Understanding and navigating the green steel transition – from BOF to efficient EAF operations

A great deal of what has been published with regard to the steel industry in recent years, relates to the need to decarbonize the iron and steelmaking industry. The holy grail of achieving this is Direct Carbon Avoidance (DCA) by switching technologies from the integrated BF-BOF steel plants toward DR-EAF steel plants.

Choosing scrap, or iron-based EAF production as a means to move away from integrated routes is an easy task to include at a high level in a company strategy presentation, but this might not address the uncomfortable detail of the manifold challenges in various metallurgical, operational, and logistical areas, while keeping production, the product portfolio, and safety unchanged – even during the transition.

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POLITICAL AND SOCIO-ECONOMIC SITUATION

The world is emitting a remarkable amount of CO_2 into the atmosphere and many parts of the world have decided to first limit and eventually even eliminate these emissions to fight climate change. As the iron and steel industry is a major industrial emitter, strategies have been forged to minimize CO_2 emissions in a stepwise manner, to comply with the local political framework and the wider interests of society.

The iron and steel industry is capital-intensive, so for businesses to be profitable, productivity needs to be high over a period extending beyond a decade to reach full amortization. Usually, new investments require amortization within three years. The green steel transformation is bringing the industry to a stress test of incomparable magnitude and therefore many companies are expressing their concerns and describing their challenges, neither to gain pity nor to increase short-term sales. However, what are the options on the table?

Figure 1 indicates the three main strategies by which which each steelmaker can choose to achieve their decarbonisation plans.

- Foremost are Process Optimizations (*Figure 1, step 1*) the action which requires effort and additional budget, but initial capital investment is initially minor. By increasing output, or decreasing material consumption, it is possible to decrease specific CO_2 emissions per tonne of steel. This is possibly not easy to achieve without external expertise, which can help to find the fastest path. This immediate action is very effective at targeting the low hanging fruit, but might be limited.

  A scrap-based EAF steelmaker might reduce their emissions to below 100kg CO_2/t steel by reducing power-on-time (PON), specific electrical consumption (kWh/t) or optimization of the use of different carbon carriers (such as bucket coal, or injection coal).

- When process optimization reaches its limits, initial capital investment becomes necessary to Adapt Existing Technology (*Figure 1, step 2*) and push the limits further. Older machinery can be replaced with new and more efficient machinery and classic fossil carbon carries, such as coal, can be replaced with less carbon-containing materials, such as natural gas, or carbon free fuels and reducing agents, such as hydrogen, or ammonia. Carbon-free materials, or non-fossil substitutes, such as biomass, result in the greatest reduction of specific CO_2 emissions. In these cases, direct investments and even research are necessary.

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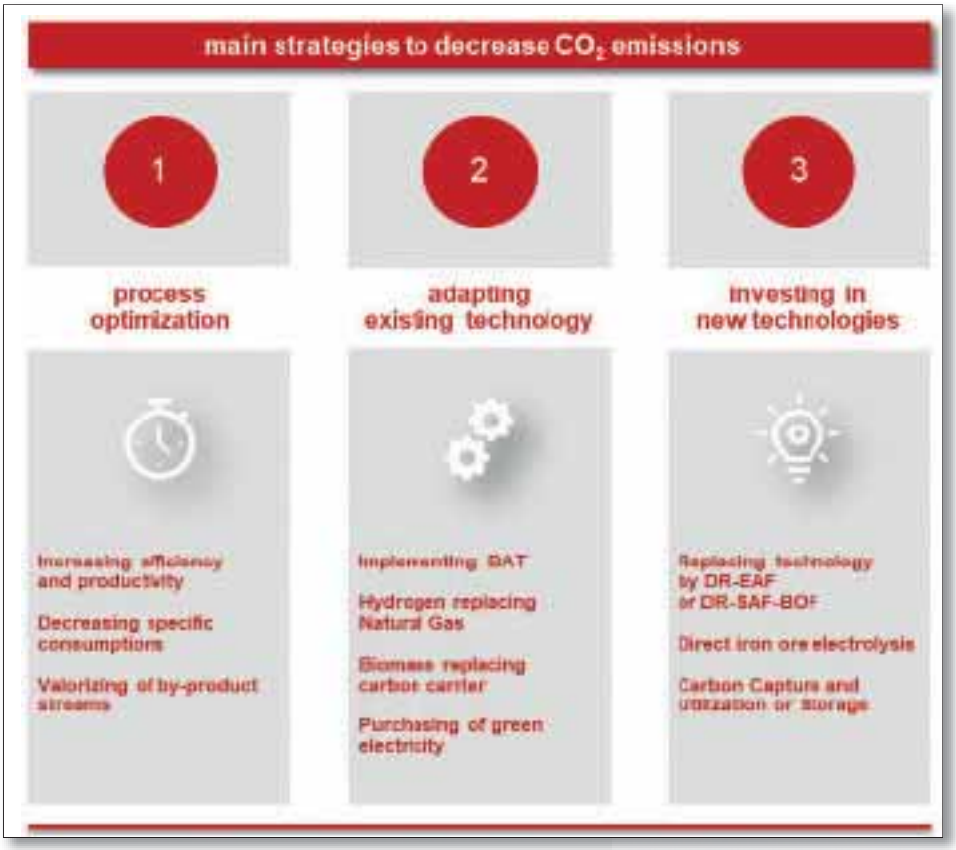

Fig 1 Three main strategies to mitigate CO_2 emissions in the iron- and steel industry [1]

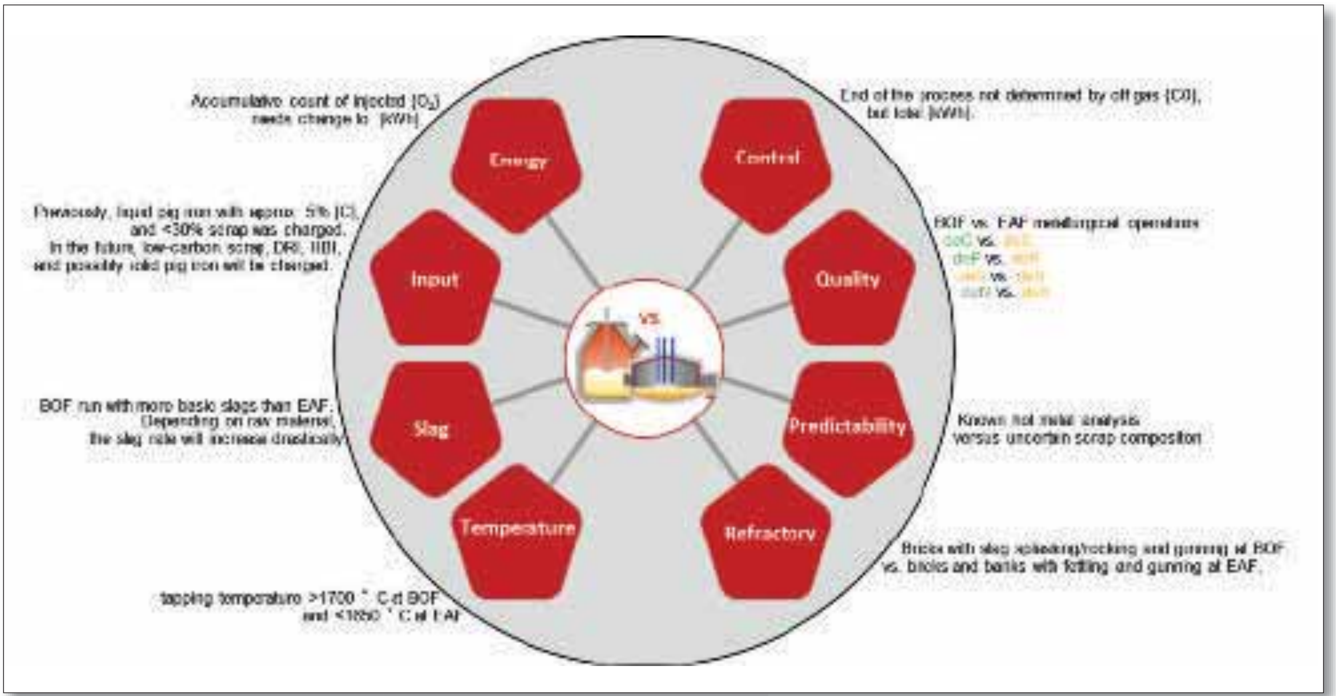

Fig 2 Direct comparison of metallurgical and operational differences in crude steelmaking via BOF (*left*) and EAF (*right*)

Requirements	**Challenges**
Minimized direct CO_2 emissions	• DR-EAF steelmaking is today only possible with natural gas and emits 1.0 ton CO_2/ton steel until green hydrogen is commercially available. • Electricity is mainly fossil coal-based and nuclear energy is in discussion to be a transition energy supply.
Keep the current product portfolio	• Demand on scrap will increase, making it a scarce product. • Scrap quality might deteriorate due to increased amounts of different steel grades with increased amounts of added alloys. • High-grade iron ore is highly demanded but limited. • Iron ore quality in general is deteriorating, which will increase EAF slag volumes and energy consumption when charging DRI/HBI. • Quality demands can be met, but need in-depth analysis on how current specifications can be met with current or modified secondary metallurgy.
Keep the current productivity	• Adjusting furnace specifications and designs with portfolio and logistics and available raw materials. • Unclear development of availability of raw materials and energy sources. Full flexibility is required while working in tight boundary conditions. • Heat size given, but tap-to-tap time of the EAF is different to the BOF, as melting large amounts of ore-based metallic increases EAF melting time. • EAF knowhow and training requirements.
Keep the current location and size	• If green hydrogen is not available, own production must be considered. • Carbon capture and either storage or utilization will be required for the last kg of CO_2, which in return requires additional space and investments. • If the political framework is posing too many hurdles, relocation is a considered option.
Keep current material logistics	• Almost impossible with a smooth transition while keeping current production. If one or a few EAFs are to be built next to BOFs, space is necessary for the vessels, transformers, electricity lines, DR unit(s) with hot link, and a new scrap yard. • Unclear development of availability of raw material and energy sources.
Smooth transition to new technology while continuing production	• Increasing personnel if different vessels (BOF and EAF) need to be run at the same time. • Increase complexity of materials logistics during the transition.

Table 1 **Challenges of meeting the strategic requirements for integrated steel mills to implement the green streel transition [1]**

- Finally, Carbon Direct Avoidance (CDA) at its final stage means Investing in New Technologies (*Figure 1, step 3*), with large investment of billions of Euros, or US Dollars. While step 1 and 2 might be sufficient for steelmakers already operating EAFs, integrated plants cannot avoid step 3.

CHALLENGES OF IMPLEMENTING THE NEW TECHNOLOGY: EAF

Commencing the transition from BOF to EAF operations is a large challenge demanding holistic planning, engineering, and as well as metallurgical and operational understanding – at best years of experience. Beforehand, an internal analysis is necessary to define requirements and their respective boundaries. Simple but effective questions might be self-explanatory, but reveal new challenges underneath. *Table 1* indicates six self-evident requirements and their challenges, whose solutions will influence further decisions.

When all requirements have been clearly defined and the challenges addressed, steelmaking metallurgists in the operations and quality departments must fine-tune these to the reality of EAF steelmaking. While both the BOF and EAF produce liquid crude steel which is refined in secondary metallurgy (LF, VOD, RH, etc.), the circumstances to obtain crude steel are quite different.

An empty BOF is charged with analyzed, liquid hot metal tapped from the Blast Furnace, desulfurized before charging, and with inherent heat. Removing carbon, silicon, and manganese with oxygen further increases the heat and gives the operator a handy control tool in the CO compositional analysis of the off gas. Scrap is charged at up to 30 wt.% to cool the liquid steel bath to a target temperature.

The EAF works quite differently. It starts often with a liquid hot heel of a few tonnes, but its main task is to liquefy cold and solid scrap, pig iron, DRI, or HBI. Possibly some sensible heat might be introduced by preheating these solids, or by a hot-link with a DR unit to obtain hot DRI (HDRI). The energy input is mainly electrical via one DC or three AC graphite electrodes. Electrical energy demand is reduced mainly by using natural gas oxy-fuel burners. Different systems with tiltable burners further improve the chemical energy input. As heat is not easily obtained and needs detainment, foamed slag helps to reduce heat losses.

The main differences between the two operations, BOF and EAF, are further explained in *Figure 2*. Each BOF has its own characteristics and no vessel, nor process equals another. Therefore again, individual conclusions have to be drawn BOF by BOF, steel grade by steel grade, as for the EAF processes as well.

Once the goals are well defined and the process characteristics and demands are clarified, the transformation strategy is faced with the last set of sleep-depriving questions:

- How many EAFs will replace the BOFs?
- Which type of EAF do we need for our circumstances: AC or DC?
- Single-shell or twin-shell EAF?
- Should scrap preheating be in a shaft, a conveyer, or the scrap bucket?
- What tap weight and productivity can I achieve with the feasible tap-to-tap time?
- What about safety, other environmental concerns, and maintenance?
- What is the impact on quality and secondary metallurgy?
- How to evaluate the impact on existing inbound and internal logistics?

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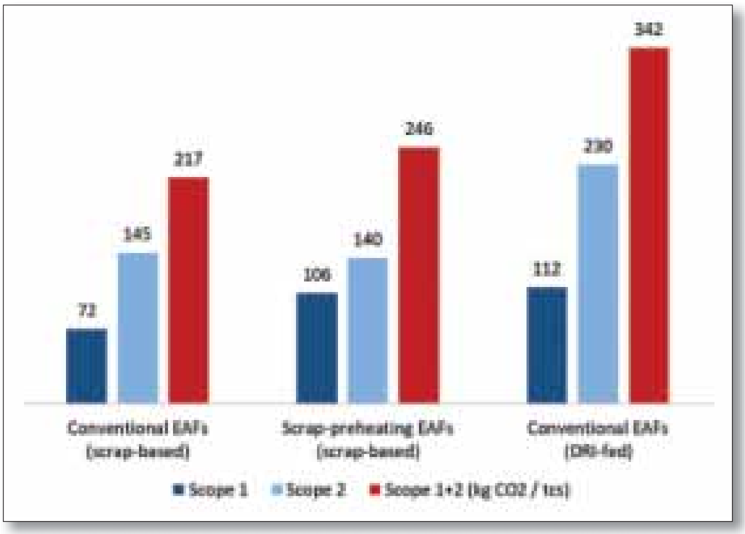

Fig 3 General overview of CO_2 emissions from different EAF technologies [2]

Fig 4 Addressing the challenge in five main areas

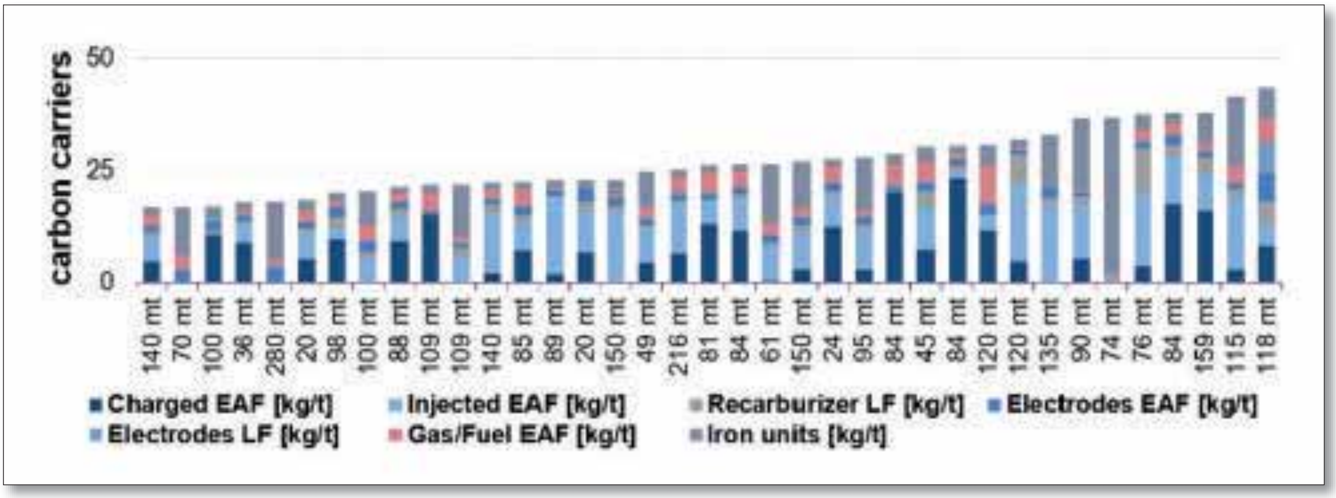

Fig 5 **Benchmarking of different EAF plant carbon carriers' consumption, to identify CO_2 reduction potential**

Based on actual industrial results, a comparison has been made for the three main EAF designs by selecting the most developed and proven concepts, also by the number of installations. Yearly performance data from plants with adequate tap sizes >80t and high performance levels (low power off / high power on time) were selected for the evaluation from the global BSE benchmark. For simplicity and comparability, the same material composition of all carbon carriers were assumed for all plants to calculate the scope 1 emissions. Similarly, for the scope 2 calculation, which is based on the EAF electrical energy consumption, the same grid factor for all plants was used.

Size does not have a major impact within this selection of EAFs, more important is the charge mix. The conventional EAFs in this database achieve 385kWh/t as its average electrical energy consumption, while a well managed EAF can achieve <340kWh/t. The overall effect of preheating results in a lower consumption level of 370kWh/t for the scrap preheating technologies, with vertical preheating EAFs being overall much more efficient. The EAFs using DRI achieve around 500 kWh/t.

The major impact on the required electrical energy consumption is the amount of DRI charged and the melting behavior of DRI, which is strongly related to the composition of the iron ore used for making DRI. BF-grade iron ore pellets are in some cases already in use today, despite the increase in slag amounts. The lowest electrical consumption can only be achieved with Hot DRI. *Figure 3* shows the benchmark's average CO_2 emissions in a direct comparison between the different EAF setups. Scrap-preheating EAFs, both vertical and horizontal, have the clear advantage of lower scope 2 CO_2 emissions, based on the reduced electricity demand due to preheated scrap. The operation itself does result in higher scope 1 emissions than conventional EAFs which overall increases the sum of scope 1 and 2.

STRATEGIES TO MITIGATE RISKS AND CAPTURE OPPORTUNITIES

To address all these challenges and initiate mitigation strategies, the operational challenges have been subdivided into five main areas as illustrated in *Figure 4*.

Long gone is the time when flat products were solely produced via the BF-BOF route. Over many years, we have seen that DRI-fed EAFs with operational tools and suitable secondary metallurgy can achieve similar if not the same qualities.

Product quality and the availability of raw materials are the first concern for a technological transition. Second, the mastery of the metallurgical process and procedures, utilizing the necessary and equipment and tools, is itself dependent on the products and raw materials. One example for both points is the iron content, and consequently the gangue content, of iron ore pellets for direct reduction, which determine the impact of DRI and HBI on yield and slag rate in the EAF.

Tight nitrogen specifications can be met with shortened boring periods and proper carbon

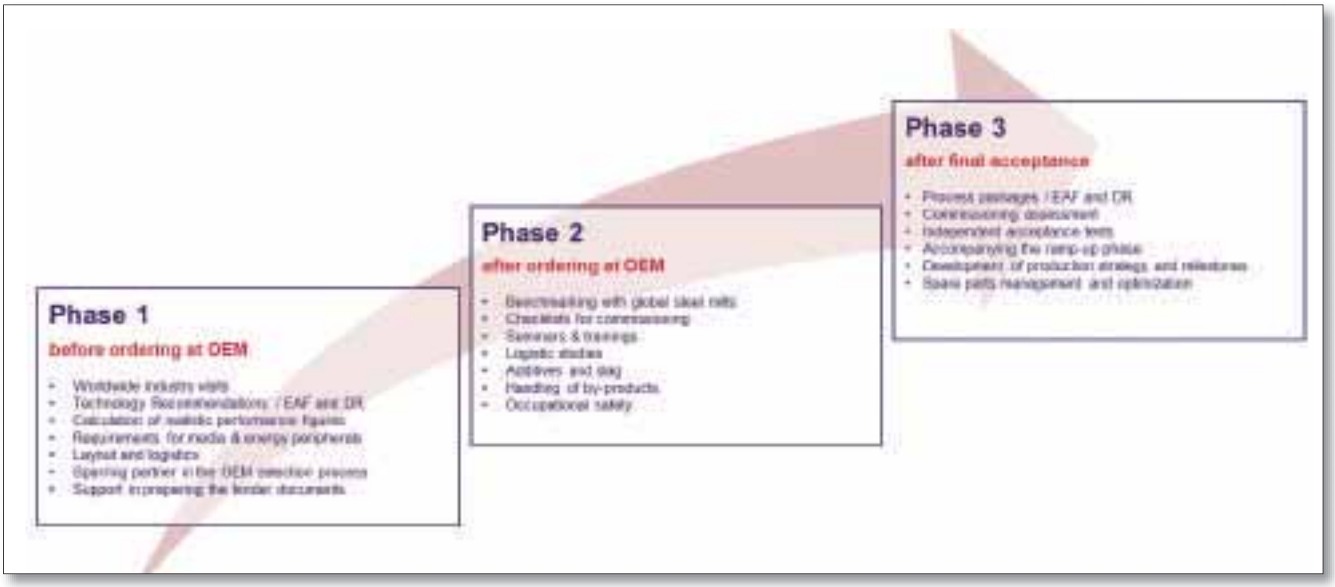

Fig 6 **Various needs and respective options to address them at different stages of the ordering and implementation process**

boiling, either with pig iron, or DRI/HBI, with excess carbon to finalize the reduction of the remaining iron oxide. Dephosphorization can be enhanced with respective slag procedures that could even include double slags. Desulfurization will need to move from hot metal desulfurization to steel desulfurization in secondary metallurgy. These examples depict the flexibility the EAF offers.

The considerations outlined above can be characterized as relating to productivity and cost, enabling an evaluation of what is economically feasible and reasonable. However, safety is also a top priority and must not be overlooked. We cannot afford to expose employees to mitigatable risks and so proper protocols, well maintained equipment, and investment in safety equipment are essential. Today, it is no longer necessary to manually introduce oxygen via a lance through an open slag door, or to manually fill an EBT or ladle well block with filler sand. The risk of water in scrap can be avoided and there are well proven concepts for water cooled parts in the EAF, like spray-cooled roofs, side panels, and off-gas ducts, that reduce the risks of explosions to a bare minimum.

Finally, the environment is the reason for starting this endeavor. Even when operating an EAF there are scope 1 and scope 2 CO_2 emissions of up to 500kg/t of crude steel. Depending on the energy input of electricity, natural gas, and other carbon carriers, the potential exists to reduce this for the top performers to less than 85kg/t (*Figure 5*).

CONCLUSIONS

There are manifold and powerful options to lead the green steel transformation. Navigating through these options becomes easier with the guidance of experienced hands and cutting through the jungle with clear, but not less than profoundly built plans. Each transition project has its own characteristics and dynamics and is for itself unique and never light. Embedding elements of consultancy in each step will help to realize a successful green steel transition timely and within budget (*Figure 6*). **MS**

REFERENCES

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