Factors Affecting Throughput and Configuration of an Open Bath Furnace for the Production of Hot Metal

BY

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SYNOPSIS

The decarbonization of steel production is of urgent importance to support the limitations on global warming stipulated in the Paris Agreement. Multiple technology options are emerging in the race to minimize the historically CO_2-intensive iron production stage. One leading candidate is the combination of the well-proven direct reduction of iron ore using a shaft furnace and an open bath electric furnace (OBF). The OBF technology stands out as a viable candidate to significantly lower the CO_2 footprint of the iron making stage, meeting many criteria that other technology options are not immediately able to satisfy.

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Introduction

The steel sector is the second largest industrial CO_2 emitter, and responsible for approximately 7% of global CO_2 emissions.[1,2,9] Given the Paris Agreement of 2015, the decarbonization of steel production is of urgent importance to support the limitations on global warming.[3] In the steelmaking value chain, targeting CO_2 reductions in the ironmaking stage of the conventional blast furnace (BF) - basic oxygen furnace (BOF) route offers the largest opportunities. The BF-BOF route accounted for 71 % of global steel produced in 2021 as indicated in **Figure 1**.[4] With an average footprint of 1,9 t $CO_{2,\ eq.}$ per ton of crude steel[7,8], decreases in emissions of this dominant sector offer the largest reduction potential.

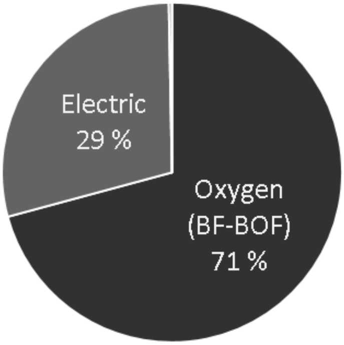

Figure 1: Share of world crude steel production by technology route in 2020.[4]

In the context of the South East Asian market, access to high grade ores is limited. There is also growing pressure on localization of ore usage, confining some countries in the region to deriving value from the ore grades within their territories. Therefore, strategies that are emerging in other global markets with access to high grade ores may not be suitable to South East Asian steelmakers.

Multiple technology options are emerging in the race to decarbonize iron production[5]. But to be a viable short- to medium-term candidate in the period up to 2050, the technology must:

1. Offer substantial CO_2 footprint reductions against the conventional BF-BOF route.
2. Be in a state of immediate technology readiness.
3. Be capable of producing millions of tons of hot metal per annum.
4. Be capable of producing value-adding slag as a by-product.
5. Replace ironmaking plants on existing sites to allow brown fields adaptation whilst integrating with existing upstream routes for shortest time to market of the resultant steels.
6. Offer an operational cost base comparable with existing processes.
7. Offer proven versatility in processing low-grade iron ores.
8. Offer opportunities for future adoption of non-fossil utilities and raw materials such as hydrogen and bio-carbon.

In the race to carbon neutrality, the technologies that meet the above listed criteria are limited. One leading candidate is the combination of the well proven direct reduction of iron using a shaft furnace operating on natural gas (direct reduction plant/DRP), in conjunction with an open bath electric furnace (OBF).

This paper aims to firstly emphasize the immediacy of the need for mature technologies to initiate and sustain steel decarbonization. And secondly to suggest the OBF as a candidate for short-term deployment by summarizing its key attributes and advantages.

THE TASK AT HAND

The immediate steel decarbonization task is substantial. The International Energy Agency (IEA) projects that the global steel industry has to cut total emissions by at least 50% by 2050.[2,9] However, despite stagnant or even slightly decreasing steel consumption per capita globally, overall demand is expected to rise due to population growth until at least 2050.[2,7,10] In consequence, *specific* emissions will have to decline even more to at least 60% to meet *total* emission targets.[2] The corresponding scenarios developed by the IEA can be observed in **Figure 2**.

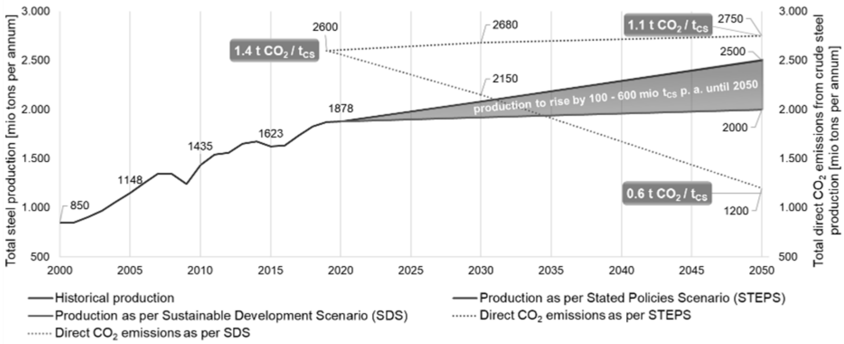

Figure 2: Possible future world crude steel production with corresponding CO_2 emission targets.

When comparing current national net zero targets with their respective national integrated steelmaking production in 2021, a staggering 35 - 37 million tons of production have to decarbonized every single year from today until 2050 in order to meet those net zero targets (**Figure 3**).

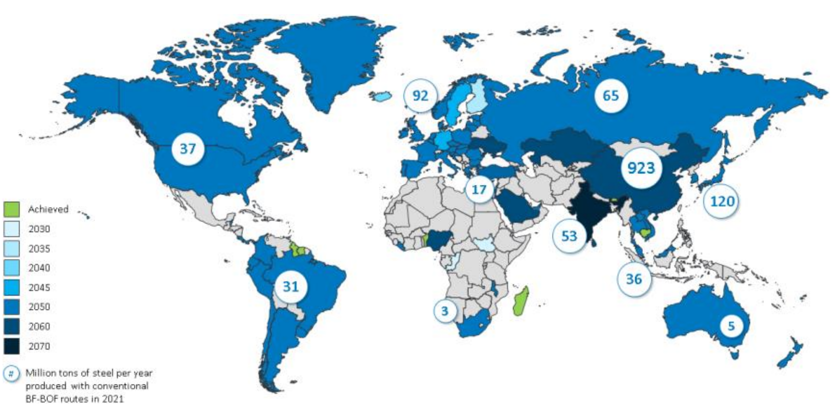

Figure 3: Crude steel production by BF-BOF route per region in conjunction with national/regional net zero targets.[4]

Increasing scrap availability and recovery rate, coupled with a shift towards a larger share of secondary steelmaking will enable a portion of these emission cuts to be achieved based on available technology and processes.

However, the finite availability of steel scrap puts a limit on this emission reduction potential. High quality/low-gangue ore feed for natural gas or hydrogen based direct reduction and immediate melting in an electric arc furnace (NG DRI-EAF or H_2 DRI-EAF route) suffers from the same problem, but with projected declining raw material availability and quality. As per **Figure 4**, the IEA foresees a total production share of 380 million tons per annum based on direct reduced iron, of which more of 50% would have to be processed in electric reduction smelters due to insufficient high-grade ore supply for economic EAF melting.

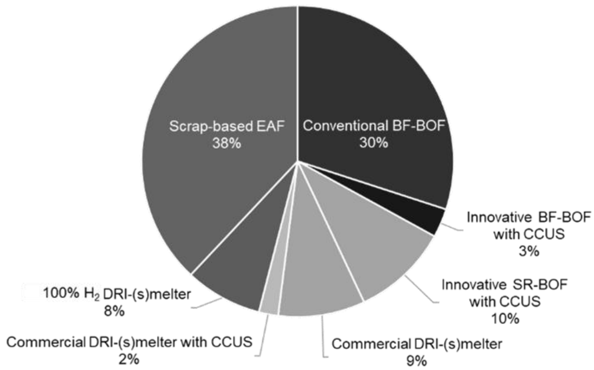

Figure 4: Estimated shares of steel production by route in 2050 by a total forecast of 2000 mio t_{CS} p.a.[2]

Experience and Short Term Enablers for Steel Decarbonization

Against the backdrop of the immense task at hand, it is clear that immediate progress must be made. To successfully deploy a large-scale DRP-OBF plant in the short term, qualifying suppliers should demonstrate key attributes that are already entrenched in their organization:

1. Foundational knowledge of the design and operation of the BF-BOF route.
2. In-house knowledge of the design, construction and operation of DRPs and electric reduction smelters.
3. Proven references for the DRP at high throughputs utilizing low-grade iron raw materials.
4. Proven references for high-powered electric reduction furnace technology.
5. Proven references for best available technologies in emission reduction and granulation.

As a leading supplier of steelmaking plants, the SMS group is uniquely positioned to offer a significantly decarbonized ironmaking route. This ability rests on the multi-process knowledge base summarized in **Figure 5**, complementing the above listed drivers for short term deployment of DRP-OBF plants.

To complement the strong grounding in each of the foundational elements of the DRP-OBF technology route, SMS group has to date undertaken numerous *Green Iron* studies for leading international steel producers looking to identify decarbonization roadmaps for their individual sites and circumstances. Each of these studies is unique, with no one-size-fits-all solution for each client nor for each site.

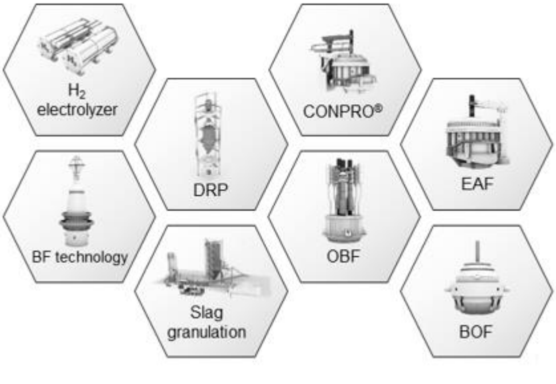

Figure 5: SMS group‘s technology portfolio for the primary stage of steelmaking

At a macro level, the region in which the plant is located is driving the decarbonization timeline, affecting the availability and price of feed stocks and utilities, determining the future links to green power and hydrogen networks, and driving the technology selections to manage the “green” handling of waste streams.

Additionally, the regional price of CO_2 emissions and the impact of regional import and/or export barriers for high CO_2 footprint steels will continue to alter the medium- and long-term operational expenditure of certain production routes.

The SMS group’s combination of the key enablers to immediately deploy an ironmaking alternative, coupled with the growing experience in practical application of this technology to real-world sites, makes us a leading partner for short-term decision making and execution to decarbonize existing integrated-, or green field steel plants.

Open Bath Furnace Technology and its Suitability as a Major Ironmaking Alternative

A key advantage of the DRP-OBF is that it can be adopted within the integrated route, or installed on a green field’s site. The combination of the DRP and OBF replaces the BF and its associated sintering-, stove- and coke facilities.

The ideal combination of a DRP and associated OBFs is to have both installed immediately alongside one another. This enables the DRI to be fed at an elevated temperature directly to the OBF, making use of the sensible energy to lower the specific energy consumption. A typical flowsheet is shown in **Figure 6**.

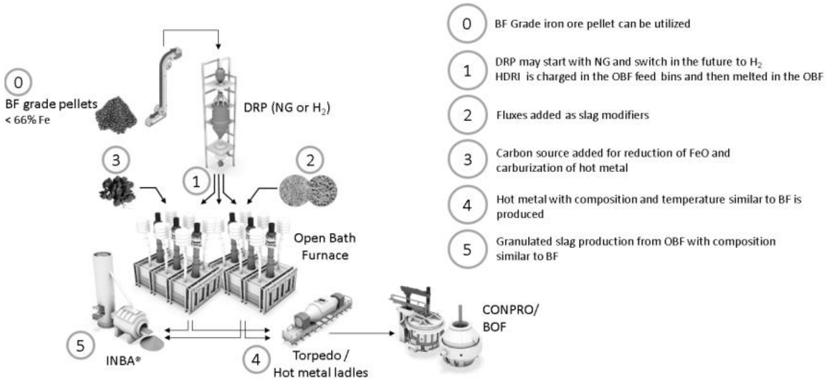

Figure 6: Simplified flow sheet for DRP-OBF integration.

The upper limit on OBF throughput from a single vessel is constrained currently at circa 1.5 million tons per annum (mtpa) hot metal production [6]. The current proven ceiling on shaft furnace DRP production is 2.5 mtpa DRI. This presents a potential mismatch in DRP and OBF capacities. Thus multiple OBFs are required above 1.5 mtpa. **Figure 7** shows common DRP unit capacities and the proposed OBF configuration to suit.

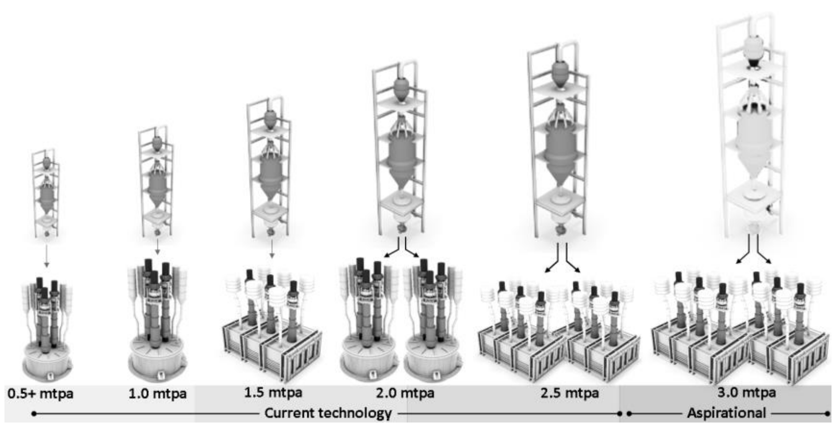

Figure 7: Throughput and configuration of common shaft furnace DRP units with associated OBFs.

A viable arrangement for configurations employing DRP capacities above 1.5 mtpa is a freestanding DRP linked via hot feed conveyor to at least two OBFs. **Figure 8** presents a layout of two rectangular OBFs associated with a 2.5 mtpa DRP. An alternative configuration linked to a 2.0 mtpa DRP could be two circular OBFs as shown in **Figure 9**. Either configuration could satisfy the required throughput, with the final decision often resting on the particular needs of a given site and the envisaged mix of raw materials.

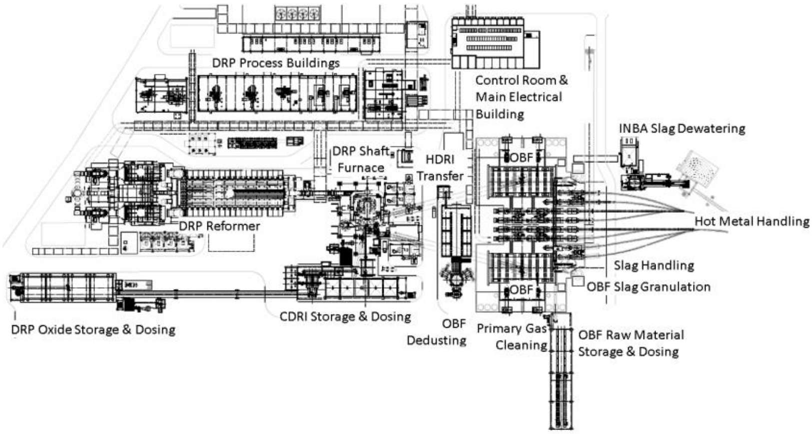

Figure 8: Configuration of two rectangular OBFs linked to an associated 2.5 mtpa DRP (DRP layout published with consent of Midrex).

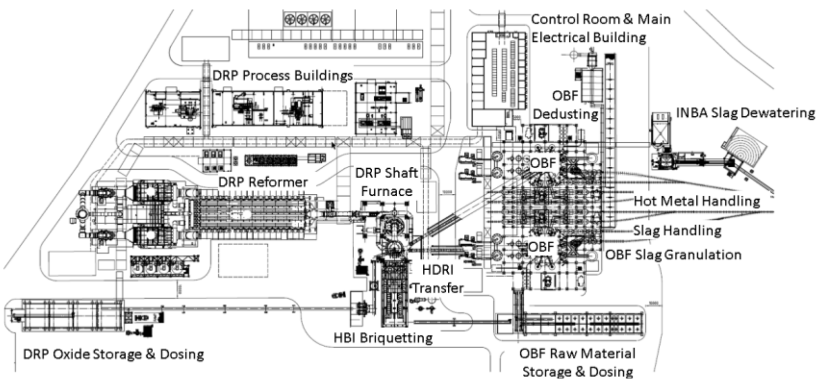

Figure 9: Configuration of two circular OBFs linked to an associated 2.0 mtpa DRP (DRP layout published with consent of Midrex).

The OBF does have the distinct advantage that it can be uncoupled from the upstream DRI production step, which may be of particular interest in the South East Asian market. The OBF can accept metallic feed in the form of HBI or cDRI that is produced in an alternative location and transported to the site at which the smelting takes place.

Another advantage is that the products of the OBF largely mimic those of the blast furnace. As seen in **Table 1** and **Table 2**, both the hot metal and slag properties are comparable with blast furnace products. Specifically for the slag, fluxing agents can be dosed to the OBF to fine-tune slag composition. In addition, the DRP-OBF process is not limited to feed from a high-quality oxide pellet source. The nature of the reducing environment in the OBF means that the DRP-OBF combination can consume BF-grade pellets with higher gangue quantities and still deliver high yields and BF-type slags with FeO contents less than 1 wt.-%.

Table 1: Element composition of blast furnace hot metal and OBF hot metal.

Element	Blast Furnace [wt.-%]	Open Bath Furnace [wt.-%]
C	4.5	4.5
Si	0.75	<0.5
Mn	0.13 – 0.15	0.14
S	0.02 – 0.025	0.025 – 0.03
P	0.10 – 0.12	0.02 – 0.03
Fe	94.6 – 94.8	94.7 – 94.8
Tapping temperature	1,480 – 1,500 °C	1,490 – 1,510 °C

Table 2: Composition of blast furnace slag and OBF slag.

Slag component	Blast Furnace [wt.-%]	Open Bath Furnace [wt.-%]
CaO	41 – 43	40.5 – 41.5
SiO_2	37 – 38	36.5 – 37.5
MgO	7.3 – 7.5	7.0 – 7.5
Al_2O_3	10.5 – 11.0	10.5 – 11.0
FeO	0.3 – 0.5	0.6 – 0.7
S	0.75 – 0.80	0.50 – 0.60
MnO	0.15 – 0.20	0.20 – 0.25
***TiO_2**	0.60 – 0.65	0.50 – 0.60
Other	0.8	2
Tapping temperature	1500 – 1550 °C	1550 °C

* TiO_2 in the final slag is driven by the feed materials.

Figure 10 presents the range of suitability of global iron ores mined for the EAF and OBF process. The span suitable for the OBF is seen from iron ore sources with a total iron content as low as 58 wt.-%$_{Fe}$ to those of the highest quality.

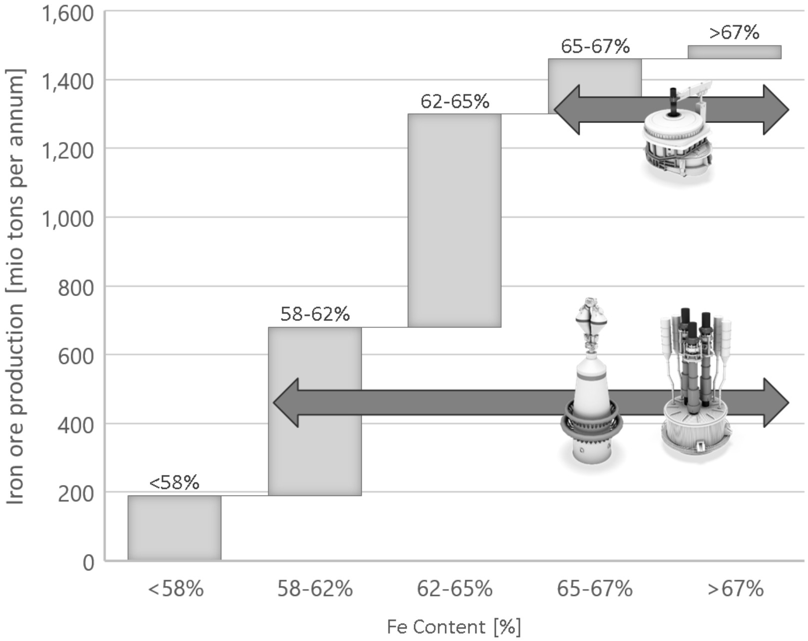

Figure 10: Distribution of global iron ore production by iron content with given ranges of suitability for the EAF and OBF process.

In addition to the hot DRI fed to the OBF, up to 10 % of the OBF material feed can be comprised of agglomerated waste or free-flowing scrap as shown in **Figure 11**. This allows steel plants to consume wastes arising from their existing facilities by utilizing an inexpensive agglomeration process to prepare these for addition to the furnace. BOF sludge and mill scale are popular considerations, as well as any waste streams high in fluxing components such as CaO. The addition of waste and scrap to the furnace does come at a power penalty, with 1% waste feed accounting for an increase in OBF real power of between 2 - 3% [6].

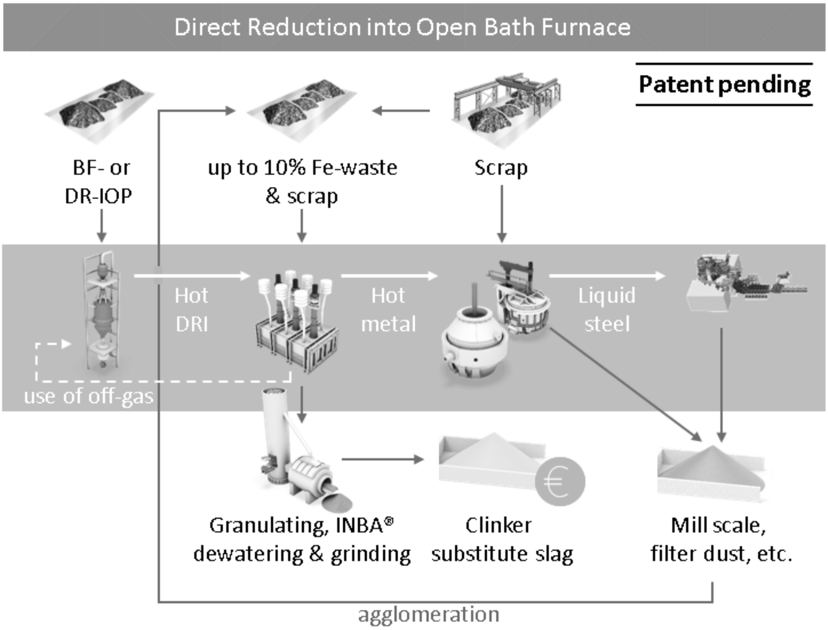

Figure 11: DRP-OBF valuation chain indicating the circulation of waste and scrap.

The ability to generate a BF-type slag that can be used as a clinker substitute by the cement industry is not a factor to be overlooked. It offers the plant owner a desirable, sellable by-product, thus improving OPEX potential, and reduces the CO_2 footprint of the cement industry downstream significantly.

Given that multiple OBFs are required to accept and process the HDRI feed from the largest DRPs, an inherent benefit is the flexibility of the hot metal tapping. Multiple tap holes, tapping sequences and quantities can be adjusted to exactly match the downstream steel plant requirements, with a reduced dependency on the hot metal buffering typical of existing blast furnaces.

Conclusion

The Paris Agreement's limitations on global warming and regional net-zero goals place steel producers under immense pressure to decarbonize rapidly. Accompanied with forecasted rising steel demand, the current CO_2 footprint of the dominating integrated steel route has to be lowered. This can be achieved by reducing the emissions of the CO_2-intensive ironmaking stage. The market-ready combination of the DRP-OBF offers the production of suitable quantities of high-quality hot metal that can be integrated into existing steelmaking sites. Moreover, this technology can be deployed immediately to assist in the realization of short term decarbonisation goals. In the future, further CO_2-reduction will be possible in the same DRP-OBF plants through integration of (green) hydrogen and bio-carbon sources.

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