ecology eco-e economy

LOW-EMISSION STEEL

Decarbonisation – yes, but which way to go?

ABSTRACT

The traditional supply chain to produce steel has changed with the arrival of DRI as substitute of the bast furnace route. An analyse of the energy need and the GHG emissions of this new distribution scheme and the perspective of this important change questions the feasibility and designs a new much simpler solution. See a feasible and economic way to fulfil the targets of 2050.

Roland Mueller

eco-e AG (www.eco-eag.com)

Keywords: Decarbonisation, Iron and steel, Supply chain, Energy demand, GHG, Thermochemical cycle, eco-e tech, Sector coupling, low-emission steel, Green Steel, Efficiency, COPxx, DRI, EAF

Decarbonization yes, but which way to go?

What will be the future of the steel industry? A question that interests all, professionals and more. Decarbonization of the steel industry has a lead function. Is DRI – SAF – BOF the salvation? What does this mean to the supply chain? Can this way be realized or is it a dead-end road?

These and many more questions are in the air. Lets' have a look at the facts.

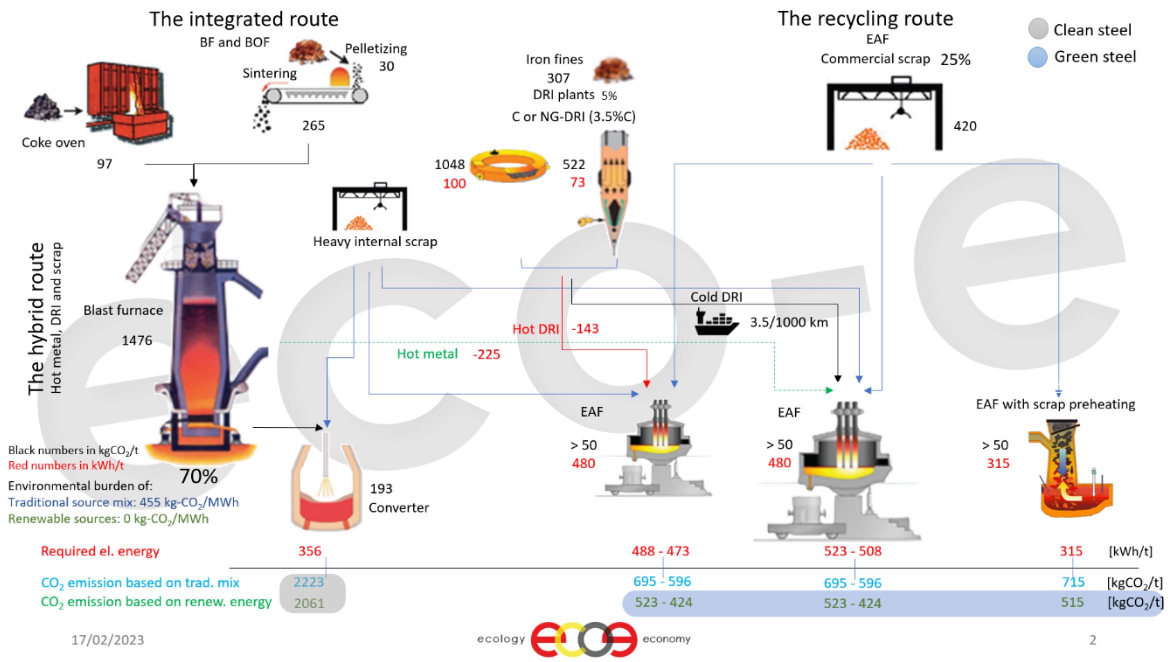

Figure 1 / Green Steel 2023

Not long ago, steel was produced by two major routes with an appendix, the integrated route, and the recycling route. The appendix was DRI (direct reduced iron ore), DRI (5% of the total crude steel production) as a substitute for missing scrap especially in areas where energy costs are neglectable, and scrap was missing or too expensive. This appendix was exclusive and expensive, exclusive because only selected ore is used to make a workable DRI, and expensive because much more energy is needed to melt DRI unless hot DRI is processed, and a much bigger amount of slag is arising. Without considering the newly drafted replacement of the integrated route green steel comprises all the production variations based on the electric arc furnace.

Noteworthy in figure 1, the supply chain. While for the integrated route and the EAF with scrap preheating the supply chain is clearly defined and narrow, the supply chain for the traditional EAF has some variations. In some steel plants where a DRI reactor is near the EAF, hot supply of DRI is possible. This saves an important amount of energy. Distant transports of hot DRI are rather seldom and transport of cold DRI must happen under severe control and with precautions regarding the formation of explosive gases. Integrated steel plants with nearby EAF facilities can save even more energy by supplying hot metal to the EAF.

Another important message is the differentiation between Clean Steel and Green Steel. Note: Clean Steel is a quality message, while Green Steel is nothing else than marketing, it's wishful thinking that one day there might be enough renewable energy to produce steel, one of the most energy demanding processes.

This was yesterday – since the eighties of last century, illuminati (club of Rome) remind us of the growing environmental threat which might lead us to an environmental disaster. Finally, humanity has noticed that something must change. Change? – yes change, but what? Well, the most man produced green house gas is CO_2, and green house gas is the declared initiator of the global warming. There are three main man produced CO_2 areas – energy production, steel production and the combustion engines. The so-called energy transition which includes the energy production will cost enormous amount of money, money which must be paid by the users, which are already now struggling. A quick change on the combustion engines is no short-term business as about 1200 million cars are running on fossil fuel and only countries where wealthy people live can think about a forced change. Thus, if we can't decarbonize the steel production, we possibly can't decarbonize the world.

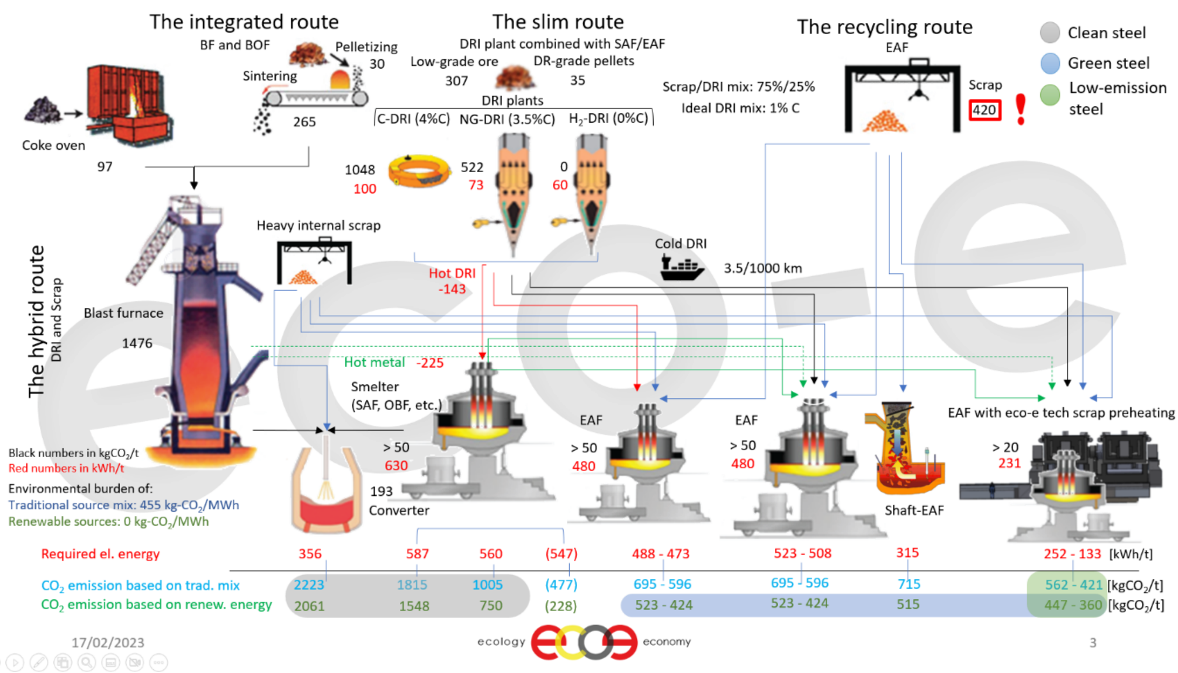

Figure 2 / the steel transition

Now, global warming or earth fever has become noticeable. The request to decarbonize the steel industry has brought up a 'new' less polluting production process. The scrap replacement production bypass takes now a new important part in the primary steel production, it replaces the blast furnaces and forms by that a new route, the slim route. The so-called appendix grows, grows to new horizons, and as usual the novelties require new procedures and new 'food'. However, later in this article we'll ask some quite important questions around this transition. But first, the changes in the supply chain and the requirement of versatility.

Not considering the timeline and the feasibility of the proposed growth, the transition from the integrated route to the slim route implies some modification.

The slim route comprises various direct reduction processes, from the open-heart furnace to the H_2-reactor. The C-content of the produced DRI varies from 4% to 0%. The emitted GHG are between 1048 $kgCO_2/t_{DRI}$ in the open-heart furnace to 0 $kgCO_2/t_{DRI}$ at the H_2-reactor. The produced DRI varies according to the supplied material, thus low-grade ore produces a DRI with low metallization and consequently high content of gangue while the enriched ore produces a DRI with a high metallization and a lower gangue content.
A low gangue content is important for a stress-reduced melting in the EAF whichever the supply, hot or cold. If low-grade DRI is processed directly in an EAF, then the melting turns-out to be very expensive (high amount of slag builders, increased energy consumption, higher electrode consumption, high wear on refractory to name only the important ones) and implies immense losses (slag, FeO, etc), in short, this route is not profitable and the GHG emissions increase. The low-grade DRI requires a smelter-type arc furnace, whether open slag bath furnace or a submerged arc furnace to be installed between the direct reduction and the steel producing process.

In conclusion it turns out, that there is no ‘best' way to replace the primary route, but there are good ways to benefit from lower energy input and lower GHG emissions as well. In the first level, the direct reduction a combination of natural gas and H_2-reduction to produce a high metallized DRI with 1% C and low gangue content turns out to be the best choice. For the large-scale production, the low-grade ore reduction with natural gas to produce hot metal which can be processed in the converter (BOF) is a feasible way which still produces much less GHG than the blast furnace. The end-of-life scrap part will increase over the years, that's why the scrap preheating becomes more and more important. The traditional scrap preheating with one chamber (shaft or belt conveyor) is not versatile enough to cope with the demand for combined utilisation of DRI and scrap. The eco-e tech solution allows to best use all sorts of scrap, including heavy internal scrap and light scrap, it allows to take advantage of residual heat after the scrap preheating, e.g., for steam production, DRI hot storage etc., and allows to reduce both, the electric input and the GHG emissions.

The bottleneck, however, remains the supply chain of the end-of-life scrap. The assembly, the treatment, if ever, and the supply of this scrap to the steel works cannot be easily decarbonized. Steel works who want to supply Green Steel have primarily to take care of their scrap supply chain as the scrap supply chain counts much more than the use of green energy.

The road to decarbonization

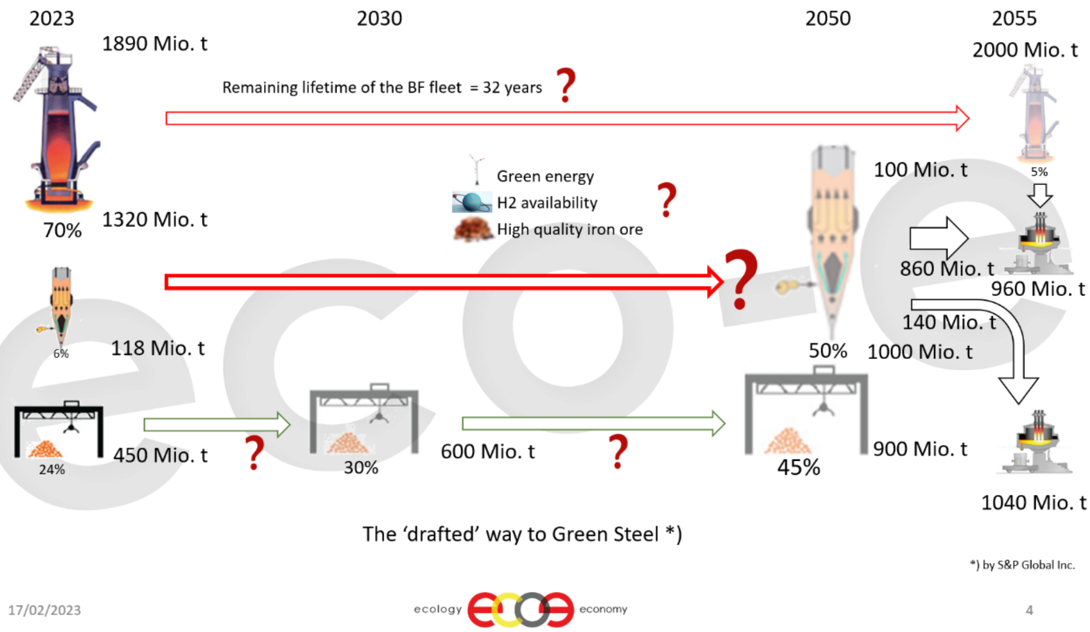

Figure 3 / The road to decarb

Here above the drafted way to Green Steel from 2020 to 2055. At the right the current situation, a global crude steel production of 1890 million tons subdivided into the primary route, the secondary route which contains the DRI production and the total scrap market. The scrap market subdivides into heavy internal scrap, return scrap and end-of-life scrap. Organisations like IEA, worldsteel, and Eurofer predict a scrap increase, especially in emerging counties, from 450 million tons to 600 million tones in 2030 and again to 900 million tons in 2050.

Another prediction is, that the total crude steel production will remain stable or slightly regress.

These two predictions, together with an also questionable remaining lifetime assumption of the existing integrated works leads us to the required growth of the DRI market from 6% of the world crude steel production up to 50% of the crude steel production. By then 48% of the crude steel production shall be via the slim route and 52% via the secondary route, where DRI is contributing with a mean share of roughly 15%.

This leads us to several questions:

- The mean lifetime of a blast furnace is around 45 years. The average age of the blast furnace fleet is 13 years. As most of the 'young' blast furnaces are in PR China, are they going to be replaced staggered or all at once?
- Will the primary transition be on track with the drafted schedule?
- Will the green energy growth follow and what about the energy transmission from the production place to the user?
- Will the H_2-transport be that easy and what about the losses? Unburned H_2 is a climate-killer as well – what about that?

- Low-grade ore = low metallization of DRI and high amount of slag. Is the final primary slag equivalent to the blast furnace slag (essential for the cement production)?
- Another big question mark is the increase of the DRI-reactor availability and the connected ore logistic.
- Finally, the projected increase of end-of-life scrap goes together with the very high environmental load of the scrap assembly and transportation to the steel works (remember the scrap preparation takes 420 $kgCO_2/t_{Scrap}$ of 480 $kgCO_2/t_{HM}$ which is more than 80%). Is it possible to reduce this load?

Some of the questions may be answered easily, some remain open, however, there are quite a lot of obstacles on the road to Green Steel. Let's look at it on another picture and allow-us to ask a simplistic question …

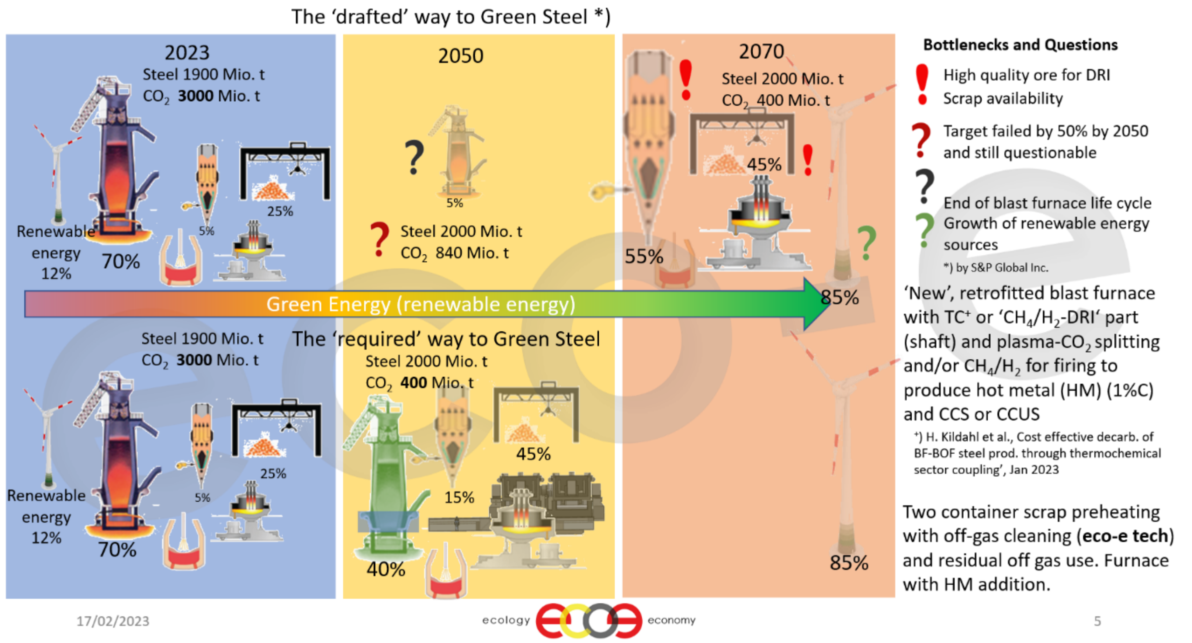

Figure 4 / The 'drafted' way to Green Steel

According to some sources we will fail to reduce CO_2 production to the target level by 2050. Main fears are that the remaining time and recourses are not enough to fulfil that herculean task, and that the treasury of subventions and perks are empty long before and that the required renewable energy will be available by 2070 at the earliest.

And now, before asking the simplistic and silly question here some quasi-historical facts. The blast furnace has a very long history and so has the basic oxygen furnace (BOF). They have already made a long journey, sure both have been developed and modernized, but the basics are still the same. DRI has had its first appearance in the 60's of last century, but it's as old as the first one's, only the name has changed. Now my ingenuous and silly question: wouldn't it be possible to combine the blast furnace and the DRI reactor and make one new reactor-furnace? A kind of thermochemical reaction giving the existing blast furnaces a new 'coat', allowing them to reduce their important GHG emissions, e.g., as described in the article of Dr. H. Kildahl[i]. The output could also be a 'vitrified' iron pellet, easy to transport and without risk of oxidizing. If it should turn out that this question should be ingenious then we would be able to reach the target 2050 by far, because that would save a lot of energy and CO_2 – give it a go!

The smarter way (required to reach 2050 targets)

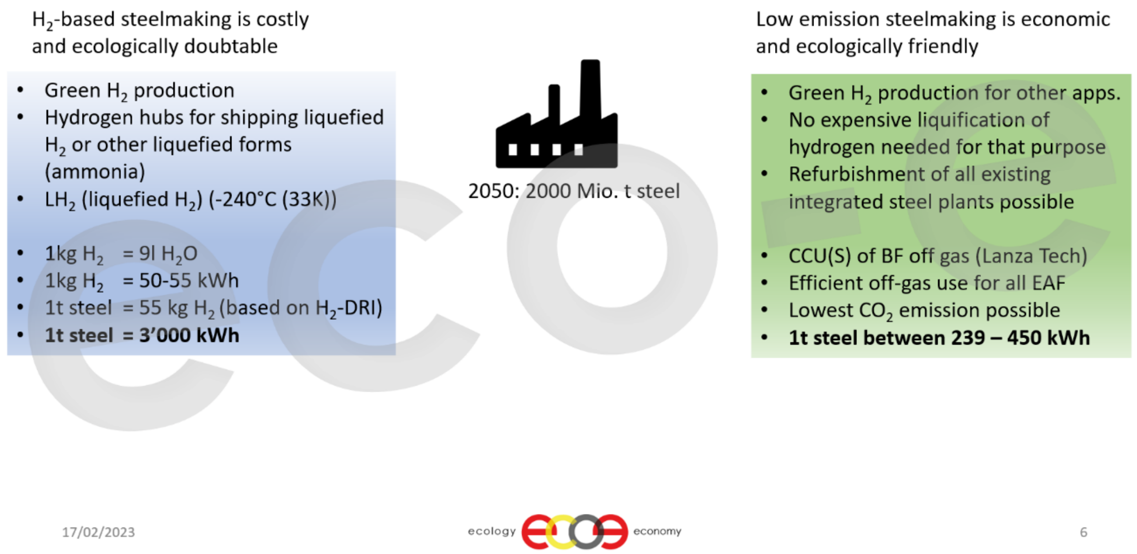

Figure 5 / The smart way

Meanwhile there are some experiences with electrolysers, with fuel cells and the application for the mobility of cars, trucks, trains and even planes. There is a lot more H_2 needed in this sector. Is it wise to transport liquified hydrogen from the sunbelt to the polar regions? Is it wise to burn 3000 kWh/t_{Steel} and not even reach a low degree of environmental emissions while there are ways to reduce losses by transportation, liquification, and transformation by just finding a compromise and apply CCU(S) where the CO_2 is produced? DRI is a dirty pre-product, difficult to manage, transport and melt, produces masses of slag and a lot of costs in the secondary steel production – why not bypass that step, why not produce hot metal in pellets directly and coat them with some slag-building glassy product which render them save against moisture oxidizing? As the scrap mount is increasing and one day the primary route will step back to second position why not preparing the production processes regarding this?

As said, the scrap supply chain is the big GHG producer in the secondary steel making, GHG saving tools are needed there as there are 1200 million vehicles polluting and at the steel production there are only a few stacks producing the GHG emissions. These emissions can be treated much easier by CCU(S). Think about that!

Our target is to preserve life on our planet. By further releasing GHG emissions to the atmosphere we risk that temperature continues to rise, leading to a rise in sea levels, that certain species will be wiped out, that life becomes increasingly threatening due to unpredictable weather, drought, floods, and storms. By further increasing our energy consume (see figure 5) we still increase the production of greenhouse gases. Is that smart? I don't think so.

Let's look at the green energy requirements based on the above.

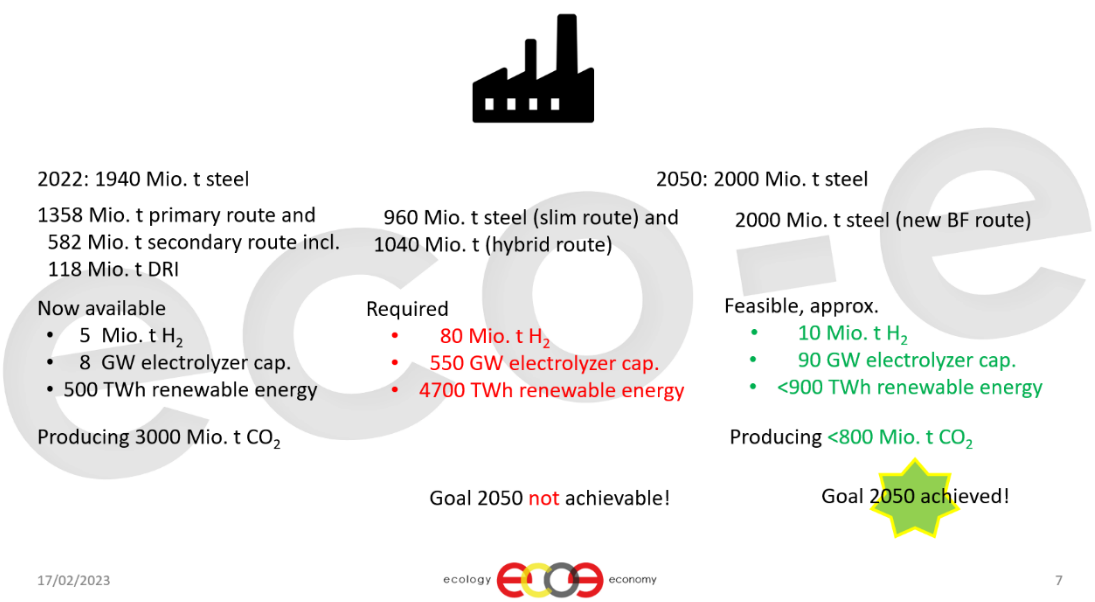

Figure 6 / The smart way cont.

By basing on the drafted way for reaching the goal set for 2050 this goal will be massively missed not only by the requirement of green energy but also for the possibilities to produce hydrogen and by the produced greenhouse gas. The slim route seems to be the wrong way. The main components are the upstream greenhouse gas emissions, especially for the increasing part of the end-of-life scrap, the exorbitant demand for energy of this route, mainly the H_2-DRI, the various issues around DRI transport, the massive slag amount, the logistic needs (cooling and cost) of hydrogen, etc.

We need to find a way where the hydrogen produced can be made available to many and not only to a few consumers. This because this green energy carrier is easily transportable and usable in a 'packaged' way in compounds such as ammonia or others. These compounds should be able to be used by existing combustion engines.

In a new, retrofitted blast furnace, either equipped with a new thermochemical sector coupling or in a combined reactor type blast furnace with CCU(S) and an oxygen mixture to obtain a hot metal which could either be pelletized or tapped as pig iron for further processing by a BOF, much energy could be saved, and the greenhouse gas emission would be still reasonable. The greenhouse gas, which are emitted, can be collected directly, and biochemically processed (LanzaTech). With such a solution the target 2050 could be reached and the steel making process would be more economic. Mission accomplished.

The supply chain of the afore said is shown in figure 7. The bottleneck, however, is still the end-of-life scrap with over 400kgCO_2/t $_{scrap}$. The direct connection of the new blast furnace with the electric arc furnace is feasible with the correct mixture CH_4/H_2 at the reactor. So, the process would benefit of the enthalpy of the hot metal and both, the energy and the emissions would be optimized.

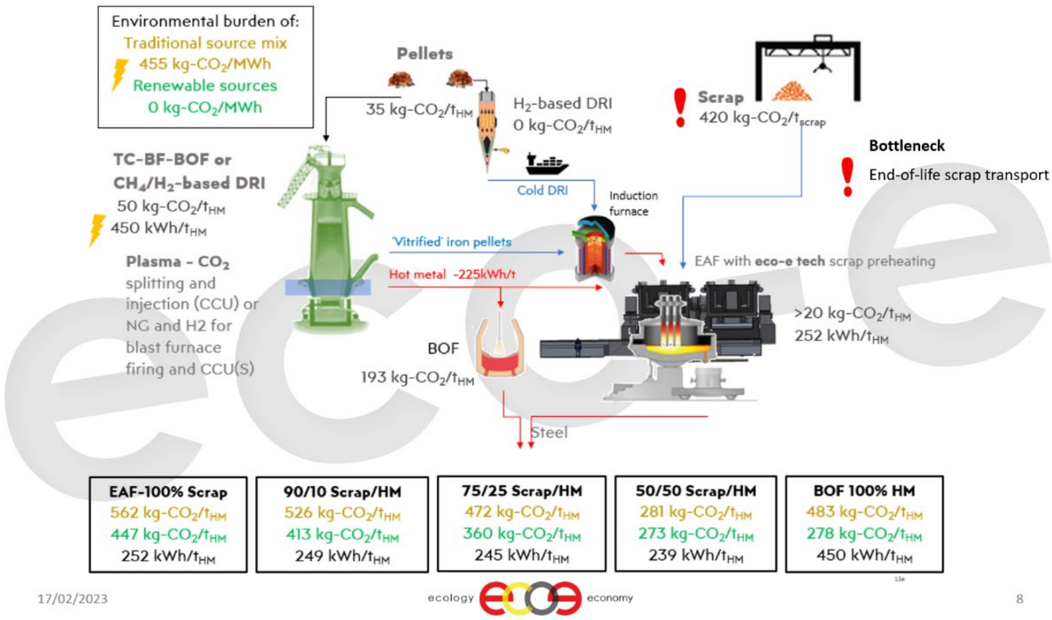

Figure 7 / The smart way

The target 2050 is achievable with the preheating of the end-of-life scrap and other 'preheatable' scrap mixes. Heavy internal scraps such as ladle and tundish sculls, crop ends and head pieces of the CCM are added through the roof of the furnace. In such a way an ideal energy saving installation is born – a versatile, flexible, and economically unbeaten solution.

Any existing electric arc furnace can be upgraded with minimized down time and in a very economic way.

We have the tool, ask us for details like layout, synopsis, energy flow, and other interesting information like ROI and other economic data.

Roland Müller

CH-Freienbach, March 2023

---

[i] H. Kildahl et al, Cost effective decarbonisation of blast furnace – basic oxygen furnace steel production through thermochemical sector coupling, ELSEVIR, Journal of Cleaner production 389 (2023), Jan 2023