Enhancing Direct Reduced Iron (DRI) for use in electric steelmaking

Direct Reduced Iron (DRI) is a valuable source of virgin iron for the electric steelmaking process. Its production is associated with less than half the CO_2 emissions of blast furnace produced pig iron, but has a less favorable value in use and potential difficulties with transport and storage. Two concepts are discussed for the improvement of value in use of DRI, namely preheating and melting. An oxy-fuel preheating process is described that can result in savings of $2.3/liq ton in the steel plant and this is currently subject to further evaluation.

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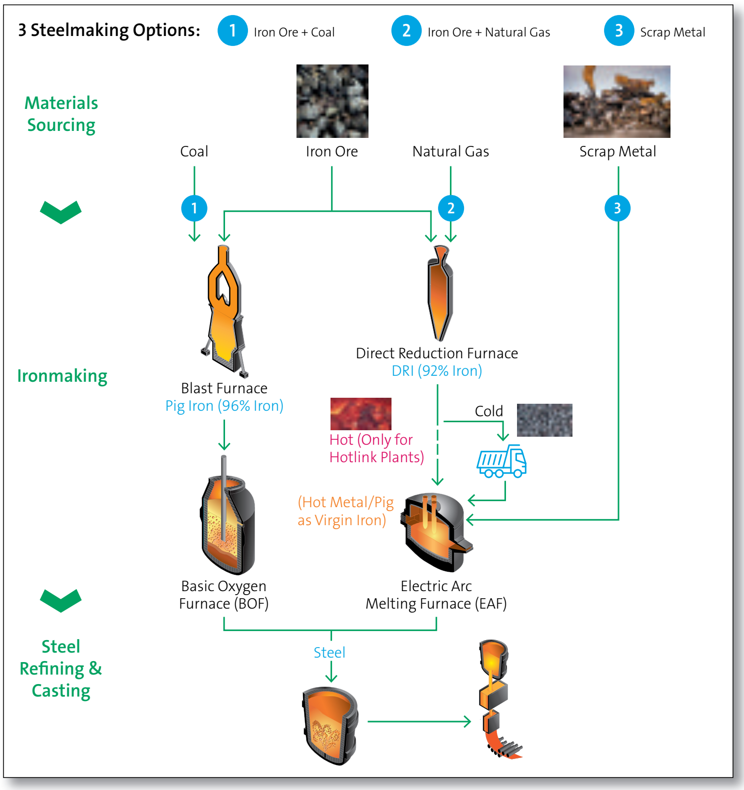

Fig 1 **Prominent routes for steelmaking**

INTRODUCTION

Direct Reduced Iron (DRI) is the second most viable source of virgin iron used in steelmaking after pig iron, or hot metal produced in blast furnaces. DRI is produced by direct reduction of iron ore using carbon monoxide and hydrogen. Natural gas-based shaft reactors are commonly used in North and South America for DRI production, while coal-based DRI is common in Asian markets **[1]**. An inexpensive supply of natural gas in the United States makes DRI an attractive source of iron for steelmakers.

Figure 1 shows the different steelmaking routes, namely the integrated approach with the blast furnace, and electricity based approach consuming DRI and scrap. In North America, more than 60% of steel is produced through the EAF route **[2]**. In electric steelmaking, where residual elements are required to be low, from 10% to 30% of the charge material may need to be ore based metallics, such as pig iron, or DRI, to compensate for the impurities in the scrap and to increase the carbon content of the charge.

Pure iron units provided by Ore Based Metallics (OBMs) help electric steelmakers produce advanced grades of steel and control the alloy chemistry. The dilution of residuals is becoming more and more of an issue for steelmakers in markets where scrap is continually recycled, and thus steelmakers require more and more 'virgin' iron units in the raw materials mix to maintain low levels in the final product. Many EAF operations prefer consuming pig iron because there is a substantial decrease in the electrical energy required and thus a corresponding increase in furnace productivity. OBMs typically have much more consistent chemistry and physical characteristics than recycled scrap iron and steel. Today, variations in scrap iron and steel chemistries can cause significant variation in operating results.

The steady nature of OBMs means that they are a viable option for controlling process variation and especially increasing productivity in a controlled, safe manner. However, not all OBMs are the same. *Table 1* shows the comparison of OBMs with respect to their value-in-use for electric steelmaking. Pig iron has several advantages over DRI, namely higher metallic iron content, lower impurities, lower melting point, and higher carbon content, resulting in a lower melting power requirement. Additionally, DRI presents significant challenges with transport and storage, as it generates significant fines during conveyance.

Description	Pig Iron	DRI
Melting of iron	Yes	No
Primary fuel	Coke	Natural Gas
Total iron (%)	~96%	~92%
Iron oxide (%)	<1%	~7%
Gangue + impurities (%)	~1%	~5%
Density/porosity	High/Low	Low/High
Carbon (% by weight)	>4%	2 to 4%
Material handling	Easy	Challenging (Pyrophoric and fines)
Melting temperature (˚C)	~1250	~>1300 ˚C
Power to melt in EAF (with energy from carbon, kWh)	~150	~400
Cost to melt in EAF	~50 $/ton of liq steel	~108 $/ton of liq steel
Price on merchant market	~350 $/ton	~250 $/ton

Table 1 **Comparison of Pig iron and DRI**

EAF charge weight	180	Tons
% of charge as DRI	25%	%
Target burner firing rate	600	F
Total burner firing rate	35	MMBtu/hr
TAP-TAP time =	50	Min
Additional CO_2 emissions	0.02	MT/MT of DRI
Fixed cost savings due to productivity increase	$3,207,116	
Productivity and power cost savings	$996,058	
Preheating operating cost	$864,464	
Net savings	$3,338,710	Per year per furnace
Furnace production	1,430,784	Tons/year
Net savings per ton	$2.30	Savings/ton

Table 2 **Benefits of DRI preheating for a mini mill**

From an operational perspective, pig iron appears to be a more favorable choice as an OBM source in electric steelmaking.

Currently, pig iron is produced mainly through the blast furnace route. Blast furnace operation and its ancillary processes contribute the largest amount of CO_2 per ton of steel production, due to the use of coal and coke. DRI processes, which are based on natural gas, produce less than half of the CO_2 emissions of a blast furnace. Therefore, there is an underlying opportunity to remove the disadvantages of DRI and bring it closer to pig iron, while keeping the overall emissions low.

In this paper, two approaches are outlined to enhance the value-in-use of DRI in electric steelmaking. The first approach is based on preheating the DRI before it goes into the electric furnace using oxy-fuel combustion, and the second is completely converting DRI to either hot metal, or pig iron by melting using oxy-fuel combustion. Both approaches are based on combustion of natural gas and/or hydrogen as fuel to minimize CO_2 emissions. The next sections describe both these approaches, outlining the advantages, feasibility and potential next steps.

ENHANCING DRI'S VALUE-IN-USE

DRI Preheating

The advantages of charging DRI hot coming out of the shaft reactor have been well documented, namely productivity increase and decrease in power use **[3]**. Few DRI plants in the world have the ideal setup with an EAF downstream of the DRI plant, where the DRI coming out of the shaft furnace can be charged hot into the EAF. However, a significant number of steelmaking plants that use DRI receive it at ambient temperature, thus reducing its potential value-in-use.

Preheating the DRI presents a way for such operations to increase the value-in-use of DRI before it is charged into

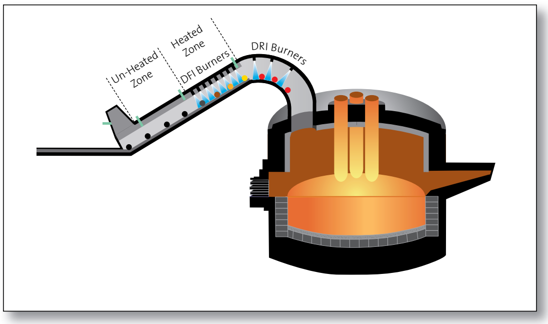

Fig 2 **Air Products' DRI Preheating Process *(patent pending)***

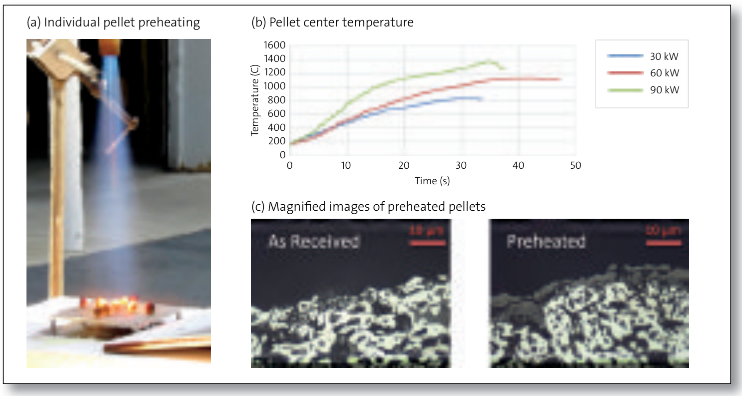

Fig 3 **Single Pellet preheating results**

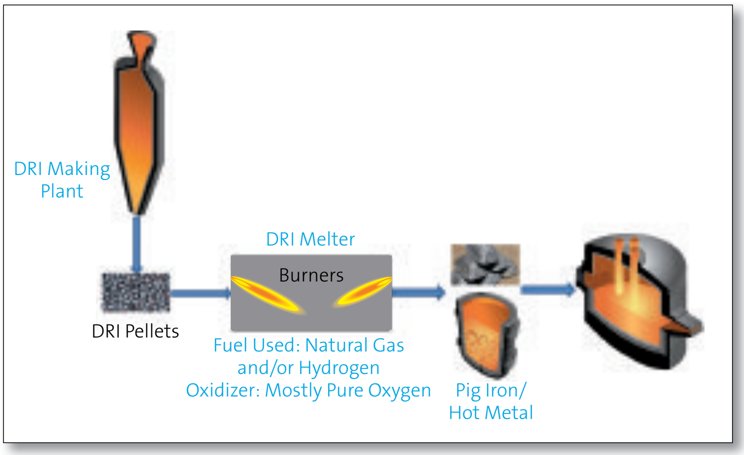

Fig 4 **Air Products' DRI Melting Process *(patent pending)***

the furnace. Air Products' DRI preheating process *(patent pending)* **[4]** is shown in *Figure 2*. In this embodiment of the process, DRI is preheated using oxy-fuel burners on a conveyor belt before charging into the furnace. The end section of the transport conveyor is envisioned to be converted to a refractory walled tunnel, housing the oxy-fuel burners. Oxy-fuel combustion pertains to combustion of fuel in the presence of pure oxygen as the oxidizer. In contrast to air-fuel combustion, in oxy-fuel combustion nitrogen is not present to take away the heat of combustion through the flue gases. Thus, with oxy-fuel combustion, more heat is available to the product, increasing the efficiency and achievable temperature. Oxy-fuel combustion is effectively used in EAFs to supplement the electric energy for melting steel, as well as in the glass industry for melting glass.

Various suggested parameters used in the process are described in *Table 2*. The additional CO_2 impact of combustion is estimated to be insignificant at 0.02Mt/Mt of DRI. Calculations suggest that the addition of this preheating process for an EAF mill charging cold DRI can lead to $2.3/liq. ton saving for the mill, after considering improved fixed cost utilization and operating costs.

Currently this process has been evaluated for feasibility and applicability of oxy-fuel burners for preheating DRI. For example, *Figure 3* shows results from single pellet preheating experiments conducted at Air Products combustion laboratories. Significant preheating temperatures >800°C (*Figure 3b*) can be achieved at single pellet level with insignificant re-oxidation of the pellets (*Figure 3c*). Currently, further evaluation is underway with multi-layered pellet stacks simulating the charge load to be preheated on a conveyor belt. Multiple layers do present some challenges with heat transfer from the burners but can be overcome using increased momentum on the burners, distribution of the pellets, and effective recirculation of product gases of combustion. Next steps involve scaling up the experiments to prototype scale and a field trial at an EAF mill.

DRI Melting

To further enhance DRI for steelmaking, it can be converted to pig iron or hot metal via melting. There are existing processes in the industry that use electric energy in furnaces, such as submerged arc furnaces, to convert DRI into hot metal. Air Products' novel DRI melting process uses oxy-fuel combustion in place of electric power to accomplish this melting. *Figure 4* provides a process diagram *(patent pending)* **[5]**. It is envisioned that the DRI produced by a shaft furnace would, in a second step, be melted inside an oxy-fuel fired furnace to produce pig iron or hot metal that can be used in steelmaking. The furnace can be fired using natural gas and hydrogen, with minimal additional CO_2 emissions from the process.

Table 3 shows the important parameters related to the Air Products' DRI melting process. The energy required per ton of DRI to be melted is ~2MMBtu, leading to an additional 0.12Mt of CO_2 per Mt of DRI melted. The cost of conversion via the combustion route is estimated to be ~$50/ton of DRI, which by a conservative calculations will be ~$10 to $15/ton DRI lower when compared with the electric melting route. The proposed process would be continuous, using a simple box-type furnace design equipped with oxy-fuel burners. DRI will enter from one end with slag and hot metal extracted from the other end.

Energy needed (per ton of DRI at input temperature of 300 °C)	1.9, 550	MMBtu, kwh
Additional CO_2 generated	0.12	mt/mt of DRI
Total CO_2 generated (DRI process + conversion)	0.85	mt/mt
Cost of conversion (capital + operating)	~$50	per ton DRI
Production furnace size	50	tons per hour
Cost savings compared to electric conversion (SAF/EAF)	~$10-15	per ton DRI

Table 3 Energetics and Economics of DRI Melting Process

Results from an initial investigation into this proposed process are shown in *Figure 5*. In laboratory experiments, DRI was melted using oxy-fuel burners in a crucible. A reducing atmosphere was created at the melt surface by modulating the burners. After melting, the liquid metal was cooled down under an inert atmosphere and then analyzed for appearance and chemistry. As shown in *Figure 5e* and *Figure 5f*, after cooling, a clean iron cross section was obtained. In these initial melting experiments, minimal oxidation of iron was observed due to the oxy-fuel burners. Gas stirring was employed to enhance mixing and heat transfer. The recovered slag weight, ~2% of recovered product weight, matched well with the charge gangue weight, allowing for the conclusion that minimal additional slag was produced during melting.

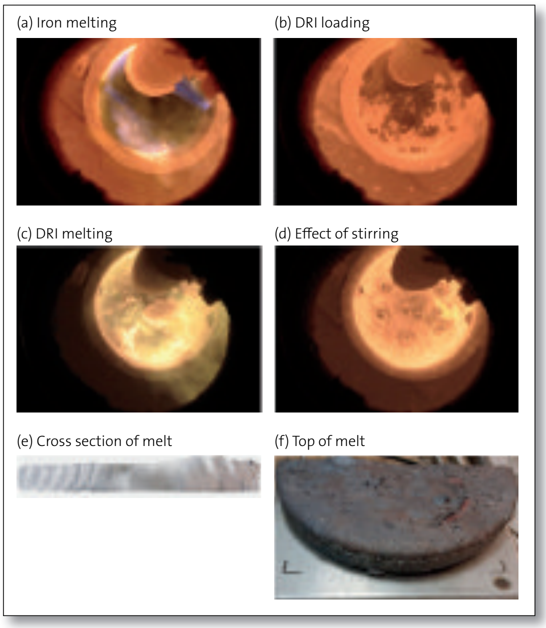
(a) Iron melting
(b) DRI loading
(c) DRI melting
(d) Effect of stirring
(e) Cross section of melt
(f) Top of melt

Fig 5 DRI Melting Experiments at Air Products' Laboratories

CONCLUSIONS

The two novel approaches outlined in this paper present an opportunity to enhance DRI for use in electric steelmaking.

DRI preheating offers productivity and efficiency increase for EAFs with a low additional CO_2 footprint. Existing conveyor feed systems can be adapted to use the preheating furnace. Technical feasibility trials show no, or minimal, oxidation due to direct flame impingement. Next steps for this process development are to scale up the lab system, and have field trials of the system at a mini mill.

DRI melting takes the use of oxy-fuel combustion one step further. This process offers an alternative to sourcing pig iron from blast furnaces. DRI converted to pig iron offers a higher value source of virgin iron for steelmaking in EAFs, leading to improved productivity and efficiency. This process, coupled with DRI production, can directly compete with the blast furnace route to produce pig iron, at less than half of the CO_2 emissions. Technical feasibility trials show DRI can be melted using oxy-fuel combustion with a good yield. Favorable economic and environmental parameters for the process warrant further investigation of the concept. **MS**

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AUMUND: Leading Technology Specialist in Hot Conveying and Cooling of Direct Reduction Products

As an international supplier of specialist conveying technology for metallurgical processes in the iron and non-iron smelting industry, AUMUND Fördertechnik GmbH is an established provider of solutions for handling hot, abrasive and chemically reactive bulk materials. Much of this innovative equipment has helped AUMUND to become a technological leader, with patented solutions driven by market pressure from strict energy efficiency and environmental standards in the steel industry.

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Fig 1 **AUMUND 250tph hot DRI conveyor, Hadeed, Saudi Arabia**

Steel production is responsible for around 7% of global CO_2 emissions, a large portion of which results from using coking coal to process steel from iron ore, particularly in China, India, Japan, South Korea, Russia and the EU countries, which in 2018 generated 90% of the world's CO_2 emissions between them. The pressure on the steel industry from climate and energy efficiency policies continues to grow, and the decarbonization trend is also growing.

Intensive efforts are being made to develop low CO_2 producing processes such as replacing coal with electricity or hydrogen, as well as capturing and storing, or using, the CO_2. At the beginning of the 2000s, direct reduction established itself as a viable large-scale alternative to the classic blast furnace process. Direct reduction by natural gas produces pig iron from iron ore pellets. Depending on the technology used, either Direct Reduced Iron (DRI) or Hot Briquetted Iron (HBI) is produced. The operators of direct reduction plants avail themselves of highly innovative solutions for handling these products in the cooling and charging processes.

Global crude steel production reached 1.864Bt in 2020, around 110Mt, approximately 6%, of which was produced using direct reduction technology. This percentage will be higher in 2021. The 6% of direct reduction products is divided between DRI and HBI at a ratio of 5:1.

Unlike the classic blast furnace route, where steel is produced in an oxygen converter, direct reduction uses an electric arc furnace (EAF). This DR-EAF route can process both DRI and HBI. Among the direct reduction processes in use, the technology from MIDREX, USA, has been predominant since the 1970s. In this process the pellets are subjected to heat and methane gasification. The oxygen is removed and pig iron is produced as sponge iron, the DRI