# Pathways towards green steel

***The technologies for achieving climate-neutral steelmaking are available right now. They are ready to be implemented in existing and future plants. How, what, when and where this can happen depends on several factors. Thankfully, there is an SMS group solution available for all such requirements. Various options are presented in this paper, for both brownfield and greenfield solutions.***

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The green transformation of the steel industry is a marathon, not a sprint. By the middle of this decade, lighthouse projects like H2 Green Steel will prove that carbon neutral steel production is possible. However, due to the long investment cycles for metallurgical plants, a large part of future $CO_2$ savings must come from the conversion of existing mills. Here, there is no one-size-fits-all ‘best’ option. That is why tailor-made solutions are required for any scenario, taking into account local conditions such as iron ore quality, energy infrastructure, and existing equipment, as well as local policies, rules, and regulations.

All three major decarbonization routes (*Figure 1*) have the potential to achieve climate neutrality by introducing innovative integrated process solutions in new greenfield, or existing steel brownfield sites and by putting in place additional infrastructure for the use of fossil-free energy sources like hydrogen, biomass, or green electricity. Carbon capture can further be applied to go the last mile towards climate neutrality.

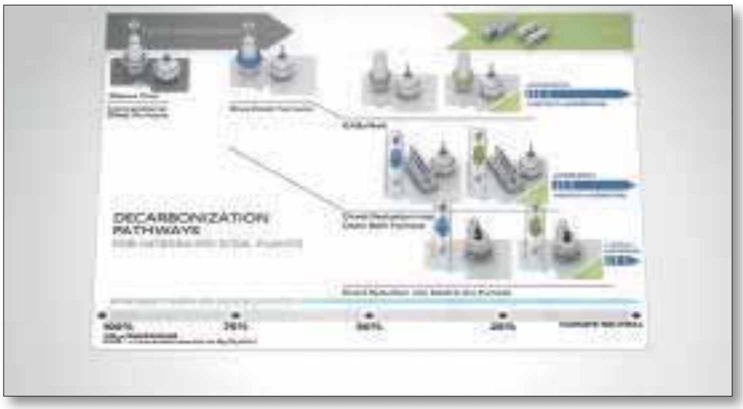


**Fig 1 Decarbonization routes for integrated steel plants**

## OPTIONS FOR BROWNFIELD SITES

### Blue blast furnace to reduce emissions by 30%.

Today, the integrated, ‘primary’ Blast Furnace-Basic Oxygen Furnace (BF-BOF) route is the dominant configuration for iron and steel production. Despite its high $CO_2$ emissions resulting from the use of large amounts of iron ore, mostly with low iron content, and limited amounts of scrap, blast furnace technology remains a crucial component of the iron and steel production process. Rapid greenhouse gas emissions reduction requires the gradual conversion of existing plants and infrastructure. That’s why Blue Blast Furnace technology has been developed as a bride on the path to a greener future in steel production.

The defining feature of the Blue Blast Furnace is the generation of syngas and its injection through a new bustle pipe at the lower shaft portion of the blast furnace. This achieves emission reductions of up to 28%. Synthesis gas (or syngas) consists primarily of carbon monoxide and hydrogen and works as a reducing gas to enable a reduction of the iron burden in the shaft, thus replacing coke.

The gas may be produced via a variety of technologies. One is a new reforming process, the so-called dry reforming of coke oven gas in reformer stoves, during which blast furnace gas and coke oven gas are reformed at a high temperature. As the process only uses exhaust gases from the steel plant and can replace coal, the potential to reduce $CO_2$ is high. Apart from the reformer stoves, there are other available technologies to produce syngas, like the reforming of natural gas, coke oven gas and tar.

Paul Wurth has successfully operated a syngas pilot plant in Dillingen, Germany at ROGESA Roheisengesellschaft Saar mbH for testing the dry reforming process of coke oven gas with blast furnace gas (*Figure 2*). The first months →

Fig 2 **Pilot plant for syngas generation at ROGESA**

of operation have proven the feasibility of the process, with excellent conversion ratios of up to 98%. The produced syngas has the optimum composition and temperature for versatile use, such as a reducing gas in the BF process, significantly surpassing the syngas quality produced by traditional catalytic reforming processes. The quality and high temperature of the reducing gas allows for utilization at both shaft and tuyere level.

## Upgrade with Easymelt for 60% emissions savings

Based on, but going beyond the emission reduction potential of the Blue Blast Furnace, SMS group is developing EASyMelt. This Electrically-Assisted Syngas Melter will function as an alternative to the direct reduction route and as a complementary process for filling the gap between iron ore availability and green steel demand. For brownfield sites, 60% and more $CO_2$ emissions can be saved by transforming existing BF-BOF plants via the EASyMelt, or the Direct Reduction Plant-Open Bath Furnace (DRP-OBF) route, as described below.

This concept aggregates the latest technologies developed by Paul Wurth for substitution of the traditional blast furnace in integrated steel plants and helping to achieve carbon neutrality. EASyMelt is an electrified direct reduction and melting process, using a minor quantity of coke to entirely replace the traditional hot blast with gases like coke oven gas, natural gas, hydrogen, and ammonia. Depending on the energy input, the technology can achieve emission savings greater than 60%, compared with the traditional BF-BOF route. Remaining direct emissions can be reduced by applying carbon capture, or through the use of biomass, or biogas as feedstock. Using existing plants as a basis, EASyMelt is less CAPEX-intensive than any other low-carbon ironmaking technology.

The process is flexible in its input, adds resilience against supply shortages and market volatility, and can be adapted to various scenarios. Most importantly though, traditional sinter feed may still be used in EASyMelt, avoiding fierce competition for the limited supply of high-grade pellets. This gives both flexibility and highly competitive operational costs. Just like the Blue Blast Furnace, EASyMelt can be realized in a step-wise approach to implementation, with several technological elements working together to achieve net-zero ironmaking. The central elements are the injection of the reducing gas at the shaft, plasma-based superheating for tuyere injection, and the capture of remaining emissions for storage or utilization.

## Direct reduction into open bath furnace saving up to 65% $CO_2$

Another leading candidate in the race to decarbonize existing sites is the combination of the well-proven MIDREX® direct reduction process using a shaft furnace and an open bath electric furnace (OBF), in place of existing blast furnaces. SMS group is supplying this combination of hydrogen powered direct reduction plant, OBF and BOF steel making to thyssenkrupp Steel in Duisburg.

The technology combines two key processes: the direct reduction of iron ore in a shaft furnace and the conversion of the resulting sponge iron into high-quality steel. It is possible to run the direct reduction plant (DRP) on a natural-gas basis initially, gradually introducing hydrogen at higher rates. The OBF is similar in design to a conventional Submerged Arc Furnace (SAF) operated in a so-called 'brushed arc' mode. SMS group has several hundreds of references for these kinds of furnaces.

The DRP-OBF route is suitable for both brownfield and greenfield projects. In existing steelworks, this combination replaces the BF and its associated sintering, stove, and coke facilities. The ideal combination of a DRP and associated OBFs is to have both installed alongside one another from the start. This

Fig 3 **DRI plant of Algerian Qatari Steel (AQS), supplied by MIDREX with Paul Wurth**

enables hot charging DRI to the OBF, making use of sensible energy to lower the specific energy consumption.

The combination of direct reduction based on natural gas together with an OBF reduces $CO_2$ emissions by about 50% compared with the conventional BF-BOF route. These emission savings are achieved thanks to the higher hydrogen content in natural gas. In a second step, the natural gas can gradually be replaced with hydrogen as a reducing gas, which allows for further $CO_2$ reduction, up to around 65 %.

One of the main benefits of this technology is that it reduces the need for coking coal, a key ingredient in traditional steelmaking processes. The direct reduction with OBF and BOF converter technology is highly flexible and adaptable. Today's direct reduction shafts require pellets or high-grade lump ore. The OBF would then ideally be charged with hot DRI, significantly reducing electrical energy consumption. Alternatively, the OBF also accepts any pre-reduced iron ore feed, including hot briquetted iron (HBI), cold DRI pellets, or even DRI fines.

Thanks to its reducing nature, the OBF is not sensitive to low ore quality, addressing the electric arc furnace's inefficient processing of low-grade iron ores and making hydrogen-based green steel from low-grade ore more feasible in the future. In addition to the hot DRI fed to the OBF, up to 10% of the OBF material feed can be comprised of agglomerated waste or free flowing scrap. This allows steel plants to consume waste from their existing facilities by utilizing an inexpensive agglomeration process to prepare these for addition to the furnace. The OBF can also generate a slag similar to BF slag that can be granulated and valorized in the cement industry.

## IRON MAKING WITH MIDREX® TECHNOLOGY FOR BROWNFIELD AND GREENFIELD SITES

Based on a construction license agreement, Paul Wurth supplies MIDREX® direct reduction ironmaking plants as part of its portfolio (*Figure 3*). MIDREX offers three main technologies bridging the transition from 100% natural gas to 100% hydrogen:

- MIDREX NG™ allows up to 30% of natural gas to be replaced with hydrogen without equipment modifications.
- MIDREX Flex provides the flexibility to →

Fig 4 **H2 Green Steel plant in Sweden**

operate on any mixture of natural gas and hydrogen (up to 100% hydrogen) with some minor modifications.
- MIDREX H2 is designed to use up to 100% hydrogen in a MIDREX shaft furnace as feed gas.

## GREENFIELD SITE: DIRECT REDUCTION INTO AN ELECTRIC ARC FURNACE FOR 95% $CO_2$ REDUCTION

In a greenfield project and with green hydrogen available at competitive prices in sufficient quantities, the combination of direct reduction and electric steelmaking is the best solution. $CO_2$ emission reductions of up to 95% can be achieved with a DRP-EAF steel plant setup, based on green electricity and hydrogen.

To operate any direct reduction technology while remaining competitive, sufficient natural gas, or green electricity are a necessity. This is the reason why gas-based direct reduction plants have been built in locations like the Middle East, North Africa, North America, and Russia. The pre-reduced high-grade grade iron ore pellets are reduced in a MIDREX® shaft and then fed into an electric arc furnace as hot DRI. The EAF then melts the material and produces liquid steel. No intermediate step is required, and, depending on the MIDREX® technology in use, only minor carburization is needed to reduce the nitrogen in the steel.

Switching from natural gas use to renewable hydrogen, this route comes closest to carbon neutrality. The carbon content of low to zero carbon DRI resulting from H2 reduction may be modified in the lower cone (or cooling zone), of the shaft furnace. Scrap can be added to the EAF with only the potential scrap contamination and quality requirements of downstream processing stages setting an upper limit. This route is particularly interesting for greenfield projects and newly constructed steel plants.

The H2 Green Steel project in Boden, Sweden (*Figure 4*), is an excellent example of this technology in action and marks an important milestone in the transition of the European steel sector towards climate neutrality. This project aims to demonstrate the feasibility of producing high-quality DRI using 100% hydrogen as the feed gas. As the world's first almost carbon-neutral steel plant, H2 Green Steel has the potential to lead the way toward a more sustainable steelmaking industry.

## CONCLUSION

In the race for green steel production, different, tailor-made solutions will be required to decarbonize existing brown field sites, as well as build new green field sites. Technologies such as the Blue Blast Furnace, EASyMELT and Direct Reduction can be retrofitted to existing iron producing facilities, to give $CO_2$ emission reductions of between 30% and 65%. For green field sites and new plants, the combination of hydrogen reduction and green electricity can reduce emissions by 95% or more. MS

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