Fig 1. In co-operation for the development of 'crafted scrap,' Primetals Technologies and SICON are working to automate and digitalize the scrap handling process to improve logistics, chemical purity, and pre-sorting.

The era of hybrid steelmaking

While pressures to decarbonize the steel industry continue, increasing scrap rates and hybrid steelmaking can transform the traditional integrated steel route, reducing emissions and maintaining quality. By **Bernhard Voraberger[1], Dr. Gerald Wimmer[2], and Benjamin Kradel[3]**

THE global reality of climate change has placed increasingly intense pressure on the steel industry. As a producer of nearly 10% of global greenhouse gas emissions and second in worldwide coal consumption, decarbonization has become a primary focus for major steel producers[1]. Currently, the traditional integrated steel production route – i.e., BF-BOF (blast furnace-basic oxygen furnace) route – makes up 70% of steel production globally.[2] With a continued focus on new and innovative ways to decrease CO_2 emissions related to steelmaking, including innovative use of scrap and direct reduced iron, the electric arc furnace (EAF) is often the solution of choice for "green steel" production. However, as the industry transitions towards environmentally friendly steel production, increased scrap usage will also impact traditional integrated steel production. As scrap use and decarbonization become more than just talking points, expanding the scrap rate will impact BOF operations and EAF use, ushering in the era of hybrid steelmaking.

Challenges facing BOF steelmaking

The traditional integrated route, which includes blast furnace and basic oxygen furnace steel production, presents ample opportunities to reduce overall CO_2 emissions from steelmaking. One area that has received an exceptionally high amount of attention is the production of liquid hot metal due to the high amount of CO_2 emissions associated with this step in the process. By reducing iron using natural gas or, in the future, hydrogen, iron and steel producers can see a significant reduction in carbon emissions. Yet decarbonization for the BF-BOF route presents a different set of challenges.

Increased scrap use is the most immediate solution for reducing CO_2 emissions in BOF steelmaking. As scrap-based EAF steelmaking becomes more present worldwide, it will require massive investments. Many challenges accompany the introduction of EAFs into existing integrated plants – e.g., plant logistics and layout changes. Considering the demands of implementing an EAF, it will be essential to reduce the carbon footprint of the existing integrated plant to maintain capacities in the short term and during the transition to electric steelmaking. Higher scrap rates in BOF steelmaking will be one of the first steps to decarbonize existing plants. However, several considerations face steel producers regarding an increased scrap rate in BOF steelmaking.

Firstly, scrap contamination presents an immediate problem for both EAF and BOF steel production. Often containing residual elements such as copper (Cu), tin (Sn), chromium (Cr), molybdenum (Mo), and other harmful elements such as sulphur (S) and phosphorus (P), the steelmaking

1. Head of technology and innovation for converter steelmaking, Primetals Technologies Austria GmbH
2. Vice-president converter steelmaking, Primetals Technologies Austria GmbH
3. Head of technology and innovation for electric steelmaking, Primetals Technologies Germany GmbH

Fig 2. Interface of the BOF Optimizer Level 2 process model for simulation and control. The calculated temperature, carbon, and silicon content are shown in the upper diagram. Slag composition, blowing patterns, and schemas for additional material are illustrated in the lower diagrams.

process cannot remove many of these elements – e.g., copper.[3] Thus, an increase in scrap rate logically means an increase in contaminants, often limiting the steel grades available for scrap-based production (see **Fig. 1**). While this issue primarily affects scrap-based EAF operation, an increase in scrap use will also impact BOFs. Thankfully, developments are underway at Primetals Technologies to improve and advance scrap sorting and reduce the number of residuals and creating "crafted scrap.[4]"

However, scrap availability and logistics also present another set of challenges. Scrap logistics and handling of increased volumes at plant level means expanding the size of the scrap chute or using a second scrap chute. Raising the amount of scrap processed will lead to increased charging time, extended process times, increased crane use, and potentially transforming plant logistics entirely, resulting in additional costs.

Finally, the amount of scrap usable in a BOF is limited due to the energy required to melt the scrap. Unlike electric steelmaking, the BOF does allow for external energy input. Still, it relies on chemical reactions, such as the heat from the hot metal and the combustion of carbon and silicon. So, increasing the scrap rate from 15–20%[5], e.g., up to 25%, requires additional energy in a BOF. Despite this, scrap shows immense potential to reduce the combined BF-BOF CO_2 emissions by lowering the amount of hot metal in the BOF.

Decarbonizing BOF steelmaking

Several innovative solutions present themselves to help steel producers increase their scrap rate in the BOF as they transition to reach their decarbonization goals. The first of these goals focuses on heat and process optimization for BOF steelmaking. Using Level 2 process models and online heat scheduling, the BOF Optimizer from Primetals Technologies allows fast and accurate pre-calculations and simulations (see **Fig. 2**). Covering off-gas analysis, an automatic blow stop, and extreme accuracy for achieving carbon targets and temperature, avoids reblows and improves the use of scrap as a coolant.

Scrap preheating using a preheating lance presents an opportunity to improve scrap rate and raw material flexibility. While scrap is typically charged to the BOF without heating, scrap preheating uses a burner lance with natural gas. The preheating lance can also preheat the converter after relining or during standby times. A preheating lance can increase the scrap rate by around 8%, thanks to increased energy input. However, this process does increase the tap-to-tap time since preheating takes about 10 to 15 minutes.

Another innovation that enables higher scrap rates is the dual flow post-combustion lance, comparable to an oxygen blowing lance, with a second port for additional controlled oxygen and inert gas blowing. With the dual flow post-combustion lance, the post-combustion degree is nearly doubled, leading to higher energy in the liquid steel bath. The secondary port focuses on the combustion of carbon monoxide from the bath, wherein the primary oxygen jet focuses on the combustion of carbon. The lance design ensures that the heat generated by the post-combustion returns to the liquid bath allowing for an increase in heat transfer

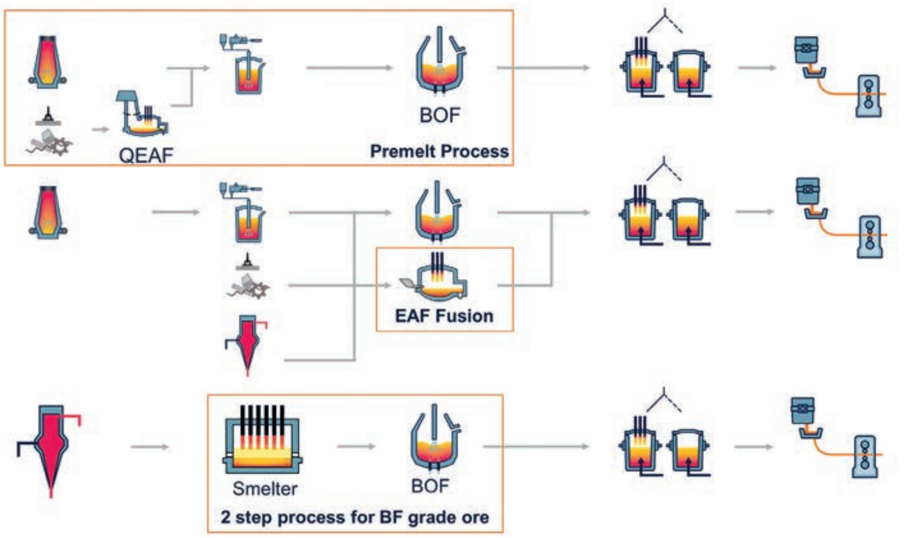

Fig 3. Hybrid EAF-BOF plants and various routes for transforming blast furnace grade iron ore-based integrated steelmaking. The upper diagram illustrates the PREMELT process, the middle diagram depicts the parallel operation of an EAF Fusion and BOF, and finally, the two-step process for blast furnace grade ore, utilizing a smelter to produce liquid hot metal.

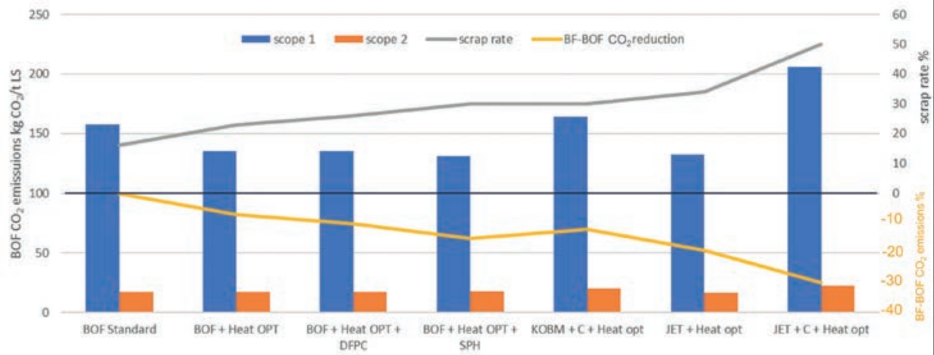

Fig 4. Specific CO_2 emissions (Scope 1 and Scope 2) per ton of liquid steel (LS) for different solutions, including possible scrap rate and potential reduction in total BF-BOF CO_2 emissions. Variations are likely, based on individual operating conditions.

efficiency, resulting in an increased scrap rate of approximately 4%. The advantage of this solution is that the blowing rate remains the same; thus, total blowing time is unaffected, meaning an increased scrap rate with constant productivity.

For the highest scrap rates, converting a traditional BOF to a combined blowing converter – i.e., KOBM – is required to ensure sufficient mixing. A KOBM provides intensive bath mixing and ensures uniform scrap melting, faster slag formation, increased yield, and post-combustion. With a KOBM, scrap rates up to 30% are possible. For even higher scrap rates, Primetals Technologies developed the JET process, combing a bottom blowing converter with coal and lime injection and a hot blast lance[6]. In one instance, at POSCO, heats with up to 50% scrap ratios proved immensely successful. However, an increase in the BOF scrap rate will only reduce emissions by as much as the scrap rate can be reached, and due to various limitations, the BOF will never be able to operate using scrap entirely. Therefore, a combination of technologies is required to reduce CO_2 emissions further.

The era of hybrid steelmaking

While a combination of technologies will no doubt lead to improved decarbonization for the steel industry, steel producers often consider transforming their entire process from BOF steel production to an EAF. However, comparing BOF and EAF steel production is challenging due to their distinct characteristics. An EAF is highly flexible regarding its charge mix thanks to external electrodes, which can melt up to 100% scrap, HBI, or DRI. For a BOF, scrap rates of 30% are feasible when applying the previously mentioned solutions, or even 50% in the case of the JET process for a KOBM. However, questions of steel quality may also come into play regarding the charge mix. There are several steel grades, such as external automotive grades, where scrap-based EAF steelmaking falls short of industry standards.[7] Yet, as steel producers seek solutions to decarbonize their entire production process, combining steel production routes may be the most viable stepwise transformation.

Primetals Technologies is developing the PREMELT process (see **Fig. 3**), wherein an electric arc furnace melts scrap and DRI to mix with the hot metal from the blast furnace to then be charged into the BOF converter. A 100% solid charge mix is standard in the premelting phase since the EAF focuses only on melting. Premelting is ideal for BOF heat sizes of 300 tons or more, where the cost of replacing the BOF with an EAF would incur extensive expenditures. The PREMELT process can also be placed outside the steel plant, leaving pre-existing plant logistics intact.

The solutions for the PREMELT process are also flexible. An induction furnace is applicable for smaller heat sizes, and for larger heat sizes, an EAF is preferable. The EAF Quantum, which includes scrap preheating using off-gas, is an ideal solution for producers looking to use high amounts of scrap to reduce their carbon footprint. For plants looking to transition away from blast furnace operation and focus on scrap and high-grade DRI steelmaking, the EAF Fusion offers a comparable heat size to the BOF and would melt and refine the steel. However, in the case of the EAF Fusion, changes in logistics, layout, and steel quality would have to be considered.

Approaching zero

By increasing the scrap rate for BOF steelmaking, steel producers can immediately reduce their Scope 1 and Scope 2 $C0_2$ emissions (see **Fig. 4**). Scope 1 includes direct emissions, e.g., combustion processes, and Scope 2 includes emissions, for example, from electricity consumption[8]. In an optimized BOF, scrap rates can increase up to 25%, seeing an immediate reduction in Scope 1 emissions. Using a dual flow post-combustion lance, the scrap rate can be increased even further. However, CO_2 emissions from the BOF remain relatively constant, but still see a reduction in BF-BOF carbon emissions. Heat optimization with scrap preheating will increase process time and may increase Scope 1 emissions slightly, but the reduction in overall CO_2 emissions is still more significant. Finally, a KOBM featuring the JET process with heat optimization can reduce traditional BF-BOF CO_2 emissions by 20%. The JET process also means scrap rates of 30–50% in the BOF. Ultimately an increase in scrap rate benefits the reduction of CO_2 emissions in existing BOF operations.

Close to zero emissions?

Yet, as decarbonization continues to occupy steel producers worldwide, adding an EAF to integrated steel plants would allow an increased reduction in CO_2 emissions and ease the transition toward electric steelmaking. Close to zero CO_2 emissions will only be possible with scrap-based electric steelmaking powered by 100% renewable energy or green hydrogen-based direct reduction (see **Fig. 5**)[9]. As steel production transforms and the era of hybrid steelmaking commences; a smart combination of technologies and strategic adoption of solutions will define the path forward for industry leaders.

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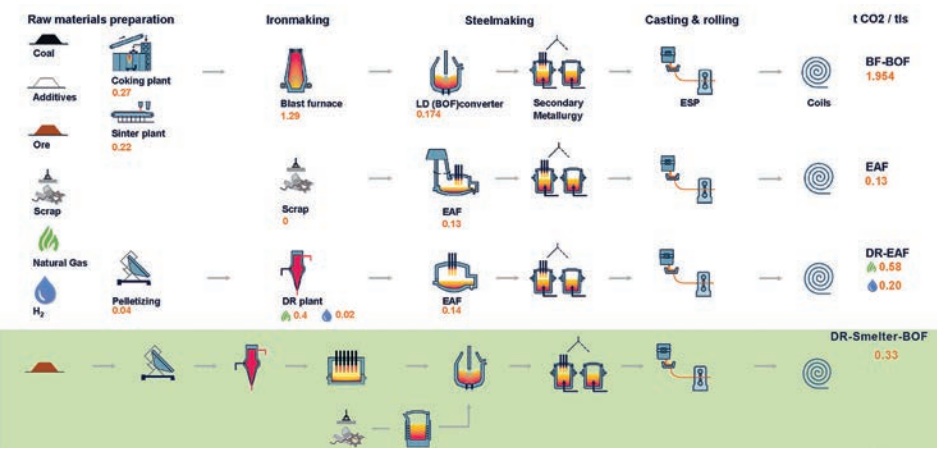

Fig 5. From the BF-BOF integrated steel route to a hydrogen-based direct reduction route with an EAF, reduction in CO_2 emissions also shows immense potential through the integration of a smelter, arriving below natural gas-based direct reduction in terms of overall emissions.