NEAR-TERM EMISSIONS REDUCTION FOR BLAST FURNACE OPERATION

THE TRANSITIONAL STEPS TOWARDS CARBON NEUTRALITY

Colin Morrison
Martin Smith
Primetals Technologies Ltd.
MetalRussia Magazine
2021

INTRODUCTION

The global challenge faced by all steelmakers to eliminate greenhouse gas (GHG) emissions, reduce raw material and energy consumption in pursuit of carbon neutrality is well documented. The route to achieving this is less clear and will be different for most producers. With around 7-10% of industrial GHG emissions being attributed to the steel industry and 70% of the total global steel production reliant on thermal reduction via the blast furnace / basic oxygen steelmaking route, replacement of carbon-based fuels will be necessary. Hydrogen as a reduction agent is seen as the natural successor.

Improvements in the circular economy of steel to increase the availability of high-quality scrap and support the transition to the electric arc furnace as the primary production route is also underway. Alternatively, complimentary processes such as carbon capture and storage (CCS) or utilization (CCU) could negate discharge to atmosphere. The final picture is likely to be a complex combination of these options for many steelmakers as this transformation evolves.

IMMEDIATE CHALLENGES

Whilst there appears to be a general acceptance of the global imperative and requirement by steel producers to change, the technologies and infrastructure to do so are not fully realized. Availability and utilization of higher proportions of hydrogen, plentiful supplies of cheap ‘green’ energy, high quality scrap and mass-capture and utilization of emissions remain frustratingly distant technical and economically viable options for operators. In each of the routes, there are substantial hurdles both technically and commercially to facilitate a change at pace. This is in addition to what could be considered an overwhelming financial investment.

Summarizing the forward-outlook:

- Decline in dominant BF-BOF route to ~45% by 2050
- DR–EAF increase to 18% (1/3 ‘green’ share) by 2050
- Carbon capture expected to be 270 Mt per year by 2050
- 45% Renewable power cost drop by 2050
- 75% Electrolyzer CAPEX reduction by 2050
- Reduction in price of green hydrogen:
    - < $3/kg by 2030
    - $1-2 / kg by 2040 ie ‘**Green’ hydrogen unlikely to be competitive before 2035**
- Decarbonization expected to increase steel costs by $100/t or more (*source: IEA*, *2020*)

It is probable that significant undertakings by governments, businesses and consumers globally will be required to provide both the legislative and commercial drivers to ensure the shift can happen to meet the ambitious, international goals set out. This will take lengthy and protracted negotiation, resulting in extended timescales to realize the necessary outcomes. What can be concluded therefore is that the movement to new steelmaking routes is coming, but not today or tomorrow and more likely not within the next decade.

CO_2 EMISSIONS – MITIGATING MEASURES

When considering how emissions are expected to reduce, it is anticipated that the overall scenario will take until approximately 2035 to begin to develop and realize meaningful impact from the applied technologies:

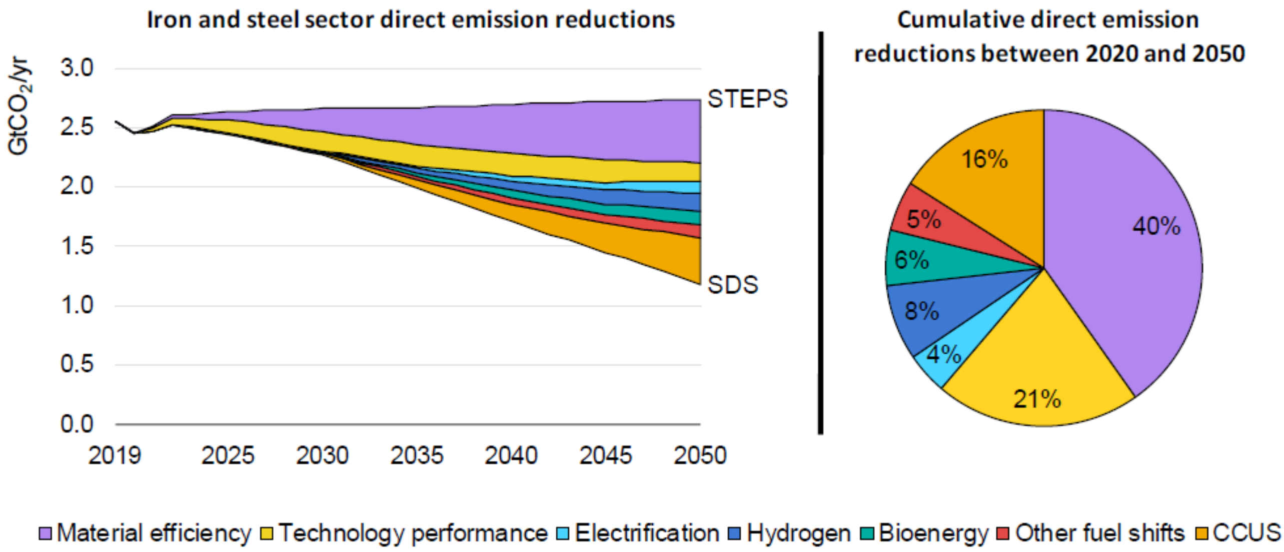


Figure 1: Iron and steel sector direct CO_2 emission reductions in the Sustainable Development Scenario by mitigation strategy

Source: IEA, 2020

Material efficiency technologies (those that reduce steel demand) alongside technology performance play the most significant role through the entire transition period. Summarizing the development of mitigation, available technologies that enhance existing asset performance will continue to be key to steelmakers and only in the longer term will these begin to make way to new process routes and innovations that can deliver at scale eg hydrogen-based ironmaking and carbon capture, storage and utilization.

THE IMMEDIATE CONCLUSION

Clearly then, the challenge for blast furnace operators to accelerate this transition is immense - but they must continue to produce competitively in the interim. Whilst the task seems daunting, it also presents opportunities where the greatest gains can be made. The blast furnace represents the single highest contributor to the production of GHGs in the process route. As carbon trading markets continue to rapidly develop, operators are facing increasing cost pressure based on their existing footprint. Many have already declared their own ambitious plans but must act now. The reality remains that there is desperate need for effective technologies to support their roadmap towards carbon neutrality. Implementing technology that can have a significant impact in the blast furnace would represent a major stepping-stone for operators globally.

Whilst the fundamental characteristics of the blast furnace have changed little over the last 100 years or so, designers and operators have implemented incremental developments for the main vessel and process equipment. This has continued to push the productivity to ever higher levels, whilst simultaneously reducing hot metal cost. Lower fuel and energy input alongside optimization of raw material quality have become paramount. In the current environment, carbon scope costs, widening climate-goal awareness and sensitivity to climate-based topics generally are increasingly influencing markets and consumers such that every marginal gain allows operators the opportunity to enhance their competitiveness.

What if that gain could be achieved now whilst also complementing and making significant contribution towards a carbon neutral production?

REDUCING BLAST FURNACE CARBON EMISSIONS

Blast furnace operators can currently utilize a number of key technological solutions to reduce carbon emission as operators must simultaneously maintain their assets whilst developing their longer-term transitional plans. Some of these are available now whilst others are emerging and require additional research and development to realize the theoretical potential. The list is not exhaustive but is seen as a realistic categorization for steelmakers that would fall within the realms of technological and economic viability within the timescales described:

Category	**Technology/Process**	**CO_2 Reduction Potential**	**Developmental Status**
Reduction with materials and gas	Sequence Impulse Process (Tuyere O_2 Pulsing)	2%	Available
	HBI/ scrap feed	10%	Available
	COG injection	7%	Available
	Expert System	2.5%	Available
	H_2 injection	20%	In development trials
Reduction with available technology	Copper Stave Hexagonal Inserts	1%	Available
	Stove optimization & WHR*	6%	Available
	Top-gas recovery turbine (TRT)	2%	Available
	TRT & MERIM Dry dedusting system (DDS) with increased TRT efficiency	1.5%	Available
	Dry slag granulation WHR	2%	Demonstration plant

*WHR = Waste Heat Recovery

Through a combination of technological and material/gas alterations to the blast furnace process, it is anticipated that CO_2 emission could be reduced by as much as 40%. In terms of the CAPEX expenditure against benefit, there is a need to understand a potential for rapid payback to be effective in the limited operating window through the transitory period:

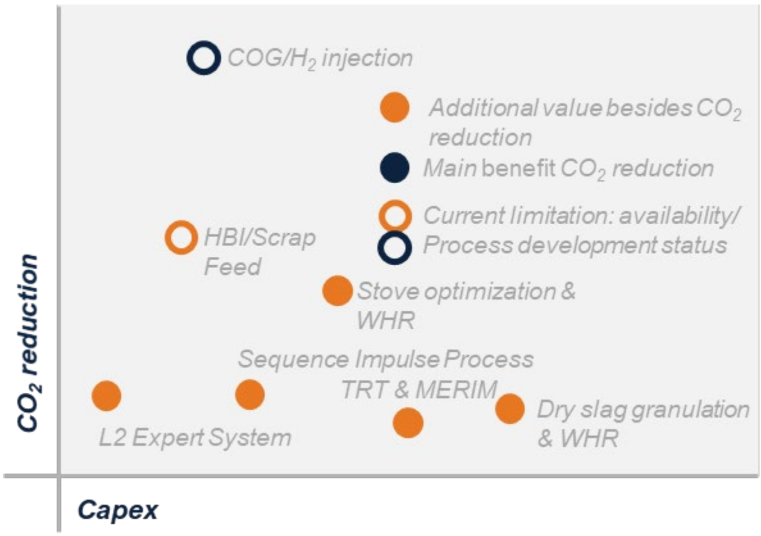


Figure 2: Relative CAPEX versus CO_2 reduction potential

Source: Primetals Technologies

CURRENT TECHNOLOGICAL OPTIONS – BENEFITS & CHALLENGES

Expert System

Use of an expert system is a well-established means of using process feedback loops to tune operational characteristics and optimize material and energy consumption. As such, they will not be the focus of this topic.

ALTERNATIVE MITIGATION PROCESSES AND TECHNOLOGIES

Newer methodologies and technological advances are now making in-roads to become options for future CO_2 mitigation steps. These come with specific benefits and challenges for their implementation:

SEQUENCED IMPULSE PROCESS – TUYERE OXYGEN PULSING

The Sequence Impulse Process was developed by thyssenkrupp AT.PRO. tec GmbH and successfully adapted for blast furnaces from proven foundry furnace applications.

Transfer of the technology to blast furnaces from initial inception in 2007 culminated in a full-scale system installation on Schwelgern blast furnace 1 at the Duisburg plant of thyssenkrupp Steel Europe. Operational start-up took place in December 2020. Primetals Technologies was granted a world-wide, exclusive license for the marketing, sales and project implementation using the technology in Summer 2021.

TECHNOLOGY PRINCIPLE

Coal injection into the blast furnace results in char (unburnt) materials accumulating, such that penetration of the ‘dead-man’ of coke is restricted. This limits the flow distribution into the center of the furnace and reduces gas utilization.

By pulsing high-pressure oxygen in a pre-determined sequence to each tuyere, shock waves penetrate deep into the raceway of the blast furnace, combusting the fine char and improving coke permeability.

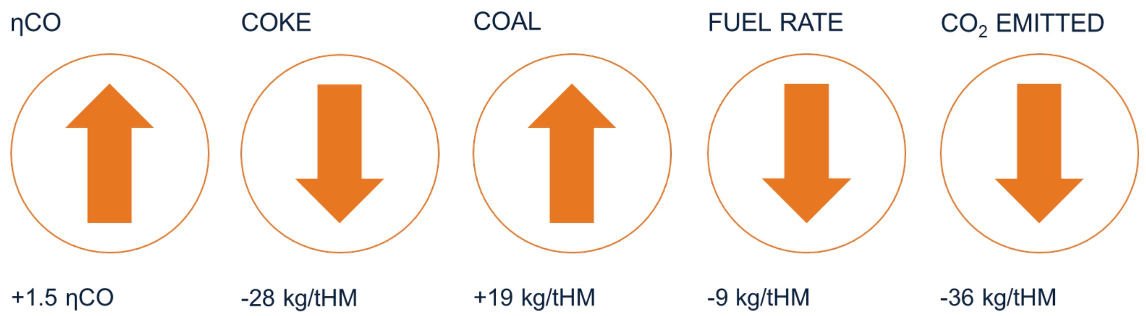
This improves gas utilization and the potential for better furnace drainage.

The control of the system with regard to pulse frequency and the admission of individual tuyeres is freely selectable and depends on the furnace operation.

Economically, the use of the technology at the blast furnace is expected to allow more cheap injection coal to be used in exchange for more expensive coke. In addition, the reduction of less thermally converted coal particles can be expected to improve the throughput and drainage, which ultimately leads to increased production.

Operational Results

Once fully operational the benefits of process were quickly apparent as experienced at Schwelgern. Overall fuel rate was reduced with the accompanying emitted CO_2 benefits:



Source: thyssenkrupp Steel Europe

RETURN ON INVESTMENT

Based on the process OPEX benefits, rapid payback can be achieved, typically between 12-18 months for fuel replacement only (dependent on furnace productivity, coke, injected coal, and utility costs):

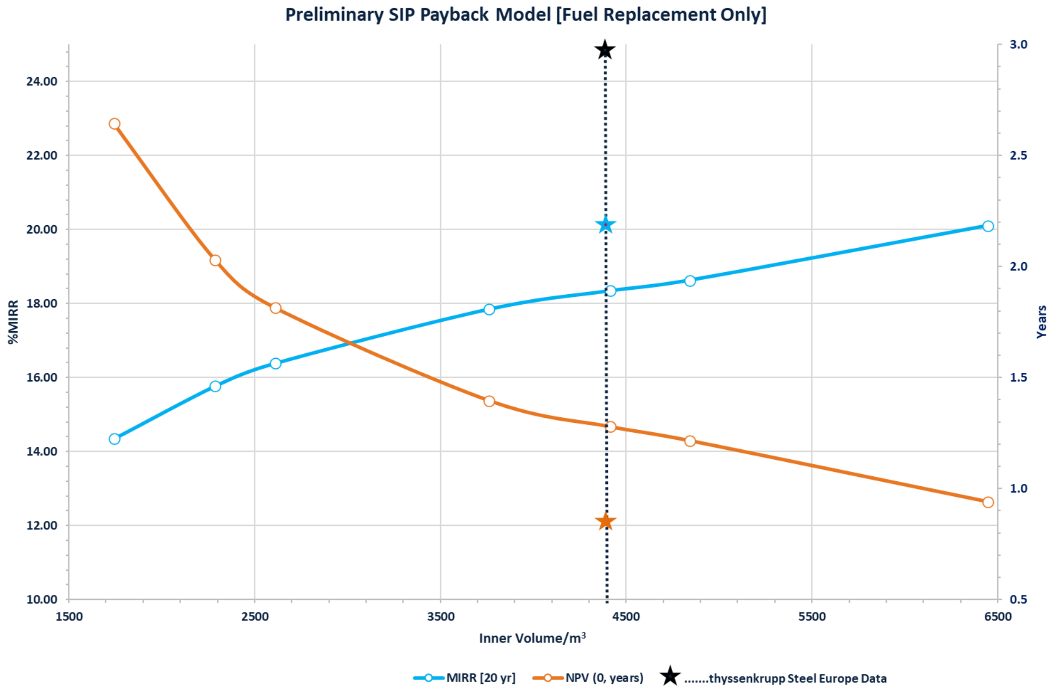


Figure 3: Typical Sequence Impulse Process Payback [Fuel Replacement Only]

Source: Primetals Technologies

Where CO_2 emission can also be credited, payback can be achieved with 12 months as demonstrated by the Schwelgern blast furnace 1 data:

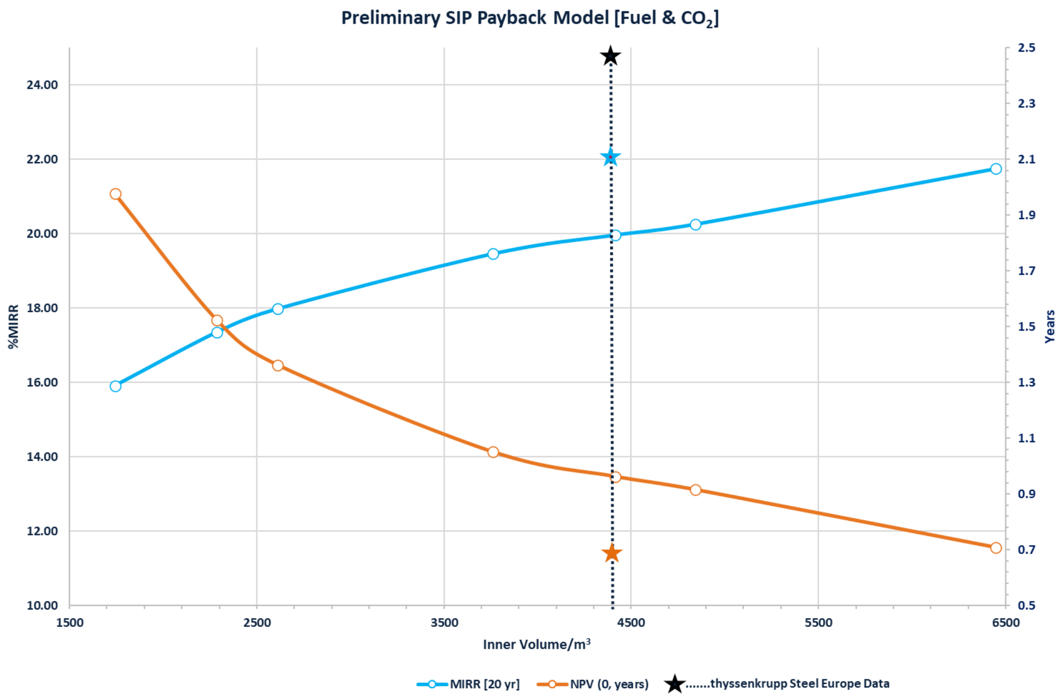


Figure 4: Typical Sequence Impulse Process Payback [Fuel Replacement & CO_2 benefit]

Source: Primetals Technologies

HBI CHARGING

Extensive tests for HBI charging have been carried out by POSCO/Korea, voestalpine/Austria, Baosteel/China. In addition, one blast furnace in the US (AK Steel, Middletown) has been operating at a typical level of 250 kg/tHM for more than 20 years. Kobe Steel suggest that 300kg/tHM is theoretically viable.

For the blast furnace process, the effects of HBI charging are proven. Such effects described are:

- Increase of BF productivity

  +8% for each +10% increase in burden metallization but cost penalty for raw material. This does afford the operator flexibility in targeted production level as it could be increased to meet peak metal demands

- Reduced coke consumption and therefore, reduction of emitted CO_2

Based on tests at voestalpine that were carried out together with Primetals Technologies, approx. 50,000 t of HBI have been charged to the blast furnaces in Linz and Donawitz/Austria. The reaction of the process to the HBI charging have been found in line with the literature. The productivity increase was confirmed as was coke consumption. For the larger furnace, the reduction was less significant as coke consumption was already close to the minimum, being mainly structural in supporting the burden. The CO_2 reduction goes in proportion with the coke consumption.

A major consideration required is then the transportation of HBI with specific design requirements that must be observed to ensure material quality and long-term equipment integrity. Primetals Technologies has specific experience in this design.

voestalpine is continuing to use HBI from their Midrex HBI plant in Corpus Christi, USA.

COG INJECTION

COG injection at the tuyere level can substitute coke/PCI/natural gas/heavy oil/plastics and supplies additional reduction gas to the blast furnace. The cooling effect of COG to the RAFT is low when compared to, for example natural gas.

However, increased COG injection also increases the demand for a higher coke quality in order to maintain good furnace permeability.

Primetals Technologies has installed a COG injection system at blast furnaces 5 and 6 of voestalpine in Austria in 2003 which is still in operation and a COG injection for a BHP blast furnace in Port Kembla, Australia.

Key considerations of the system design are the cleaning of the COG and the appropriate compression system which demands significant investment for suitable equipment.

Clearly, however, availability is the major stumbling block for the majority of blast furnace operators so COG injection would be attractive where spare gas can be given over to injection into the furnace. Being a rich fuel, COG is conventionally utilized within the site network for enrichment and reducing energy import. If the COG were to be utilized in the blast furnace, such re-purposing would demand alternatives be employed as replacements, potentially increasing overall costs.

H_2 INJECTION

The basic idea of Hydrogen injection into a blast furnace is to reduce the amount of coal required for injection and to replace it by Hydrogen to reduce CO_2 emissions as the combustion product is water vapour. Theoretical investigations show that a CO_2 reduction of approx. 15-20% can be achieved vs. a PCI rate of 120 kg/t HM. Investigations conducted in the US have found the theoretical limit, thought to be in the region of 40kg/tHM cannot be practically achieved for a number of reasons that impact on furnace stability and fuel rate. It is anticipated that perhaps 25-27kg/tHM will be the upper limit.

Trials for Hydrogen injection into a blast furnace have been carried out at thysenkrupp Steel are now progressing to a full-scale system with a capacity of just under 12kg/tHM.

Current hydrogen generation costs (high electricity requirement) clearly identify PCI operation as more cost effective when considering CO_2 emission costs although this will shift in the future-looking scenario.

COPPER STAVES WITH HEXAGONAL WEAR-RESISTANT INSERTS

Primetals Technologies has developed a revolutionary technology for use in copper stave coolers that not only provides long operational life against wear from the descending burden but has also been seen to deliver OPEX benefit through energy savings.

Capture of burden material which protects the softer, copper stave material provides an insulative layer which reduces energy loss to the cooling circuit.

The equivalent coke consumption reduction has been calculated to be typically in the range of 3-5kg/tHM and can be more in the periods of process instability. The requisite emitted CO_2 reductions would accompany this.

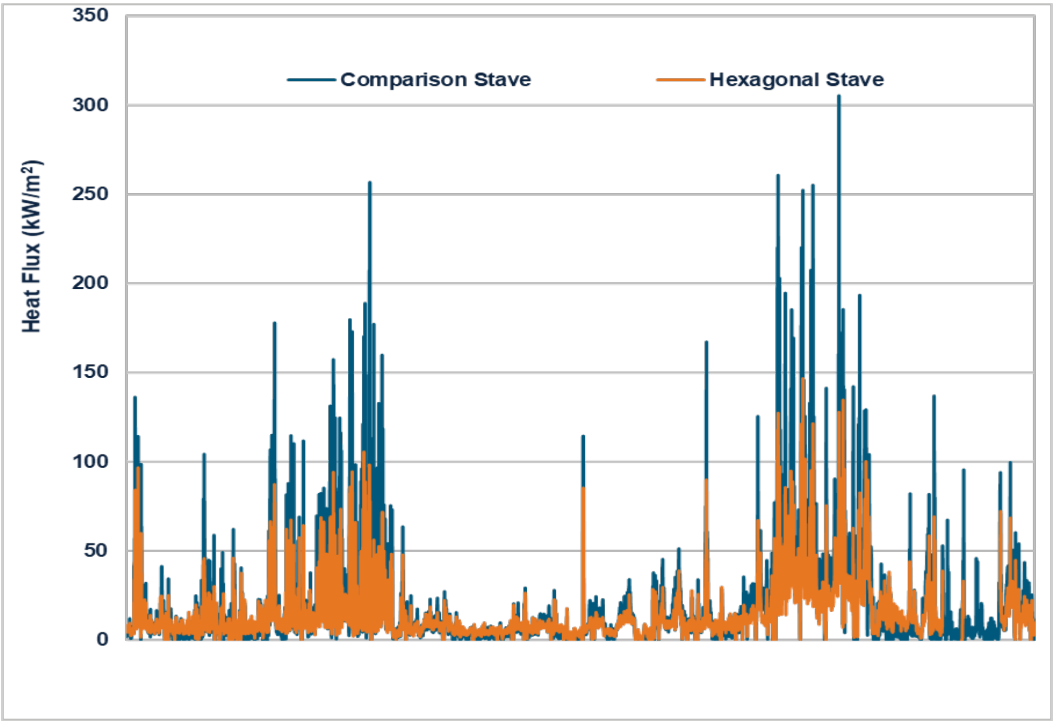


Figure 5: Operational Data: Hexagonal Inserts Performance against a conventional, comparison stave

Source: Primetals Technologies

Test stave data, January to December 2020

Period	Hexagonal Stave (GJ)	Comparison Stave (GJ)	% heat load difference	Coke saving kg/tHM*
Overall (330 days)	842	1111	32%	3 – 5
Stable Operation (283 days)	534	626	17%	2 – 3
Unstable period (54 days)	216	345	60%	4 – 8

* depending on coke quality, productivity, etc.

TOP-FIRED, HOT BLAST STOVE TECHNOLOGY & WASTE HEAT RECOVERY/OXYGEN ENRICHMENT

Hot Blast Stoves and the ancillary processes offer the blast furnace operator a multitude of opportunities to reduce fuel consumption leading to the additional associated lowering of emitted CO_2.

To expand their current technology portfolio, Primetals Technologies have begun a collaboration with Yuxing to bring Top-Fired Hot Blast stove to a wider global market.

The unique features of the top-fired design mean that the Dome to Straight-line Hot Blast Temperature can be greatly reduced from that observed in either conventional, internal, or external combustion chamber hot blast stoves. This means for the same stove thermal capacity; higher blast temperature can be achieved leading to coke savings in the furnace.

A reduction of 20kg/tHM can be achieved with the associated emitted CO_2 benefits.

Additionally, an exceptional environmental performance in terms of NOx is achieved.

Where this can be done in conjunction with Waste Heat Recovery to heat the fuel/air mixture to the stove, further savings are possible in enrichment fuel consumption or stove size optimization which potentially realizes significant CAPEX savings through reducing the required thermal mass of refractory or shell and structural steel necessary for a particular stove and the specified duty.

If enrichment COG fuel could be saved, there is the potential to repurpose the fuel in the blast furnace as described previously.

SUMMARY

The Blast Furnace will remain as a key ironmaking unit in the near mid-term as a minimum as operators evaluate and engage in transitioning to alternative steelmaking routes. To achieve the ambitious goals set out with regards CO_2 emission will demand transition at an unprecedented pace and scale as well as enormous political and commercial will. Inevitably, this will result in ongoing uncertainty for operators. Some have already committed to stringent limits sooner than the 2050 end point for climate change limitation. As such, their ambition means they must act now.

Competitive hydrogen and green energy in necessary volumes/infrastructure remains more than a decade away and conversion in the interim will therefore rely on specific emission mitigation-driven investment. This dictates that operators will be required to source and implement available, proven technological solutions at scale with rapid payback potential.

Primetals Technologies offers a superior portfolio to support blast furnace operators in this endeavor.

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