Betting on a winning horse

The winds of change are blowing in the steel industry and we are now offered long lists of new processes that are being developed to save the planet. It's like betting on horses. Who will win and can the steel industry change? By **Rutger Gyllenram***

"OUR industry has changed very quickly in the past." The words are from Professor Chris Pistorius from Carnegie Mellon University, the venue was AISTech 2022 in Pittsburgh, USA and the context was the Brimacombe memorial lecture that, at the end, addressed decarbonisation in the steel industry. I guess we all agree when Pistorius states that it is encouraging to see how the steel industry embraces new technology, noting examples of how the Bessemer process took over from the puddling process in little more than 10 years around 1865, the BOF process taking over from open hearth and continuous casting replacing most of the ingot casting in just a number of decades after the second world war.

It is, however, fair to note that it took several years after Sir Henry Bessemer presented his invention before the first Bessemer charge succeeded. Furthermore, both using oxygen instead of air in the converter process, as in the BOF, and designs for continuous casting, were suggested by Bessemer but could not be realized in his time for technical reasons. The three technologies all increased the productivity and decreased the costs so the driving force for change was immense. The impact on society of the transition was also remarkable with smaller plants and whole communities closing and bigger plants growing.

Rutger Gyllenram. Photo by Pelle Berglund, Znapshot.

WHO WILL MAKE THE PELLETS AND DRI IN THE FUTURE?

Finally, we may ask if the changing iron and steelmaking map opens for more forward and backward integration in the industry. One of the main challenges for the mining industry in supplying the steel industry with pellets is to balance supply with demand with various quality premiums fluctuating. The dilemma of having one industry taking the cost and the other the benefit of ore beneficiation and pelletising is illustrated in Fig 3 taking iron yield as an example. DRI as a product has more potential customers and might offer a more stable demand and stable prices. So will mining companies start to make DRI, DRI producers beneficiate and pelletise ore or will things stay the same?

Fossil free steel or fossil CO_2-emission free steel

And now it is time to change again in a multitude of ways. A roadmap for the global steel industry to reduce emissions of carbon dioxide (CO_2) and other greenhouse gases includes multiple steps along the steel life cycle. The development of Life Cycle Assessment, LCA, has made emission data transparent upstream and downstream from a producer together with the producers' own emissions making it possible for anyone in the supply chain to make informed decisions.

In **Fig 1** production steps are shown from the mine to the end of life of a steel product followed by recycling. Necessary actions to achieve a fossil free steel production like fossil free electricity production, producing fossil free reductants, electrification, improving resource efficiency, all central to decarbonisation, are pointed out. The main questions that we need to ask ourselves are found at the bottom: do we need more stakeholder incentives, research, public information or regulations to make this happen?

For a mining company the emissions from mining, beneficiation, agglomeration and transportation are important areas for abatement of CO_2. Much can be done with electrification but using hydrogen, biofuels or other measures are necessary for some operations. The public discussion today is to a large extent focused on fossil-free reductants which will dominate discussions

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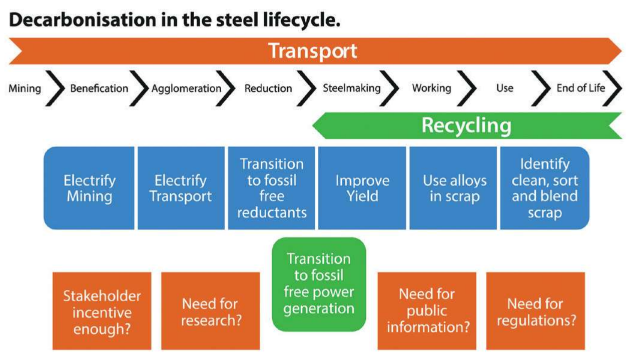

Fig 1. Decarbonisation in the steel lifecycle, from Worldsteel RAMCO meeting, Nov 18 2021. © Rutger Gyllenram Kobolde & Partners AB 2021

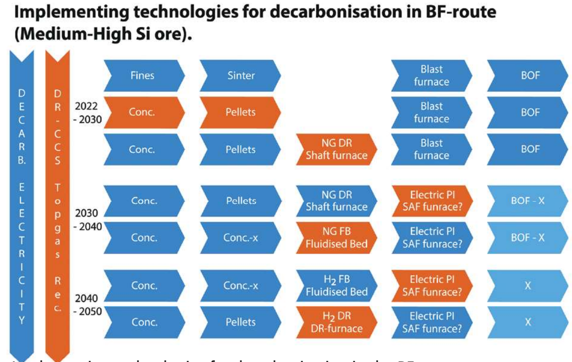

Fig 2. Implementing technologies for decarbonisation in the BF-route (Medium-High Si ore). From Worldsteel RAMCO meeting Nov 18 2021. © Rutger Gyllenram Kobolde & Partners AB 2021.

and development in the coming decades. The yield issue is to a large extent related to the amount of gangue from ore that is processed in the furnaces which is discussed later.

Finally, the steel with the lowest CO_2 emission comes from recycling but although the amount of available scrap is expected to increase in the decades to come, it will always be a limiting factor, determined by the amount of steel that goes into the use phase, the life time of the products and the collection rate. Therefore, closing blast furnaces to migrate to scrap-based production may do well for a single company, but can only work as a global solution in a rate to match an increased availability of scrap. Although scrap comes as a raw material almost free of burdens, a lot can be done to lower the total emissions for steel by utilising alloys in scrap and avoiding tramp elements like copper.

The transition of the entire steel industry to production without using fossil coal or natural gas will most certainly take the best part of this century and be limited by a number of critical factors. It will have to take place in several steps with intermediary solutions. One is Carbon Capture Utilisation and Storage (CCUS) where CO_2 is either used for products or liquified and stored, sequestrated in geological formations. Sequestrating fossil CO_2 will abate the fossil emissions. Sequestrating biogenic CO_2 will create carbon sinks. Both are probably necessary to reach the climate goals set for 2050. Whether we shall call steel produced from fossil reductants followed by CCUS 'fossil free' steel or 'fossil CO_2-emission free steel' or something else we may leave to academia?

Today, when we look for solutions to decrease greenhouse gas emissions from steelmaking by either replacing or modifying the blast furnace process, three questions spring to mind:

- Will we see the same rapid conversion to new processes and technical solutions to meet the climate challenge as in the introductory examples? Indeed, a lot is going on but when will they reach the market?
- Where will new ironmaking capacity be built? Will the availability of energy, the scale-up status of new ironmaking processes and availability of CCUS infrastructure draw a new iron and steelmaking map?
- What kind of immediate actions and long-term roadmaps can investors demand from steelmakers?

Processes and technical solutions

The last time we had this enormous interest in new iron and steelmaking technology was after the energy crisis of the 1970s. A big number of processes challenged the blast furnace by not demanding agglomeration of ore and/or coal. In economic evaluations the new process suggestions all outperformed the blast furnace process but at the end only a few survived to serve in niche applications. In hindsight one might conclude that the time and effort needed to develop a completely new process was underestimated and the projects ran out of funding or underperformed mainly due to low productivity, high refractory wear and difficulties in process control. On the other hand, the suppliers of blast furnace technology showed a great ability to improve, modify and scale up the process. Without questioning the good will of the steelmakers, one may conclude that the only thing that has changed is that this time, the cost of emitting greenhouse gases has been added to the equation. Is it a game changer for alternative ironmaking processes or will the blast furnace adapt? The chief objective of the EU-financed ULCOS project is to decarbonize ironmaking and it came along with other things, such as blast furnace top gas recycling which was implemented at the LKAB experimental blast furnace in Luleå, Sweden. After almost a decade of silence, it seems that the ULCOS ideas are again on the table.

Probably we can divide technology candidates to abate emissions into three categories:

1. Established, ready-to-implement, technologies profitable from the start.
2. Technology that needs to be scaled up and given the right economic conditions.
3. Development projects where function and profitability still need to be proven.

The A group includes lowering slag volumes in furnaces, replacing air with oxygen in combustion and replacing coal and coke with other reductants in the blast furnace and applying CCUS wherever possible. In group 2. we have, for example, top gas recycling, hydrogen and biogenic syngas reduction to avoid carbon, electric pig iron furnaces to melt high gangue DRI and fluidised bed reduction technology to avoid agglomeration. All very promising, but yet to be proved. In group 3. we have, for example, electrolysis projects that probably have a long way to go to the market so we will leave them out of the discussion for now.

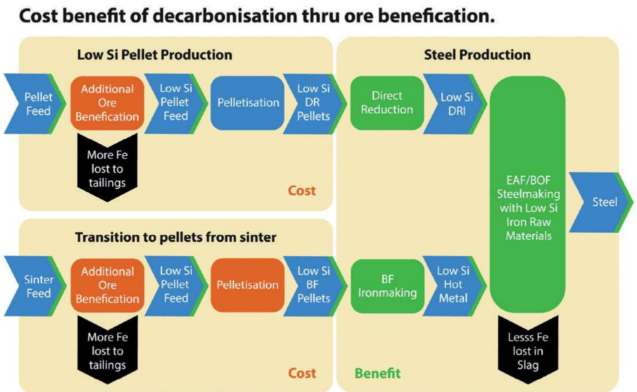

Fig 3. Cost benefit of decarbonisation thru ore beneficiation. After "How to Satisfy Steelmakers – What's in it for the Miners?" Fastmarkets Global Iron Ore 2021, © Rutger Gyllenram Kobolde & Partners AB 2021. Available at https://vimeo.com/526605624/6b72216f40.

A new iron and steelmaking map

A century ago, steelmaking plants were generally co-located with energy resources, close to a stream and a forest. Ores were by far the resources easiest to transport, easier than, for example, charcoal that is more voluminous. Coking coal and steam coal were denser and were more suitable for locations with blast furnaces producing close to 4Mt/yr of pig iron. Gas-based DR plants emerged more than 70 years ago and have now reached module sizes of more than 2Mt/yr of DRI often found in coastal locations where sea bound DR-pellets and local natural gas are the main resources.

For the new process installations that we discuss today we might, at least initially, be restricted by the availability of key resources. Regarding reductants, hydrogen production needs electricity, limited by available production and grid capacity, biogenic syngas needs a supply of biomass which is voluminous and finally, CCUS infrastructure may be limiting for processes emitting fossil or biogenic CO_2. These locations may, however, be excellent incubators and profit centres for new processes that are limited in module size depending on how far they have come in scaling up.

The debate has already started and regions with constant wind, sun and CCUS capacity are mapped. We will probably not see liquid natural gas or hydrogen shipped for iron ore reduction purposes due to liquefaction and transportation costs other than to bridge over-supply or technology gaps. The commodities transported long distances will be iron ore, DRI and steel. It has been suggested that countries like Chile and Australia will become hubs for hydrogen-reduced DRI while the MENA region may supply DRI from natural gas with CCUS.

What will happen to existing integrated plants with blast furnaces and basic oxygen furnaces? Eventually they will surely be equipped with electric arc furnaces when the availability of scrap and low gangue DRI allows for that. Until then they might continue production reinventing the blast furnace process with top gas recycling, CCUS and other measures or outsource the reduction and replace the blast furnaces with electric pig iron furnaces.

Immediate actions and long-term roadmaps

Ore products are either intended for the blast furnace – basic oxygen furnace route, BF-BOF; or direct reduction via the electric arc furnace route, DR-EAF. Although both routes benefit from a low gangue content in the ore, the blast furnace is less sensitive since it operates with a basicity (CaO/SiO_2) around 1 whereas the EAF operates with a basicity of around 4.

For mining companies with ores that cannot be beneficiated to DR-quality it is essential that either the blast furnace is adapted to new demands on CO_2 mitigation or that projects on electric pig iron furnaces with the same slag chemistry as the blast furnace succeed.

Bearing in mind that the possibility of beneficiating a certain ore depends on mineralogy and that getting permissions to build tailing dams has become increasingly difficult for some mining companies, it must be noted that decreasing the amount of gangue melted in any process should be given the highest priority in order to decrease energy use and improve yield.

Most fossil-free projects, planned for implementation this decade, are aimed at DRI production based on DR-pellets followed by an electric arc furnace. When talking about replacing the impacts from blast furnaces on a larger scale we must, therefore, look at what to do with the majority of ores which are of medium-to-high gangue content.

A possible timeline for material and process development to decarbonise steelmaking using medium-to-high silica iron ore is shown in **Fig 2.** The first row shows the situation today where sinter with a high silica content is reduced in the BF and decarburised in the BOF. In the second row the ore is beneficiated to a lower silica content and agglomerated to pellets. This will normally decrease the slag volume in the BF and lower the coke consumption and CO_2 emissions. In the third row, pellets are reduced to DRI to reduce coke consumption and CO_2 emissions in the BF. Even if natural gas is used it will decrease the emissions. If CCUS in the DRI production step is applied, the reduction will be even higher. This might be how far we get this decade, and what happens the next we can only guess. Maybe we can replace blast furnaces with electric pig iron furnaces and DR-shafts with fluidised beds, and use hydrogen made without emitting CO_2 but we do not know.

Aut Caesar, aut Nihil!

Caesar or nothing, the famous proverb of Cesare Borgia often interpreted as all or nothing, comes to mind in today´s discussions when incremental improvements of existing technology are viewed as 'less green' and, therefore, less attractive than new processes solving all our problems in an unknown future. Since we do not know when the shift will come, we have to muddle through with what we know and can do today to make whatever small steps that are possible. At the same time, we have to work hard to make the game changers ready to enter the market. It might be sooner or later. When they are ready the shift might be fast.

Which horse to bet on? Probably a herd of horses that moves fast and saves as much CO_2 as possible already today with existing technology and has prospects of achieving ambitious goals in the future. ■