_2$™ and the transition to the hydrogen economy);* Scheme [1] MIDREXNG; Scheme [2] MIDREXNG w/$H_2$ (Note: energy export@≥26%$H_2$); Scheme [3] MIDREX$H_2$

For ENERGIRON: SAME scheme for all applications, including inherent CCU for selective $CO_2$ removal

Fig. 2: DR Processes: Energy consumption/%C in DRI/$CO_2$ emissions

and/or steel quality production. Some scrap can be used depending on the steel product.

The use of 100% $H_2$ for DRI production will imply to feed 0%C DRI, which will require specific EAF melting practices. In fact, a minimum carbon content in DRI and/or carbon injected separately is required for EAF operations. On the other hand, this scheme requires the use of high-grade iron ore to be economically processed in the EAF. This scheme provides the flexibility for up to 100% $H_2$ as primary energy source and circular economy in terms of scrap recycling in a proportion depending on the steel product quality and *DRI Value*. Overall $CO_2$ emissions, other than direct emissions, will depend basically on iron ore, electricity, etc., as per Scope 2 and Scope 3 inputs.

## DRP-OSBF (iBLUE®)-BOF

The scheme consisting of ENERGIRON®plant for DRI feeding the OSBF(Tenova *i*BLUE® scheme),combines production of DRI using NG and $H_2$, and low- grade iron ore pellets with electric arc melter to produce HMand granulated slag, as a proven technology to substitute theBF, while significantly reducing $CO_2$emissions and keeping existing BOF's in operation. While the EAF operates under oxidising condition, in the OSBF the DRI is melted in a reducing environment, which allows to modify the slag chemistry, to be suitable for granulation for being used as a by-product in the cement industry.

In this scheme, hot DRI is charged from the DR reactor by gravity feed to the OSBF. The Tenova *i*BLUE® scheme allows:

- securing the continuous production of HM by matching the continuous operation of the DRP with the operation of the OSBF,
- achieving stableHM quality requirements by controlling of %Mtz and %C of the HDRI and the fine tuning during the heats.

This scheme is $H_2$-ready for the gradual switch from NG towards further reduced carbon footprint from HM to steel, using $H_2$ in the DRP. Due to the unique process conditions of the ENERGIRON® technology, even with 35% $H_2$as process energy (or ~65% vol.),it is possible to produce DRI with ~3,3%C and thus~4% in HM with carburisation balance in the OSBF.

There are various applications for the hot metal produced from the OSBF. In case of producing high-C hot metal through high-C DRI and/or carbon injection, the hot metal can be fed to existing BOF's

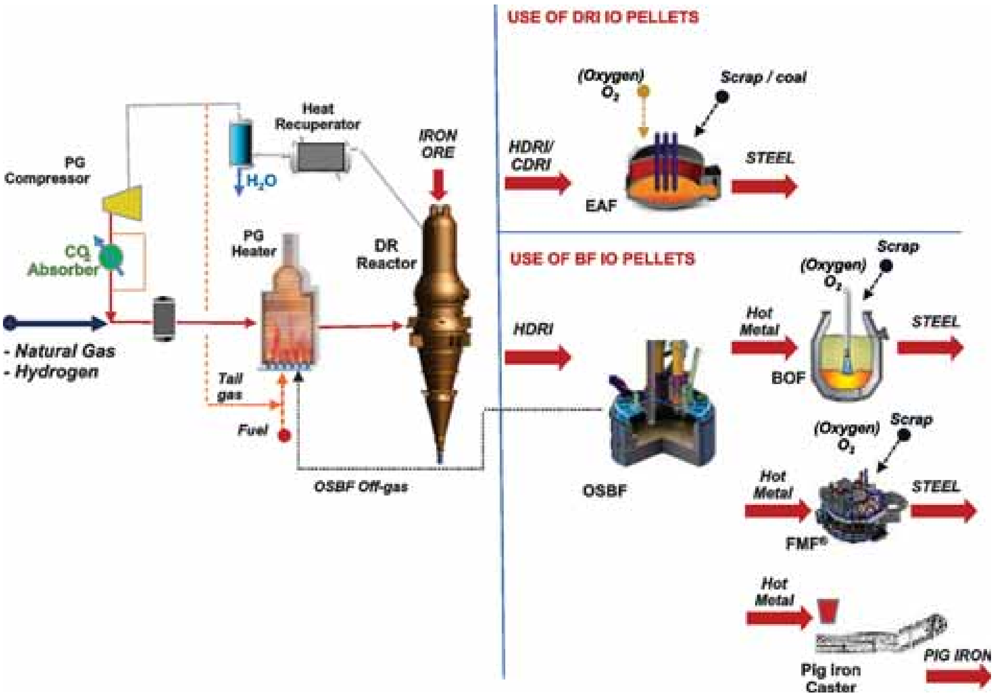



Fig.3: Routes for decarbonising steelmaking industry, based on ENERGIRON DR technology

for steel production. There is also the possibility to feeding the hot metal to casting for pig iron production. In case of hot metal with lower %C than the required for BOF or pig iron applications, the material can be fed to a FMF® from Tenova for refining and steel production.

## TRACKING PROJECTS TOWARDS GREEN-STEEL PRODUCTION

### HYBRIT FOSSIL FREE STEELMAKING PROJECT

HYBRIT, a joint venture between SSAB, LKAB and Vattenfall, was established with the aim to replace coking coalwith $H_2$with virtually no carbon footprint. HYBRIT set specific target toward the construction and operation of a pilot plant with the aim to test $H_2$


as reducing agent in the production of DRI. With this goal HYBRIT selected Tenova HYL for the main equipment of its pilot plant in Luleå, Sweden in 2018. Thanks to the unique characteristics of its process and its specific expertise in DR with high content of $H_2$, Tenova HYL perfectly fitted with HYBRIT project.

Since 2021 the facility has been operating with up to 100%$H_2$.

### HBIS DRI PROJECT

In November 2020, Tenova signed a contract with theHBIS Group for the implementation of the Paradigm Project, a High-Tech Hydrogen Energy Development and Utilization Plant. The project includes a 600.000 t/a ENERGIRON® DRI plant.

This is the first DRI production plant in China powered by $H_2$-enriched gas, which uses of the most advanced, competitive, eco-friendly and reliable technology of the Tenova process portfolio, which includes advanced digital models for equipment and metallurgical behaviour prediction. The HBIS DRI plant is fed with make-up gas with approximately a 70% $H_2$ concentration.

Due to the high amount of $H_2$, the HBIS plant is the greenest DRI plant in the world by producing only 250kg of $CO_2$/t DRI. The $CO_2$is selectively recovered and part of it will be reutilized in downstream processes, with a final net emission of just about 125kg of $CO_2$/t DRI. The plant is successfully operating since beginning of 2023 after a record time of start-up.

### BAOSTEEL ZHANJIANG IRON & STEEL CO., LTD. DRI PROJECT

In March 2022, Sinosteel Engineering & Technology Co. Ltd. contracted Tenova for the design and supply of a $H_2$-based 1,0 Mtpy CDRI ENERGIRON DR plant with preparation for HDRI production.


The plant, at Baosteel Zhanjiang Iron & Steel Co. Ltd. facilities,. is the largest $H_2$-based DRI facility in China. The new ENERGIRON plant is based mainly on the use of $H_2$, NG and Coke Oven Gas (COG) in different proportions. The plant will also be designed to have the capability to capture and sell $CO_2$ on the commercial market. It started successful operations by 2023.

## SALCOS® PROJECT

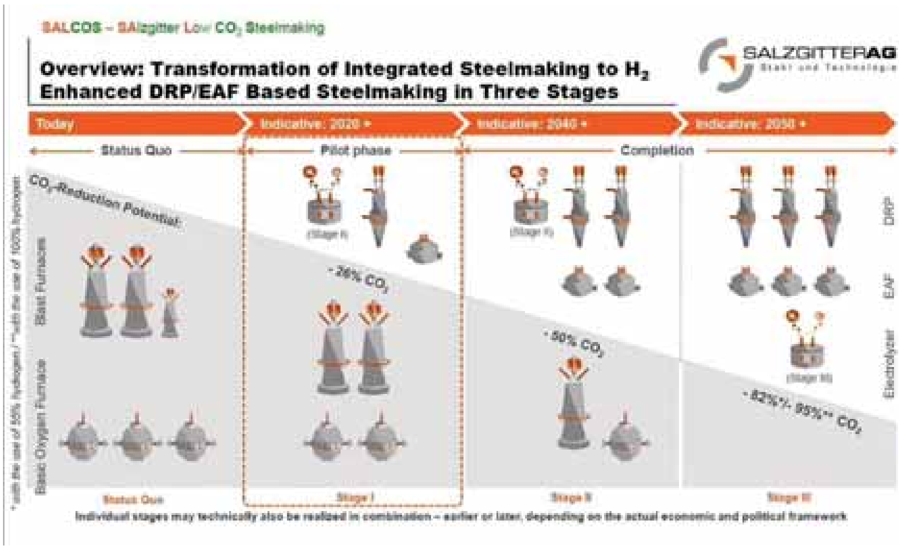
In December 2020, Salzgitter AG and Tenova signed a contract for the implementation of the demonstration ìDRAL plant, being the world's first DRI plant flexibly operated with $H_2$ and NG in an integrated steel mill, which has already started operations producing 100% $H_2$-based DRI.

Green-$H_2$ production is based on 2 projects: *WindH₂*-Wind Hydrogen Salzgitter and the *GrInHy2.0* project. This high temperature electrolyser is the largest of its kind and operates highly efficiently.

As a further step for close technical cooperation, in March 2022, the two partners signed a MoUfor the realization of SALCOS® - Salzgitter Low $CO_2$-Steelmaking for the implementation of a plant of 2,1 Mtpy HDRI/CDRI plant using NG and $H_2$ as reducing gases, currently in construction stage. SALCOS® is a ground-breaking program designed to significantly reduce $CO_2$ emissions in steel production. The program is aimed at achieving a gradual transformation process away from carbon-intensive conventional steel production and toward DR with the flexible and increasing deployment of $H_2$.

## TATA STEEL IJMUIDEN PROJECT

In August 2022, Tata Steel Netherlands awarded ENERGIRON for the Heracless (Hydrogen-Era-





Carbon-Less) project, for the DR plant of 2,5 Mtpy capacity, aiming to transition the integrated steel mill in IJmuiden from the current BF-technology to a Green $H_2$-based steel production. Selection has been based due to the fact that all ENERGIRON DRI plants are $H_2$-ready by design and can start using $H_2$ as reduction gas without equipment modifications.

DRI pellets processed by ENERGIRON® plants allow up to 96% metallization and variable carbon-content ranging from 0.5% with extensive use of hydrogen, and up 4.5% using 100% NG. “We recently made agreements about our future with two ministries and the province of North Holland. In doing so, we have indicated we want to be $CO_2$ neutral before 2045 and to emit between 35 and 40% less $CO_2$ before 2030. This will largely be achieved via the $H_2$ route. We are replacing the BF with modern technology that uses $H_2$ or gas instead of coal” [Hans van den Berg, CEO Tata Steel Nederland]. The project is under Engineering phase.

## ARCELORMITTAL DECARBONISATION PROJECT

In October 2022, ArcelorMittal contracted Tenova for the design and supply of a $H_2$-ready 2,5 Mtpy ENERGIRON DR plant, for its Dofasco plantin Canada, in the frame of its decarbonization plan through an innovative DRI program.

The plant will transition away from the BF-BOF steelmaking production route to the DRI-EAF production route, which carries a significantly lower carbon footprint. The investment will reduce annual $CO_2$/ emissions at Hamilton operations by approximately 3 million tonnes, which represents approximately 60% of emissions.The new ENERGIRON® plant will be able to use NG with the possibility to mix it with $H_2$ up to 100%. The plant will have the flexibility to use different reducing gases in any combination or proportion, using the same ENERGIRON® scheme.

## TERNIUM PROJECT, MEXICO

In October 2023,Tenova signed the contract with leading Latin American steel manufacturer Ternium for its new state-of-the-art steel mill in Pesquería, Mexico, which will make it the most modern facility on the continent. The 2,1 Mtpy HDRI/CDRI plant is based on the innovative ENERGIRON Direct Reduction technology, including the Consteel® EAF with hot DRI through the reliable Hytemp® pneumatic transport system, ensuring exceptional energy efficiency throughout the entire process. The main feature of the plant is also its charging flexibility, which allows the EAF to receive scrap in variable percentage in addition to hot DRI.

Additionally, the DR plant is equipped with carbon capture technology and is prepared for use of hydrogen. This makes it the most sustainable steelmaking solution currently accessible on the market. The project is under Engineering phase.

## VULCAN GREEN STEEL, OMAN

By end of 2023, Vulcan Green Steel, a new established company of Jindal Steel Group, relied on ENERGIRON for its new hydrogen-ready direct reduction plant in Duqm, in the Al Wusta Governorate in the Sultanate of Oman. The ENERGIRON plant will feed a new electric steelmaking complex conceived as a hub for green steel production in the country.

ENERGIRON® is $H_2$-ready and will allow to use natural gas as reducing agent with the possibility to mix it with up to 100% hydrogen, according to hydrogen availability. The new ENERGIRON zero-reformer DR plant will produce 2,5Mtpy of HDRI/HBI and will start operation with natural gas feed, increasing the percentage of hydrogen in blend as hydrogen becomes available on site.

## LKAB SWEDEN

By beginning of 2024, the ENERGIRON technology has been chosen by LKAB, an international mining and minerals group that offers sustainable iron ore, minerals, and special products, for the basic engineering of its 100% hydrogen-based direct reduced iron (DRI) plant in Gällivare, Sweden. This represents a further step in the application of the technology by the group, as ENERGIRON has already been the key equipment to the full-hydrogen pilot plant in Luleå, Sweden. Amongst the characteristics of the new installation, it is notable that an electric process heater, a world first in an industrial DRI plant, will heat the process gas using green electric power. This will reduce carbon emissions down to zero, dramatically increasing the overall energy efficiency of the process. The new DRI plant will use fossil-free electric power from different sources to produce fossil-free sponge iron that will be used by SSAB to make fossil-free steel.

## NIPPON STEEL CORPORATION JAPAN

By March of 2024, Tenova, was awarded a contract for an Experimental Direct Reduction plant (EDRP) to be operated by Nippon Steel Corporation and entrusted by the New Energy and Industrial Technology Development Organization (NEDO). This facility will be used for the demonstration test of “Development of Direct Hydrogen Reduction Technology for Reducing Low-Grade Iron Ore with Hydrogen Alone / Development of Technology for Direct Hydrogen Reduction”. This project is being undertaken by a consortium formed by Nippon Steel Corporation, JFE Steel Corporation, and the Japan Research and Development Center for Metals.

The DR plant, based on the ENERGIRON DR technology will use hydrogen as reducing gas, although, retaining the flexibility to use different gases in any combination or proportion.

## CONCLUSIONS

Selection on the most adequate route for decarbonising existing or greenfield steelmaking facilities shall be based on a flexible, efficient and proven $H_2$-ready DRI-based ironmaking technology. Other DR technologies presentssome limitations in terms of process configurations and suitable DRI carbon contentfor which, once the scheme is selected for 100% NG or 100% $H_2$, there will be not economical and efficient way back for using either reducing gas source at 100%in case of lack of availability of any.

Above listed recent projects worldwide underline the $H_2$ -ready ENERGIRON process scheme as the flexible technology of choice towards the green-steelmaking worldwide scenario.