Between a pony and a pink unicorn?

Direct Reduced Iron – or DRI – is viewed by many as a cast iron solution to the decarbonisation of the steel making process. Along with the use of hydrogen as a reductant, it's as if the whole thing is sown up, especially now that the Hybrit initiative in Sweden has delivered a consignment of fossil-free steel to car maker Volvo. But nothing is that straightforward and plenty of challenges still lie ahead. By **Rutger Gyllenram***

"WHAT the industry is promising right now is something between a pink pony and a unicorn!" The statement belongs to a young but already senior consultant at one of the major consultancy firms designing the future Swedish power grid. The discussion was about the sustainability and realism in large-scale production of DRI using hydrogen as a reductant; hydrogen produced from water by electrolysis demanding vast amounts of electric power, preferably 'green' electricity. The venue was Stockholm in April 2021.

Some years earlier, companies had started to promise fossil-free steelmaking by producing DRI with hydrogen as reductant and water as the off gas. The pressure on the steel industry to transform in order to make it possible to live up to the Paris agreement had been massive and since scrap resources are limited, a solution had to include iron ore reduction. Hence the idea was quite logical, the reduction of iron ore using hydrogen. While never used successfully on an industrial scale, it has been known since the 19th century. After the first steel company declared its ambitions, others followed and soon the technology suppliers also joined in. Today, one auto manufacturer after another declare that they want to use what they call 'green steel'. The ambition of all the actors to live up to the Paris agreement is commendable, but not without complications for them and their investors, quite often the taxpayers, as we will come back to.

Rutger Gyllenram. Photo by Pelle Berglund, Znapshot.

Choice of reductant and assessing the technical risk

Low fossil or fossil-free DRI can be produced with three alternative reduction gases which all have advantages and drawbacks: natural gas with subsequent Carbon Capture and Storage, CCS, hydrogen gas and finally syngas of biogenic origin. The principles are shown in **Fig 1**. If CCS follows the syngas alternative, this process can also be considered climate negative.

Reduction with reformed natural gas, MIDREX and Energiron, accounts for the majority of today's gas-based DRI production and is by far the process type

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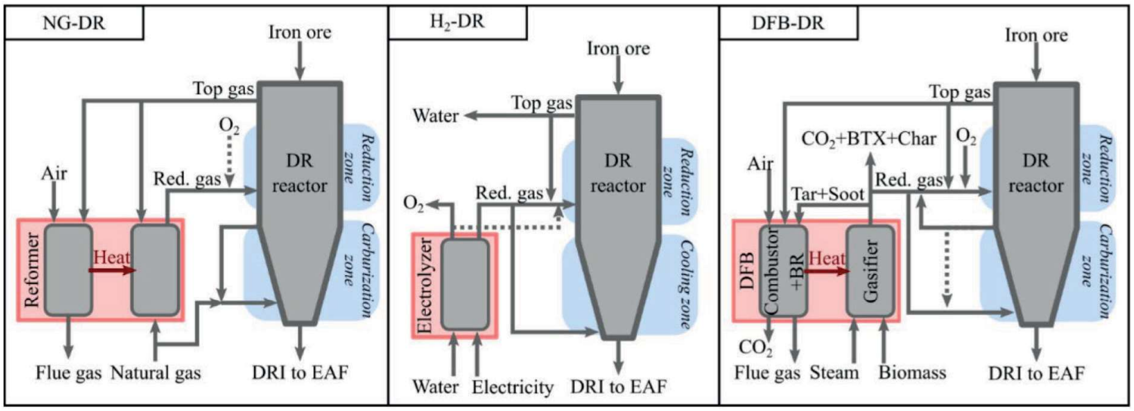

Fig 1. Pissot S et al, Production of Negative-Emissions Steel Using a Reducing Gas Derived from DFB Gasification, Energies 2021, https://doi.org/10.3390/en14164835

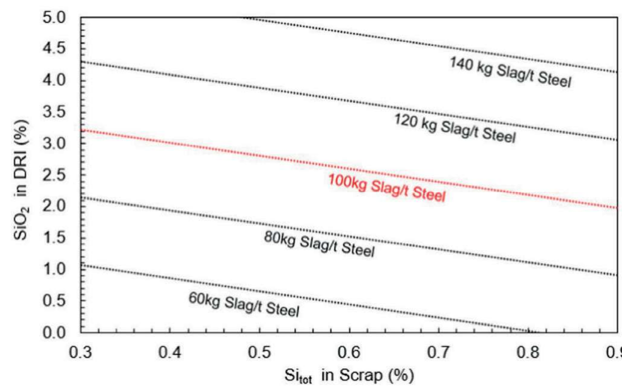

Fig 2. Gyllenram R et al, Driving investments in ore beneficiation and scrap upgrading to meet an increased demand from the direct reduction-EAF route, Mineral Economics 2021, https://doi.org/10.1007/s13563-021-00267-2

> **"Natural gas based direct reduction with CCS as implemented by Emirates Steel is today the best example of low fossil iron production."**

closest to becoming fossil free.

Since the reformed gas contains one third CO and two thirds H_2, compared with the 100% CO from blast furnace coke, the existing process provides the lowest CO_2 emissions of proven ironmaking technologies. Some of the natural gas is used for reduction and after separation of CO_2 in the top gas, a fraction that is CCS-ready is obtained. Other natural gas is burned with air to supply the necessary heat for reforming. The resulting flue gas contains nitrogen and is, therefore, not suitable for CCS unless nitrogen purification takes place. A future solution may be to burn this natural gas with oxygen instead and thus avoid mixing with nitrogen to make this CO_2 CCS-ready. The challenge is apart from making all the CO_2 CCS ready, to provide enough CCS capacity to handle the large volumes that may be produced in the future. The concept has been tried on a small scale by Emirates Steel and now a much larger implementation must be evaluated.

Reduction with hydrogen mainly entails challenges in three areas: electricity supply, heat balance and product properties. Hydrogen production requires large amounts of fossil-free electricity at a level that may affect the entire electricity balance of a steel-producing country. Furthermore, hydrogen reduction, unlike reduction with reformed natural gas or syngas, requires additional heat supply in order not to stop. This makes the process more complex than the others, which can cause problems when scaling up. Finally, reduction with hydrogen gives a carbon-free product that must either be carburised in a separate step or melted together with large amounts of carbon in the arc furnace in order not to suffer large iron losses.

Reduction with syngas of biogenic origin can be a solution where there are large amounts of biomass available as by-products from industrial forestry. Gasification is a known technology and

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Four necessary investment areas in the DRI supply chain to make a change this decade

1. Investments in ore beneficiation and pelletisation to replace sinter feed by pellets. Pellets lower blast furnace coke consumption today and pave the way for a transition to low fossil DRI production.
2. Investments in DRI-production for the blast furnace route. DRI used in the blast furnace lowers coke consumption and paves the way for replacing blast furnaces with intermediate melting furnaces when that technology is ready.
3. Investment in DRI-production for the metallics market offers a solution to scrap shortage.
4. Investment in development of DR-technology so all of the CO_2 can be captured and sequestrated.

> **"For the steel industry to turn from blast furnaces to DRI from hydrogen, about 100 new mega size nuclear plants need to be built."**
>
> **[The New Yorker magazine].**

otherwise the process is similar to reduction with reformed natural gas. The challenge here, however, is to scale up the gasification process to the volumes required. Today, forest by-products have a relatively low value and some are left to decompose in the forest. A future challenge may be competition from the production of biofuels.

Coping with both DR-grade and BF-grade pellets

A low amount of slag is absolutely crucial for the economy of steel production in an electric arc furnace. This can only be achieved with low levels of acid oxides in the iron raw material, primarily gangue in DRI and steriles in scrap. **Fig 2** shows the slag volume for 100 tons of steel with 50 tons of scrap and the rest DRI for different gangue contents in DRI and a different level of silica from dirt in scrap. A reduction of silica in DRI of two percentage points may result in savings of 12 USD/ton steel. What drives the production cost is increased energy consumption, increased consumption of lime and dolomite, increased losses of iron to the slag and reduced productivity. Forecasted growth of DRI production has led the mining companies to review their ore resources and processes to meet a possible increase in demand for DR pellets.

It is, however, a known fact that not all ores can be beneficiated to DR-grade, and technology suppliers are now working on an intermediate stage where a submerged arc furnace or resistance furnace is used to melt DRI from BF pellets under blast furnace-like conditions. In this new process, a blast furnace type slag will be separated with low iron losses and low consumption of slag formers as a result and the melted iron can be further processed in an electric arc furnace or a basic oxygen converter. The challenge here is to avoid high temperatures that make silicon in the slag evaporate and dissolve in the iron. If that happens nothing is gained from this process route compared to the traditional melting of DRI in an electric arc furnace.

Investments at low risk – now!

The development of an electric smelting process for DRI with a high silicon content will probably take most of a decade to be considered proven technology. In the meantime, the focus must necessarily be on introducing improvements in the blast furnace process in order to reduce coke consumption. There are three important areas where low risk investments are needed: further enrichment of ore to reduce the levels of gangue, expansion of pellet capacity to increase the pellet ratio and thereby reduce the amount of slag in the blast furnace, and finally production of DRI from BF-pellets to charge the blast furnace with material pre-reduced with natural gas. Although not solving the entire CO_2 problem, these investments, while being profitable, prepare the raw material supply chain for new technology when it is ready.

The more you work with DRI as a means for decarbonisation, the more obvious it becomes that the supply chain will be divided into an ore stage, a reduction stage and a steelmaking stage that do not need to be co-located. This opens up for DRI producers who are not integrated with a steel plant. They may be owned by a steel company, a mining company or completely independent. The critical conditions that will determine the location of fossil-free DRI producers for the world market are, in addition to port capacity, probably the availability of natural gas, electricity and biomass, and finally if CO_2 is produced, a geology suitable for storage through CCS.

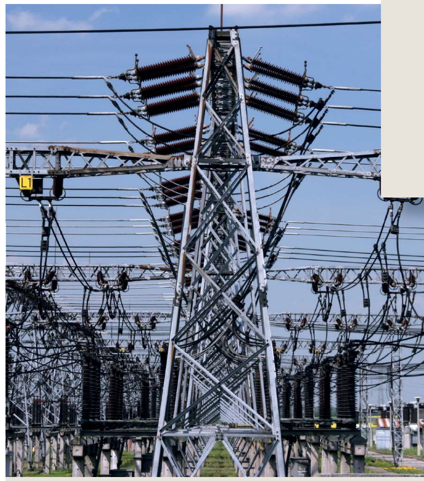
Political risk

Unlike the terms 'fossil-free' and 'fossil-

negative' which can be explained scientifically, the term 'green steel' is based entirely on values. It is impossible to predict how limited resources like scrap, electricity, biomass and geological formations for CCS will be viewed in the public eye 10 or 20 years from now. An assumed price premium based on 'greenness' introduces a significant risk in an investment calculus and in a longer perspective steel products will probably have to compete entirely on product quality and production cost, including those related to CO_2 emissions.

A major question is whether an attributional or consequential perspective will be applied on DR production in the future. The concepts are fetched from life cycle assessment, LCA, methodology and means taking the actual emissions from producing DRI into account or selecting the emissions that are emitted as a consequence of the DRI production. An example is whether a DR plant with an adjacent wind park can use wind-power emissions for the hydrogen production as is the case with an attributional perspective or if emissions from coal combustion should be used since the wind power produced could have replaced fossil energy.

The environmental product declarations, EPDs, developed for products today use attributional methodology and as a consequence are used by companies planning for fossil-free steel. Consequential analysis, on the other hand, is often used at the societal level and that may be a reason for meeting much more arguments with this perspective once an enlightened debate starts on how resources are used. In late September two articles indicate that the discussion has started. An article in The New Yorker makes the comment that for the steel industry to turn from blast furnaces to DRI from hydrogen, about 100 new mega size nuclear plants need to be built. In the same week three economists claimed in the Swedish paper Ekonomisk Debatt (Economy Debate) that investing in hydrogen-based production in northern Sweden was 'environmental nationalism'. The researchers applied a consequential perspective and suggested that fossil-free electricity from Sweden could be exported to substitute electricity made from coal elsewhere in Europe. Regardless of the quality of facts and arguments in the two articles, they highlight the fact that what is 'green' is dependent on the perspective you apply. The problem is that perspective



> "Hydrogen production requires large amounts of fossil-free electricity at a level that may affect the entire electricity balance of a steel-producing country."

preferences may change over time. Investors should consider what a gradual transition from an attributional to a consequential perspective on green production over the next 10 years may do to the investments.

Meeting the Paris agreement

There is no single solution that will turn global steel production fossil-free by 2050. Natural gas-based direct reduction with CCS as implemented by Emirates Steel is today the best example of low fossil iron production. As mentioned earlier, in this kind of process about 50% of the CO_2 in the off gas is CCS-ready which might, with some effort, increase to 100%, but again that is allowing for a speculation. Some of the research projects going on with hydrogen today are promising, but they are just that: research or pilot projects. How they perform in competition with DRI from natural gas and a hypothetical 100% CCS 30 years from now is yet to be seen. Reduction with syngas from biomass combined with CCS is finally a very attractive option since it may offer a carbon sink i.e. negative CO_2 emissions.

The elephant in the room, the large installed base of fairly new blast furnace plants, must initially be handled with traditional efficiency improvements aiming at lowering the coke and coal consumption. In this work a transition to pellets instead of sinter to lower the slag volume, which saves coke as a fuel for melting, and charging DRI to save using coke as a reductant, will have an immediate effect on global CO_2 emissions. At the same time, building up this infrastructure paves the way for phasing out the blast furnaces when they have become obsolete and new technology is available.

What is needed is agreements within the supply chain to start this transition involving steel companies, DRI producers and ore product suppliers to create the necessary market stability to allow for the investments to take place. Furthermore, huge diplomatic efforts have to be made to stabilise the political situation in countries with vast amounts of natural gas. The MENA and other natural gas-rich regions may become hot spots for fossil-free DRI production, but that demands making the regions less of hot spots in other aspects. Countries like Iran and, to some extent, Venezuela may prove to be important factors in decarbonising the steel industry, but then mutual trust must be restored. Difficult, yes, but the incentives have never been higher.

To conclude: Yes, DRI is an important tool to decarbonise the steel industry, avoid pink unicorns in the shape of wishful thinking and the elephant in the room may lead the way forward, even if it is pink. ■

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Three necessary missions to promote investments

1. Agreeing on a minimum price on CO_2 emissions on major markets.

2. Stabilising the demand and prices for pellets and DRI within the supply chain.

3. Stabilising production, transport and trade conditions in regions with large resources of natural gas and geology suitable for CCS.