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Addition of Scrap and DRI/HBI to the Blast Furnace — Technology to Overcome Top Temperature Limits and Reduce Greenhouse Gas Emissions

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ABSTRACT

Addition of scrap or direct reduced iron (DRI) to blast furnaces has known benefits for increasing productivity and decreasing coke rate. DRI additions to the blast furnace have been revisited to reduce blast furnace CO2 emissions. Carbon taxes may motivate DRI/scrap additions to reduce CO2 emissions. Technology changes are needed to overcome the challenges of low top gas temperature. In this paper, the maximum amount of DRI and scrap that can be added to a blast furnace operation and the related carbon dioxide savings are estimated, and hot N2 injection to the mid-stack to increase top gas temperature to allow for higher DRI/scrap additions is considered.

Keywords: Blast furnace, scrap, direct reduced iron, hot briquetted iron, greenhouse gas emissions, plasma torches

INTRODUCTION

Direct reduced iron (DRI) and hot briquetted iron (HBI) are added to electric arc furnaces (EAFs) to dilute scrap residuals; added to the basic oxygen furnaces to displace purchased scrap; or added to the blast furnace to decrease coke rate and increase productivity (Bolen, 2014). DRI production in the United States is of increasing interest due to very low natural gas prices that will prevail for many years to come. In Europe, the imperative to reduce carbon dioxide emissions has renewed interest in adding DRI/HBI directly to the blast furnace to reduce its carbon consumption. In the USA, scrap or iron-rich residues have been added to blast furnaces to increase productivity in periods of strong steel demand and high prices. The merits of adding scrap and DRI to blast furnaces to reduce CO_2 emissions has not been well documented.

Alternative iron units (AIUs) including DRI, HBI and scrap are high cost raw materials for the blast furnace. As a result, few blast furnaces have sustained experience adding AIUs. AK Steel, U.S. Steel and ArcelorMittal Lazaro Cardenas have historically added AIUs to their blast furnaces. Using AIUs has economic merit where the plants are truly hot metal limited, steel prices are elevated and the hot metal-to-scrap ratio in the basic oxygen furnace has been optimized.

Starting in 2017, Austria's voestalpine charged 70 - 160 kg of HBI/t HM to their Linz blast furnaces, in part to meet European Union CO_2 reduction targets (Griesser, 2018). The benefits to voestalpine included increased blast furnace productivity and decreased consumption of blast furnace reducing agents (i.e. coke equivalent). Other blast furnace trials charging HBI have been completed but few of these trial results have been reported in the literature.

In addition to the high cost of AIUs added to the blast furnace, there are technical barriers that limit the addition rate. The blast furnace top gas temperature decreases below industry accepted limits when large amounts of HBI and/or scrap are added to the furnace. The reduced coke rate results in less process gas and thermal energy available to heat and reduce the ferrous burden. The viable operating window shrinks, especially if the blast furnace injects natural gas and enriches the blast with a substantial amount of oxygen.

This paper is presented in three parts to describe how to overcome the blast furnace technical limitations related to adding AIUs. Firstly, the prior art regarding AIU additions is briefly reviewed. From this, the energy shortfall as increasing amounts of AIUs are added the blast furnace is estimated. Lastly, stack injection of hot gas using electrically powered plasma torches is evaluated as a strategy to overcome this energy shortfall and enable greater AIU addition rates. The analysis focuses on North American blast furnace practice using an all-pellet burden and natural gas injection. DRI and HBI will be used interchangeably; the authors recognize that HBI is the preferred form of direct reduced iron to be charged to blast furnaces due to its ease of handling and large size compared to DRI pellets.

PART 1 – EXPERIENCE ADDING DRI/HBI AND SCRAP TO THE BLAST FURNACE

The Iron and Steel Society (ISS) book "Direct Reduced Iron Technology and Economics of Production and Use" is the most commonly cited reference on the benefits of DRI, HBI and scrap added to the blast furnace (Ostrowski, 1999). Data was compiled from experimental and plant-scale blast furnaces between 1964 and 1994 from the U.S. Bureau of Mines, U.S. Steel, Stelco, AHMSA and Armco, Figure 1.

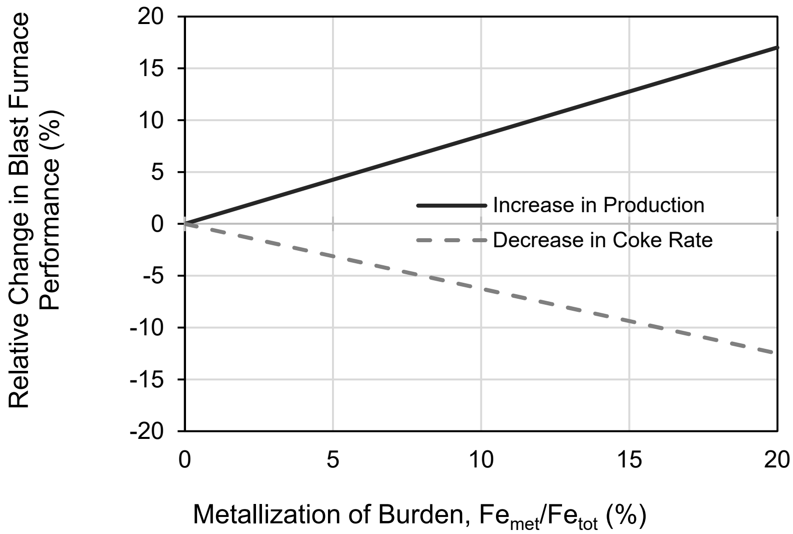

Figure 1: Impact of a metallized burden on blast furnace productivity and coke rate (Ostrowski, 1999)

From Ostrowski's analysis, for every 10% metallization of the burden; an 8% productivity increase and 7% decrease in coke rate was realized at the blast furnace. These changes in production and coke rate were used to quantify the benefits of adding AIUs presented in this paper.

Blast furnace operating window and impact of metallic iron additions with natural gas injection

Gibson and Pistorius (2015) and Jampani and Pistorius (2014) showed that when greater amounts of DRI are added to the blast furnace burden, the operating window for a viable furnace operation decreases as the natural gas injection rate is increased, as shown in Figure 2.

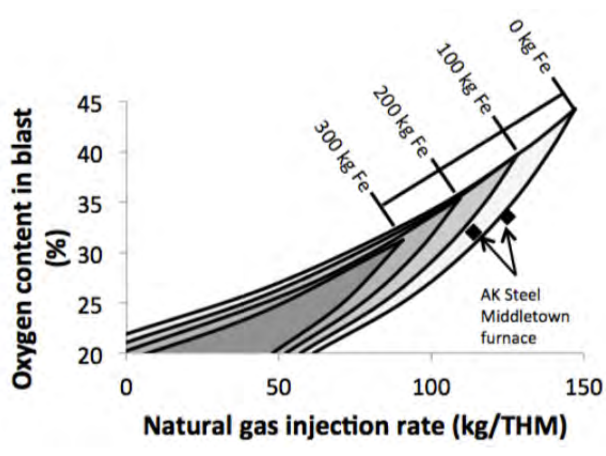

Figure 2: Changes to the acceptable blast furnace operating window with metallic iron additions and natural gas injection (Gibson and Pistorius, 2015)

Figure 2 was reproduced from Gibson and Pistorius' 2015 paper and considers a minimum top gas temperature of 110 ºC, a minimum raceway adiabatic flame temperature (RAFT) of 1850 ºC and a blast temperature of 1100 ºC. Natural gas is injected cold and consumes energy as it forms CO and H_2 in the raceway. The raceway flame temperature decreases as the natural gas injection rate increases; this is compensated for by increasing the oxygen content of the blast air. The bosh gas nitrogen content drops, the top gas volume decreases, and there is less enthalpy available to dry and heat the incoming burden materials resulting in reduced top gas temperature. As more metallic iron is added, the coke rate further decreases, less reducing gas is produced and its contribution to the heat balance further decreases. The viable blast furnace operating window shrinks, as illustrated in Figure 2 by Gibson and Pistorius.

The use of blast furnace grade pellets in the direct reduction process

Compared to the standard direct reduction (DR) shaft furnace - EAF process route, processing high gangue DRI is viable when the resulting DRI is charged to a blast furnace. DRI added to a blast furnace can lower the CO_2 footprint as it replaces carbon-in-coke with hydrogen-in-natural gas to reduce the iron bearing minerals to metallic iron. The additional gangue is converted to blast furnace slag that can be granulated and sold to the cement industry rather than being rejected as tailings at the iron ore concentrator. Slag cement is a well-established way to reduce cement industry CO_2 emissions.

Midrex (Battle, 2013), Essar (Mukherjee, 2010) and Ravnushkin (1998) reported on using lower grade iron ore pellets in a DR shaft furnace. DR grade iron ore pellets are more expensive than blast furnace pellets due to their higher iron content as additional costs such as grinding, and flotation are required to produce a DR grade pellet. These investigators determined that lower and less costly blast furnace grade iron ore pellets could be used to produce DRI and HBI with adjustment to the shaft furnace design and operating conditions. Details are available in the referenced materials.

The use of scrap in blast furnace burdens

U.S. blast furnaces have charged various forms of ferrous scrap to increase hot metal production. The scrap is usually low grade with 75-85% metallic Fe, the balance being FeO and other products of scrap oxidation. The scrap must be in a form that can be charged to the blast furnace. Common forms include granular material such as mill scale or other Fe-rich residues; cracked engine blocks to create small pieces that can be handled; and screened shredded scrap. Usage is driven by economic considerations; as a result, scrap usage can vary widely from year-to-year. AK Middletown Blast Furnace 3, ArcelorMittal Lazaro Cardenas BF1 and the four blast furnaces at U.S. Steel Gary Works are notable locations that have long-term experience with scrap additions from 100-200 kg/t HM.

voestalpine's experience charging HBI to the Linz blast furnaces

In part to meet European Union CO_2 reduction targets, voestalpine constructed an HBI plant in Corpus Christi, Texas and charged some of the resulting HBI in voestalpine's blast furnaces 5 and 6 in Linz, Austria (Griesser, 2018). When HBI was added at rates from 70-160 kg/t HM, blast furnace productivity increased, and the reducing agent consumption decreased. Griesser reported a reducing reagent reduction of 22-27 kg/t HM when 100 kg HBI/t HM was charged, which is consistent with Ostrowski's values. This decreased Scope 1 CO_2 emissions at voestalpine Linz through substitution of carbon-based reductant and energy with natural gas based HBI. A summary of voestalpine's experience is presented in Table 1.

Table 1: Impact of adding 100 kg/t HM of HBI to voestalpine Linz BF 5 and 6 (Griesser, 2018)

Item	Change for +100 kg HBI/t HM
Reducing reagent (coke equivalent) usage	-(22 to 27) kg/t HM
Productivity	+(7 to 10%)
Top gas temperature	-(2 to 12) °C
Top gas utilization	-(0.5 to 1%)
Permeability Index	+(78 to 130)
Hot metal quality, sulfur	Sulfur decreases by ~0.007% S,
Hot metal quality, carbon	Carbon increases by 0.07% C

Hatch estimated the CO_2 emissions for the complete voestalpine hot metal value chain based on the data presented by Griesser. On average, voestalpine reduced CO_2 emissions across its hot metal value chain by 76 kg CO_2/t HM when 100 kg of HBI/t HM was charged to blast furnaces 5 and 6 (Table 2).

Table 2: Estimated decrease in CO_2 emitted from voestalpine's hot metal value chain when 100 kg of HBI/t HM was charged to blast furnaces 5 and 6 in Linz, Austria, from data presented by Griesser, 2018

CO_2 impact of charging 100 kg of HBI/t HM to voestalpine blast furnaces 5 and 6	**Estimated CO_2 impact (kg CO_2/t HM)**
Change in Scope 1 emissions at voestalpine Linz	
Base CO_2 emissions without HBI added	2166
Decreased reducing reagent (coke equivalent) usage	-82.5
Reduced coke production	-11.8
Reduced sinter production	-49.4
CO_2 emission from increased hot metal carbon content	+2.6
Subtotal, CO_2 Scope 1 emissions reduction at voestalpine Linz	-141
Change in Scope 3 emissions related to HBI production in Texas	
CO_2 from HBI production	+51.3
CO_2 to make DR oxide pellets	+13.9
Subtotal, Increased Scope 3 CO_2 emissions associated with HBI production	+65.2
CO_2 emissions with 100 kg HBI/tHM added to blast furnaces 5 and 6	2090
Net change	-76

In mid-2017, voestalpine charged HBI at a high rate, 160 kg HBI/t HM, and this reduced top temperature from 110-120 to 100-105°C, albeit with significant variability. This led voestalpine to conclude that HBI additions had a negligible impact on top temperature. Later, the HBI addition rate was decreased to 90 kg HBI/t HM for an extended period. Top temperatures increased about 5°C to around 110°C. Hatch considers that for a viable long-term blast furnace operation, the top temperature must be maintained above 100 - 110°C to assure removal of moisture contained in the burden.

Additional CO_2 reduction is possible if more HBI could be added to the blast furnace beyond what voestalpine was able to achieve. In Part 2, we examine the limits of HBI and scrap additions from a theoretical point of view and the potential CO_2 reduction benefits.

PART 2 – MAXIMIZING HBI/DRI AND SCRAP ADDITIONS TO A BLAST FURNACE

Hatch prepared a 2-stage heat and mass balance for a blast furnace operating with an all-pellet burden and natural gas injection, Figure 3.

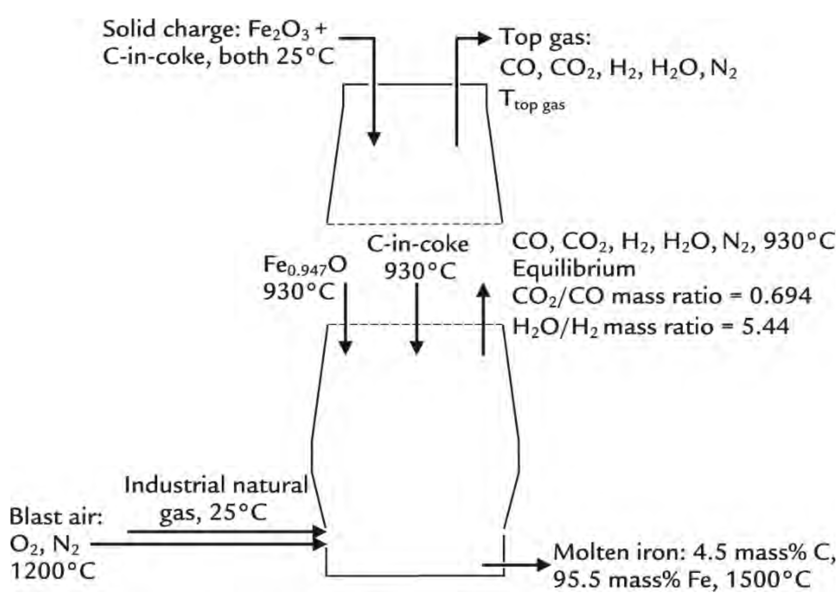

Figure 3: Two-stage heat and mass balance used to assess the impact of HBI and scrap additions to the blast furnace (Cameron, 2019)

This model was verified against a North American reference blast furnace operation prior to being used to assess how best to add more HBI or scrap to the blast furnace. The base case conditions are summarized in Table 3; the reference blast furnace operates with a low blast temperature, and as a result, a coke + natural gas rate of 511 kg/t HM.

Table 3: Reference operating conditions for a North American blast furnace operation

Parameter	Base Case
Sinter/pellet ratio	0/100
Scrap or DRI added, kg/t HM	0
Coke rate, kg/t HM	444
Natural gas rate, kg/t HM	67
Blast temperature, °C	959
O_2 in blast, vol. %	28.6
Flame temperature, °C	1993
Top gas temperature, °C	107
CO_2 emissions, kg/t HM	1877

A minimum top gas temperature constraint of 100-110°C was applied to represent a healthy long-term blast furnace operation. As the reference blast furnace already operates in this range, it would be impossible to add HBI and meet the minimum top temperature guideline. Using the heat and mass balance model, Hatch estimated the amount of additional energy to be added to the reference blast furnace top segment to maintain 107°C as a function of amount of HBI or scrap in the charge burden, Figure 4.

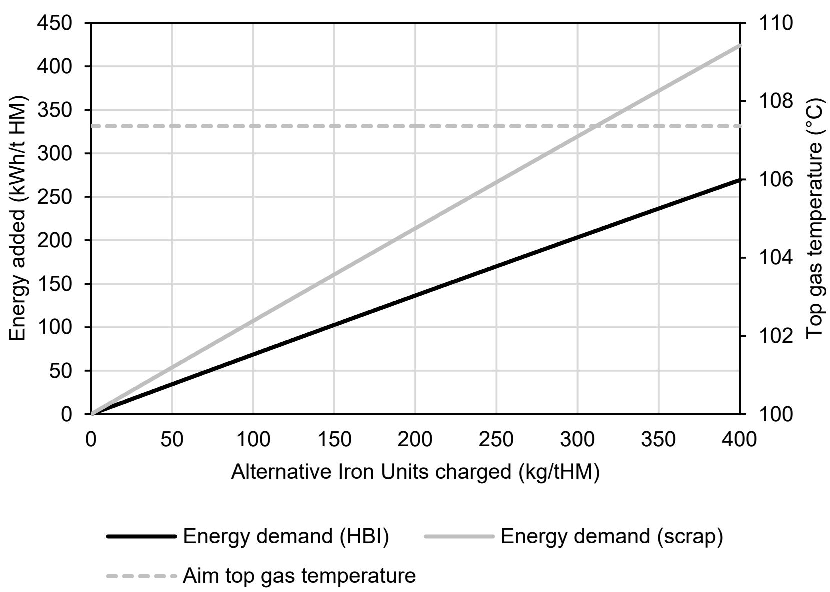

Figure 4: Energy that must be added to the top segment of the reference blast furnace to maintain a minimum top temperature when HBI/scrap is charged

Scrap with its lower iron content of 85% Fe, has a higher energy demand compared to HBI. The nominated energy addition presented in Figure 4 assumes that this energy can be provided without losses, i.e. at 100% efficiency. A technical challenge is to add this additional energy in an efficient manner to restore the minimum top gas temperature to >100 - 110 °C. In Part 3, we discuss the use of plasma torches to inject hot gas into the blast furnace stack and overcome the shortage of energy created by the addition of large amounts of HBI or scrap.

PART 3 – USE OF HOT GAS INJECTION TO INCREASE AIU ADDITIONS TO THE BLAST FURNACE

Non-transferred arc plasma torches use electrical energy to create a high temperature, high velocity plasma stream, Figure 5.

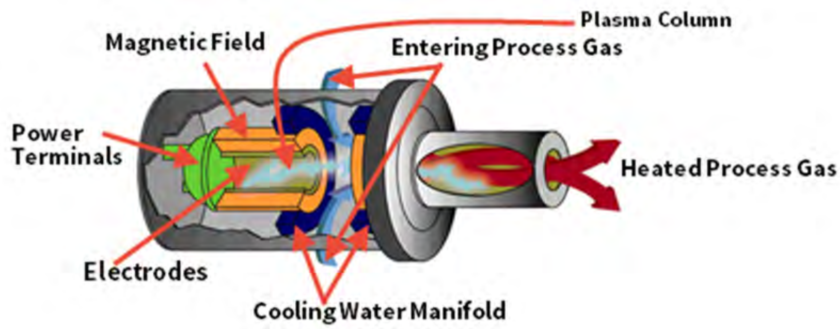

Figure 5: Schematic of a non-transferred plasma arc torch. It uses a high temperature, ionized, and conductive gas to achieve direct heat transfer from the arc.

The plasma stream is created by passing a gas stream between a cathode and anode, which are near each other within the torch. Gases capable of maintaining stable arc-plasmas include argon, helium, nitrogen, hydrogen, carbon monoxide, carbon dioxide, and oxygen. The use of non-transferred arc plasma torches to convert electrical energy into thermal heat is well known. Torches provide the advantage that a high energy input can be achieved with relatively low gas volumes and without products of combustion. Energy conversion efficiency from electric to thermal energy is typically 75-85%.

When non-carbon or green sourced electrical energy is available, plasma torches have the additional driver of carbon footprint reduction compared to fossil fuel heating. These attributes make plasma torches an ideal candidate to add heat to the blast furnace stack and enable the addition of greater quantities of AIUs while avoiding low top gas temperature issues.

Within the USA, the carbon contained in electrical power varies over a wide range. States with operating blast furnaces have an average grid emission factor of 601 kg CO_2e/MWh, which is higher than the U.S. national average of 432 kg CO_2e/MWh, Figure 6.

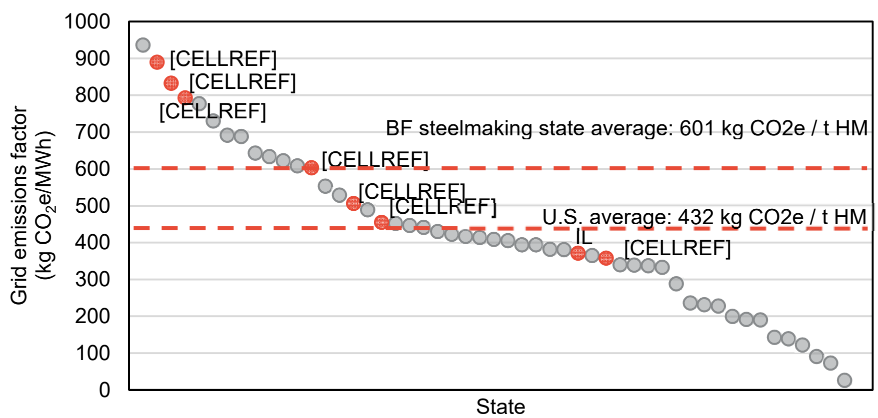

Figure 6: Electrical grid emission factors for the USA on a state-by-state basis (U.S. EPA, 2020)

Over time, national grids will become greener with a lower CO_2 content. Using electrical energy in the blast furnace offers the steel producer an opportunity to switch a portion of the needed energy to produce hot metal from coal and coke to electricity. Plasma torches offer an efficient way to deliver this electrical energy and at the temperature of the thermal reserve zone, 930°C.

Hatch estimated the change in the CO_2 emissions in the hot metal value chain for the base case and when HBI or scrap was added to the blast furnace. To fully understand the change in CO_2 emissions, Hatch considered the following changes to carbon consumption:

- Decreased CO_2 as less coke is consumed in the blast furnace
- Decreased coke plant CO_2 emissions as less coke needs to be produced
- Decreased CO_2 emissions from the pellet plant as the Fe provided from the HBI replaces Fe from fired pellets
- Increased CO_2 derived from carbon contained in the HBI added to the blast furnace. For convenience, the coke usage was adjusted to account for carbon in HBI.
- CO_2 release associated with the production of the oxide DR grade iron ore pellets and subsequent HBI.

- Increased CO_2 release for electrical power generation to supply the plasma torches and maintain a BF top temperature > 100 - 110°C.
- Scrap was considered to arrive at the blast furnace carbon free, as the origin and processing details are unknown.

An average grid CO_2 emission factor was used for U.S. states with operating blast furnaces, 601 kg CO_2e/MWh, to represent the carbon used to produce electric power. The impact of a lower grid emission factor is discussed in the analysis.

In Figure 7, CO_2 emissions were reduced by 55 and 112 kg CO_2/t HM with 200 and 400 kg HBI/t HM additions to the reference blast furnace. When the HBI is replaced by scrap, the CO_2 emissions reductions increase to 146 and 295 kg/t HM, per Figure 8, as CO_2 emitted during HBI and oxide pellet production was eliminated.

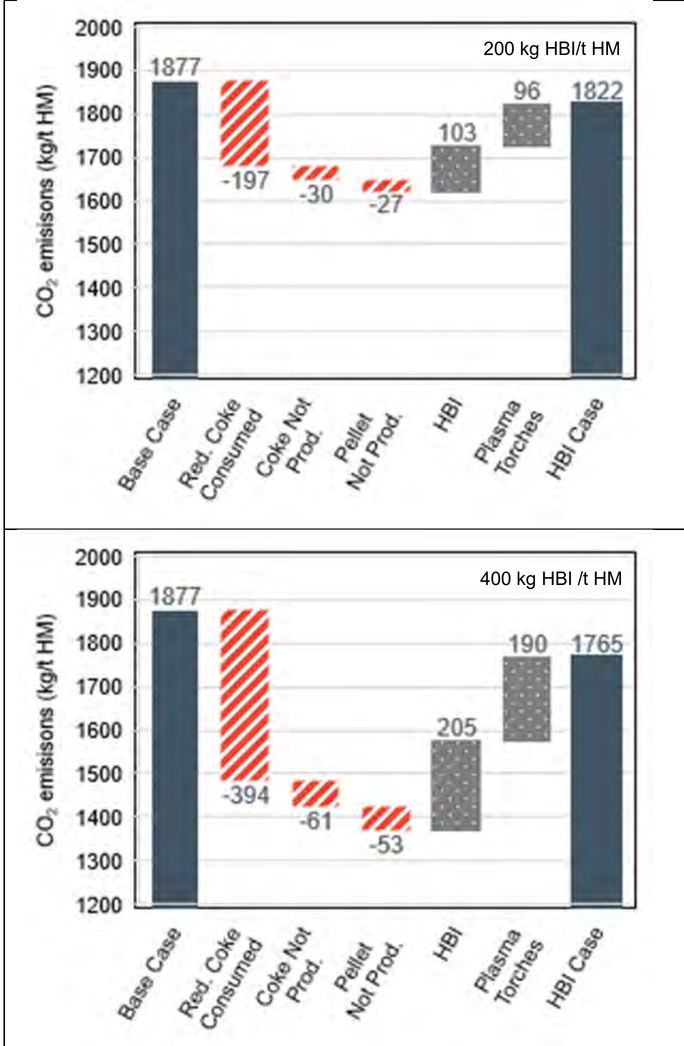

Figure 7: Reduced CO_2 for the reference blast furnace with 200 and 400 kg/t HM HBI additions

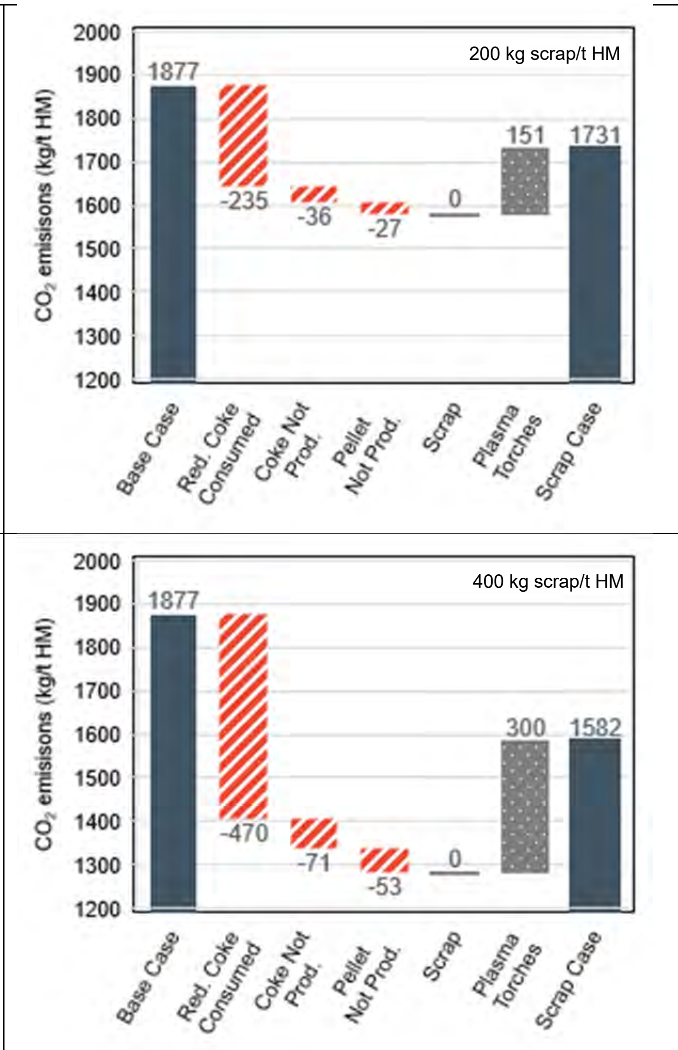

Figure 8: Reduced CO_2 for the reference blast furnace with 200 and 400 kg/t HM scrap additions

Adding up to 400 kg HBI or scrap per tonne HM maximizes the CO_2 emissions reduction as illustrated in Figures 7 and 8. Using greener electrical power, with say 140 kg CO_2e/MWh representing the best 10 U.S. states, would lead to greater CO_2 reductions as illustrated in Figure 9.

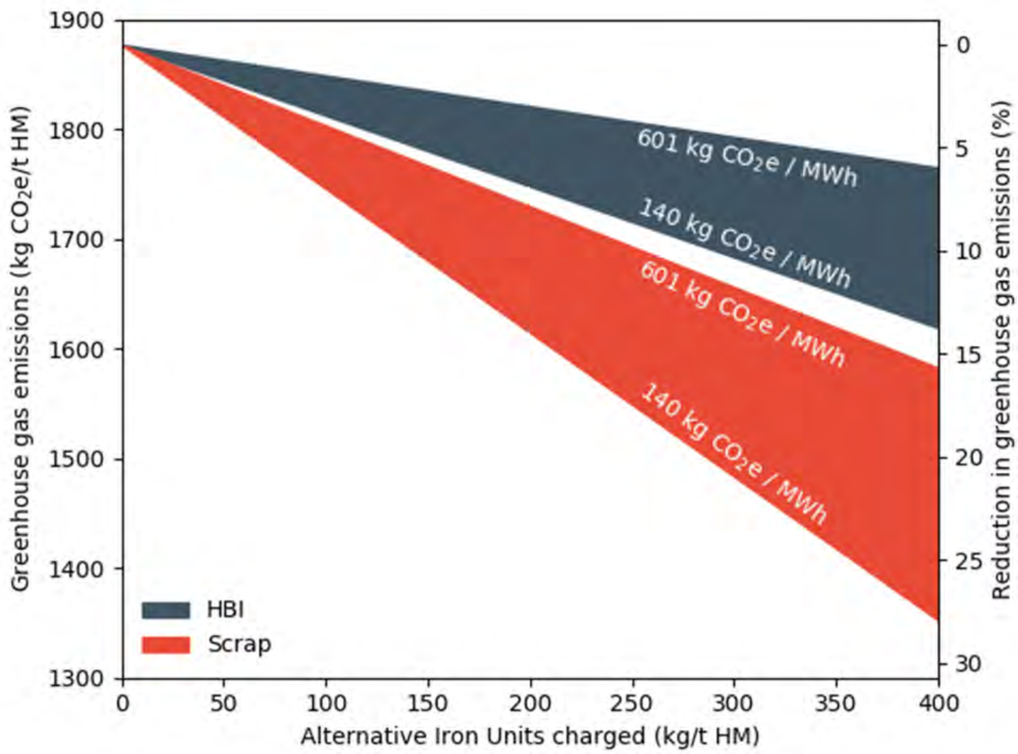

Figure 9: Reduction in greenhouse gas (GHG) emissions as a function of AIU charged and electrical grid emissions factor

Despite greater electrical power requirements to maintain blast furnace top gas temperature, scrap additions offer more potential to reduce greenhouse gas emissions compared to HBI.

Coke or Natural Gas Reduction?

In our assessment, we assumed that all carbon reductions would be achieved by reducing the blast furnace coke rate in the reference blast furnace. This resulted in the coke rates shown in Figure 10 for cases with HBI and scrap added.

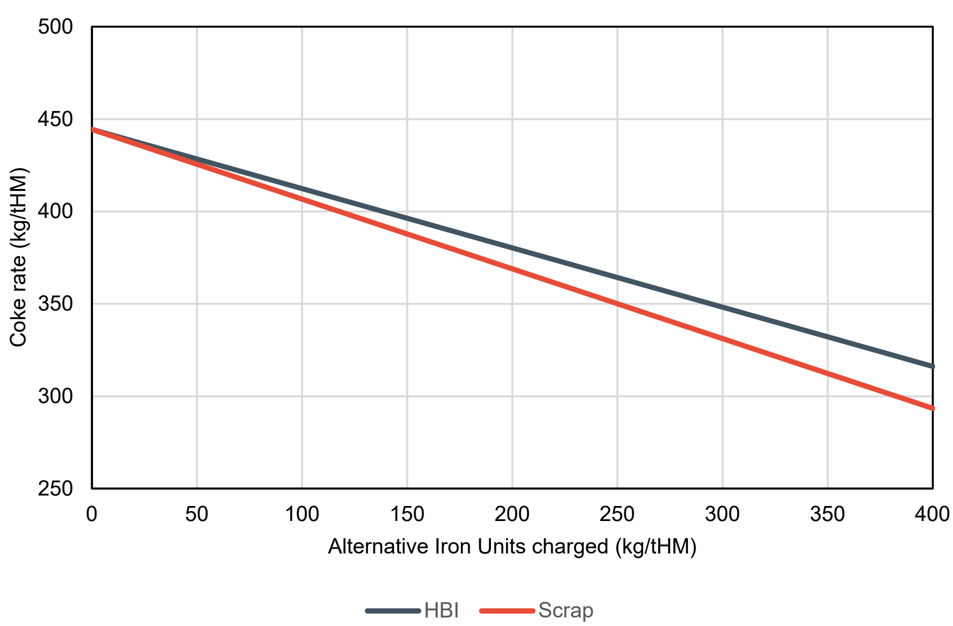

Figure 10: Decrease in blast furnace coke rate when AIUs are charged with the ferrous burden

The coke rate decrease when HBI is added is slightly lower compared to scrap as HBI contains a small amount of carbon that will reduce the iron oxides in the ferrous burden. The coke rates shown in Figure 10 have been achieved in European blast furnaces operating with high rates of coal injection. Such low coke rates can be achieved with either HBI or scrap added to the reference blast furnace and with hot gas stack injection to overcome the top gas temperature challenges. All carbon savings can be taken up by coke replacement compared to the base case.

Stack injection of hot gas in a blast furnace

To overcome the lack of enthalpy in the upper part of the blast furnace when adding AIUs, Hatch proposes to inject hot gas through a set of tuyeres located in the blast furnace stack. As part of the European Community's Ultra-Low Carbon Dioxide Steelmaking (ULCOS) research and development program, blast furnace top gas recycling and stack injection was among the first technologies to be investigated to reduce CO_2 emissions. Heavy pilot scale tests were completed from 2007 to 2010 using the LKAB experimental blast furnace located in Luleä, Sweden, Figure 11.

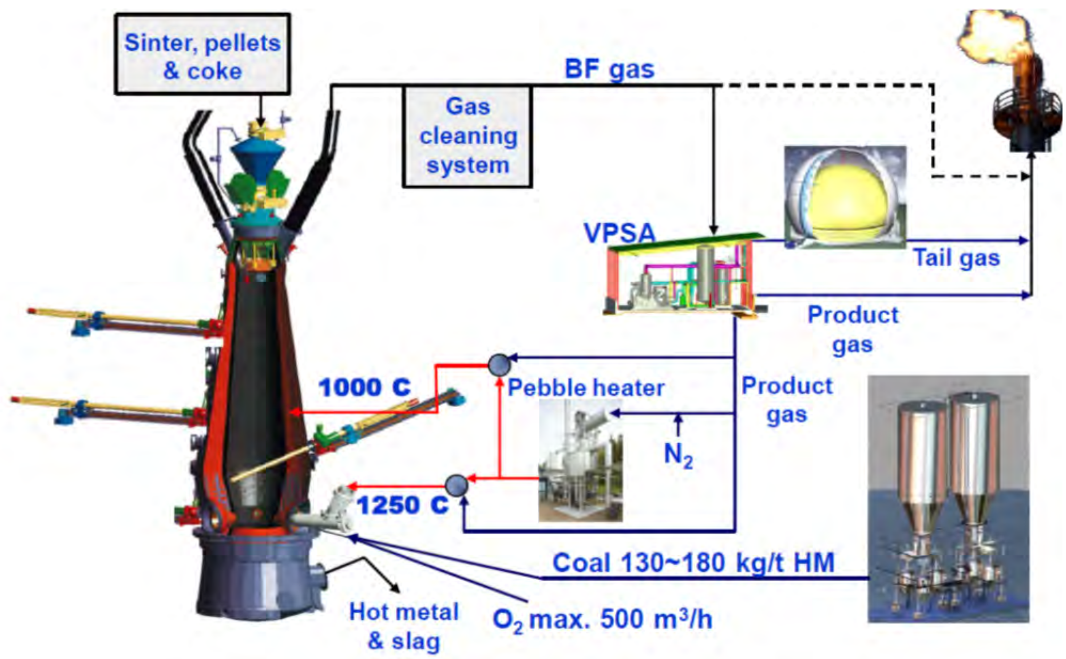

Figure 11: Technical details of the LKAB Experimental Blast Furnace (Mikael 2012)

The investigators used extensive blast furnace modeling to understand the process conditions when injecting recycled hot CO-rich top gas into the blast furnace stack (Mikeal, 2012). The impact of the position of a second level of shaft tuyeres on the melting zone position and solids temperature profile is shown in Figure 12.

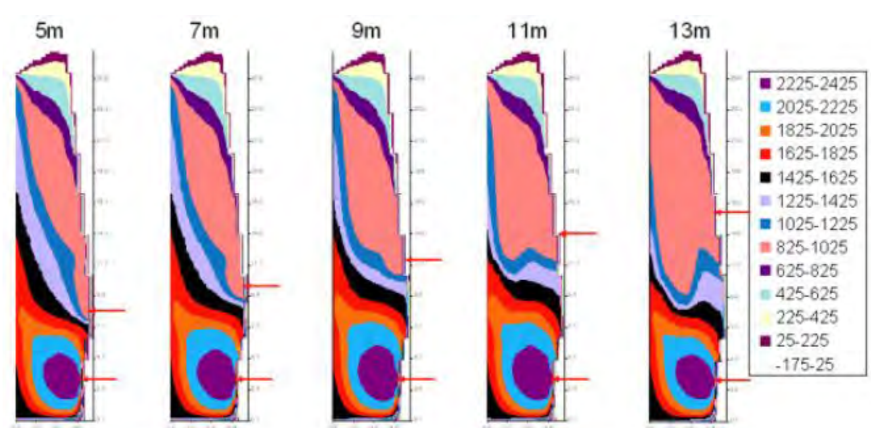

Figure 12: Effect of shaft tuyere elevation for CO-rich gas injection on blast furnace temperature profiles (Mikael, 2012)

The experimental blast furnace tests confirmed that the carbon requirement to produce hot metal could be reduced by 25% by injecting hot CO-rich gas into the stack and increasing the degree of indirect reduction from 70 to 90%. A vapor pressure swing absorption (VPSA) plant was used to recover a CO-rich gas from the blast furnace gas. During the trials, the experimental blast furnace operated stably and with good results. A stack zone temperature was maintained at 825-1025°C when injecting hot CO-rich gas at 900-1000°C and when processing iron ore sinter and pellets.

N_2, CO or CO_2 hot gas stack injection?

When HBI and scrap are used in larger amounts, the injection of hot CO, CO_2 or N_2 at 900-930°C via plasma torches located in the stack can add the process energy identified in Figure 4 to maintain the top gas temperature at acceptable levels. The hot gas will sustain the needed drying processes and early reduction reactions inherent to a normal blast furnace operation. Hatch considered the merits of injecting hot CO, CO_2 or N_2 gas. Each has advantages and disadvantages, which are summarized in Table 4.

Table 4: Comparison of CO, CO_2 and N_2 for hot injection gas into the blast furnace stack when adding AIUs.

Parameter	Hot N_2	Hot CO_2	Hot CO
Injection temperature	N_2 can be injected in the stack without consuming additional coke.	CO_2 must be injected at <930°C to minimize the Boudouard reaction with coke.	CO can be injected in the stack without consuming additional coke.
Injection location	Mid-to upper stack.	Upper stack to avoid CO_2 reaction with coke above 930°C.	Mid-to upper stack.
Source	Purchased N_2.	Purchased CO_2 or recovered from blast furnace gas (BFG).	Recovered from BFG.
CO_2 trading	No impact.	Buy distressed CO_2 or potentially sell credits by recycling CO_2 from BFG.	Potential carbon credits from recycling CO from BFG.
Scope 2 CO_2 contribution	Purchased electricity used to produce N_2.	Purchased electricity used to operate the BFG processing plant.	Purchased electricity used to operate the BFG processing plant.
Downstream benefits	None	Processed BFG has higher CO content/fuel value if CO_2 for hot gas injection is recovered from the BFG. Less enrichment gas may be needed at the stoves and other applications.	Tail gas from the BFG processing plant has a high CO_2 content. This gas has little fuel value and would be flared.
End of pipe CO_2 removal	Same treatment challenges as a conventional blast furnace.	Stronger CO-rich off gas for production of bioethanol as a CO_2 mitigation strategy.	Hard to treat gas stream, the tail gases will be flared.

Injecting hot N_2 with plasma torches is more forgiving than hot CO_2 as concerns over consuming coke in the blast furnace shaft via the Boudouard reaction are eliminated. Hot CO_2 must be injected at the upper part of the blast furnace's thermal/chemical reserve zone where the oxidation of coke by CO_2 has virtually stopped. Harvesting CO_2 from the blast furnace gas may have additional benefits, the merits of which require further assessment. The merits of hot CO injection are questionable. Little additional reduction will occur in the BF as the reducing gas temperature drops to < 900 °C. The CO-poor tail gas from the blast furnace gas treatment plant will have insuffcent calorific value to heat the stoves. The tail gas will be flared and there will be a large demand for a supplemental fossil fuel like natural gas for stove and other heating demands normally fill by blast furnace gas.

How many plasma torches are needed to heat the hot gases injected into the blast furnace stack?

In Figure 4, we can see that up to 1500 MJ/t HM of hot gas must be injected into the blast furnace stack to maintain a top gas temperature of 100-110°C when 400 kg of scrap are charged per tonne of hot metal. For a blast furnace producing 2.5 Mtpy hot metal, this requires 146 MW of electrical power to heat the hot gas considering 85% efficiency converting electrical power to thermal energy using plasma torches. Using 4 MW torches, 37 plasma torches would be required to deliver the 146 MW. With 6 MW torches, 24 torches are needed. Commercial plasma torches up to 4 MW are available and designs up to 8 MW have been proposed. Should plasma torches be employed by blast furnace operators, plasma torch technology must mature to meet these demands.

With the larger 6 MW torches, the number of plasma torches in the blast furnace stack is comparable to the number of tuyeres that a 2.5 Mtpy blast furnace would have. Twenty-four (24) torches spaced around the blast furnace circumference in the stack zone would provide even energy input to heat the charge. From a power viewpoint, 146 MW is similar to the power demand of a large electric arc furnace, so the technology to deliver this amount of electrical power is well-known.

Plasma torches deployed for hot gas injection into the blast furnace stack is a scalable technology – less powerful torches can be used to achieve moderate increases in AIU addition rates and torch power can be increased as experience grows.

Charging scrap to the blast furnace

Bell-less top charging systems are amenable to handling HBI as this is a bulk material with similar dimensions as metallurgical coke. Charging scrap is more challenging due to its irregular shape and tendencies to block material transport systems in the stockhouse and bell-less top. Re-designing the charging system to better handle scrap is an overlooked subject should blast furnace operators wish to increase scrap usage as a CO_2 emissions mitigation strategy using the techniques described in this paper. Two prior innovations that received limited commercial application come to mind – the Totem® top (Boranbaev, 2012) and the Gimbal® top (Whitefield, 2009). The Totem® top features a rotor with 4-5 reflecting vanes that can tilt to position the charge material on the stockline. The Gimbal® top features a rotating nozzle that can position the burden at virtually any position. Innovations such as these may be needed to increase the range of scrap products that could be charged to the blast furnace. Details of the Totem and Gimbal design may be seen in Figure 13.

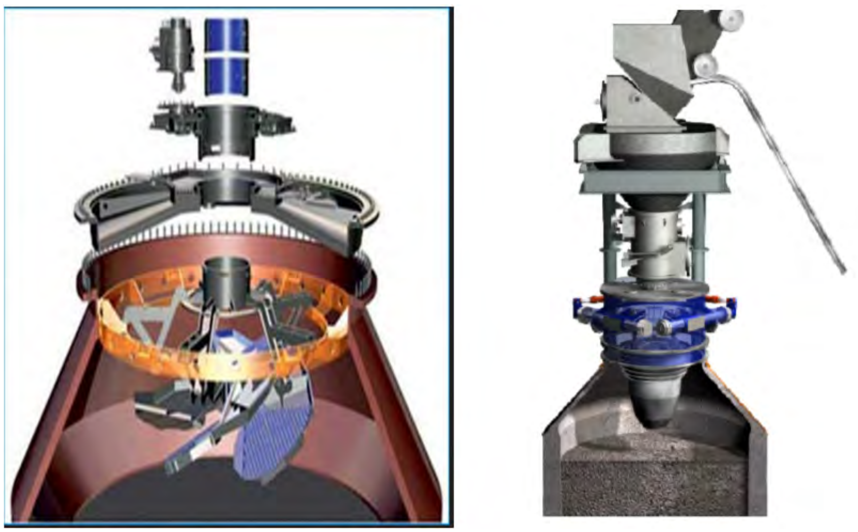

Figure 13: Innovative charging concepts; Totem® Top on the left and Gimbal® Top on the right

CONCLUSIONS

Blast furnace stack injection of hot N_2 or CO_2 using plasma torches can enable elevated addition rates of hot briquetted iron (HBI), direct reduced iron (DRI) and scrap by overcoming heat balance limitations and maintaining top gas temperature > 100 - 110 °C. Adding pre-reduced burden materials can reduce CO_2 emissions by 5-25% compared to the operating practice employed today depending on the CO_2e emissions factor of the electrical grid and alternative iron units used. Scrap usage offers the largest opportunity to reduce CO_2 emissions as residual scrap is deemed to be carbon-free compared to HBI and DRI. With hot gas injection, a scrap rate of 400 kg scrap/t HM could reduce CO_2 emissions by 15-25% depending on the CO_2 contained in the available electrical power.

Large high-power plasma torches are proposed for hot gas injection. Hot gas injection is a scalable technology, blast furnace operators can start with smaller plasma torches and increase torch size and power as the technology and its application matures. Innovation in the charging system design is an opportunity that blast furnace designers can consider to further increase scrap usage and reduce CO_2 emissions. Additional CO_2 emission reductions are possible optimizing the concepts presented in this paper.

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