

# Solving Iron Ore Quality Issues for Low-Carbon Steel

## *Technology Solutions Are Under Development*

### Executive Summary

Direct Reduced Iron (DRI) ironmaking processes are regarded as a key part of steelmaking's lower-emissions future. The ability of DRI to use green hydrogen as a reducing agent, rather than metallurgical coal, means that investment in DRI is expected to expand significantly going forward.

DRI-electric arc furnace (EAF) technology is proven and in use today. However, it requires high-quality iron ore (DR-grade) with iron (Fe) content of 67% and above, which has lower levels of impurities. DR-grade iron ore currently makes up only about 4% of global iron ore supply. Some fossil fuel-based steelmaking supply chain incumbents suggest this scarcity means that there are limits on how much steelmaking can switch to lower-emissions DRI-based technology.

BHP – one of the key suppliers of blast furnace-grade iron ore and metallurgical coal to the steel industry – has stated: “There is simply not enough high-quality iron ore suitable for efficient DRI/EAF production to meet the global steel demand.” BHP considers that most of the world's steel will still be produced via the blast furnace-basic oxygen furnace (BF-BOF) route in 2050.

However, some steelmakers are investigating and planning new technology combinations to enable the use of lower-grade iron ore in DRI processes, potentially alleviating the DR-grade iron ore scarcity problem and aiding the expansion of low-emissions steelmaking technology that does not use metallurgical coal.

A melting stage can be added to melt the DRI before being charged in a BOF instead of an EAF to produce high-quality steel. Some steel producers are investigating and developing installations along these lines:

- **Thyssenkrupp** is planning a new steelmaking route that adds a submerged arc furnace (SAF) melting stage after DRI production before sending it to an existing BOF. The company's plan is to replace four BFs with new DRI-SAF technologies by 2045, with the first two to be replaced in 2025 and 2030

**Some steelmakers are investigating and planning new technology combinations to enable the use of lower-grade iron ore in DRI processes.**

respectively. The proposed DRI-SAF-BOF configuration will allow Thyssenkrupp to use blast furnace-grade iron ore pellet in its DRI processes.

- Global steel giant **ArcelorMittal** is also looking at the DRI-SAF technology route. In March 2021 the company announced a memorandum of understanding (MoU) with Air Liquide to examine using this technology combination at ArcelorMittal's Dunkirk site using hydrogen as the reductant.
- **BlueScope** is also investigating a DRI-Melter-BOF steelmaking route to allow the use of lower-grade ores. In October 2021, the company announced an MoU with Rio Tinto to investigate technology that would allow the use of Rio's blast furnace-grade Pilbara iron ore in DRI processes.
- Italian steel technology provider **Tenova** is developing new technology to produce direct reduced iron using lower-quality blast furnace-grade pellets. The technology combination involves a new DRI melting step called an open slag bath furnace (OSBF).

Apart from the DRI-Melter-BOF routes, various companies are developing fluidised bed reduction processes that can reduce iron ore using hydrogen rather than via fossil fuels. An advantage of such processes is their ability to use iron ore fines, eliminating the cost and energy used in iron ore pelletisation or agglomeration. These technologies could help resolve the issue of limited global pelletising capacity for producing DR-grade iron ore pellets. In addition, there is the potential for these technologies to use blast furnace-grade ores.

These alternative steel technology routes could reduce the pressure of supplying DR-grade ores, shifting part of the DRI iron ore demand toward BF-grade pellets and fines. However, demand will continue to rise for DR-grade iron ore for an increasing number of DRI-EAF steelmaking operations and there still will be the need to improve the quality of iron ore via beneficiation, as well as for further magnetite mining project development (which can add to DR-grade ore supply) along with greater pelletising capacity.

However, the technology developments outlined in this report are starting to challenge the idea among some steel and iron ore market incumbents that a lack of DR-grade ore will limit any significant switch from blast furnaces to DRI processes.

Major iron ore miners should start to reassess their long-term strategies and prepare to supply more of their products to DRI-based steelmaking processes. Any significant global switch from blast furnaces to DRI processes will impact metallurgical coal demand. With new

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technology configurations set to allow more switching from blast furnaces to DRI in the longer term, miners can also bolster their Scope 3 emissions reduction ambitions.

## **Introduction**

Direct Reduced Iron (DRI) ironmaking processes are regarded as a key part of steelmaking's lower-emissions future. The ability of DRI to use green hydrogen as a reducing agent, rather than fossil fuels in other processes, means that investment in DRI is expected to expand significantly going forward.

Currently, DRI processes require a higher grade of iron ore (DR-grade), for which worldwide resources and global supply are scarce.<sup>1</sup> Some incumbents in the fossil fuel-based steelmaking supply chain suggest that this scarcity limits how much steelmaking can switch to lower-emissions DRI-based technology. BHP – one of the key suppliers of blast furnace-grade iron ore and metallurgical coal to the steel industry – has stated: “There is simply not enough high-quality iron ore suitable for efficient DRI/EAF production to meet the global steel demand... DRI production must use the very highest quality iron ore, with an average iron content in the range of 67%. Such deposits are scarce.”<sup>2</sup>

BHP considers that the majority of the world's steel will still be produced via the BF-BOF route in 2050.<sup>3</sup>

However, some steelmakers are investigating and planning new technology combinations to deal with this issue and allow the use of lower-grade iron ore in DRI processes. This has the potential to alleviate DR-grade iron ore scarcity and aid the expansion of low-emissions steelmaking technology.

## **DRI-EAF**

DRI is produced by direct reduction of iron ore without melting, usually using a mixture of carbon monoxide and hydrogen derived from natural gas, although these can also be derived from gasified coal. As such, DRI processes don't use coking coal. The DRI is then charged into an electric arc furnace (EAF) to turn it into steel. Steel companies are increasingly seeking to develop technology that uses 100% hydrogen in the DRI-EAF process. Such hydrogen has the potential to be zero-carbon

**Steel companies are increasingly seeking to develop technology that uses 100% hydrogen.**

<sup>1</sup> IEEFA. [Iron ore quality a potential headwind to green steelmaking: Technology and mining options are available to hit net-zero steel targets.](#) 28 June 2022.

<sup>2</sup> BHP. [Pathways to decarbonisation episode two: steelmaking technology.](#) 5 November 2020.

<sup>3</sup> BHP. [Pathways to decarbonisation episode two: steelmaking technology.](#) 5 November 2020.

green hydrogen, produced via renewable energy-powered electrolysis.

DRI-EAF technology is proven and in use today. However, it only accepts high quality iron ore (DR-grade) with iron (Fe) content of 67% and above, which has lower levels of impurities. DR-grade iron ore currently makes up only about 4% of global iron ore exports.<sup>4</sup> Overall iron ore quality has been in decline for 20 years with iron content dropping and the level of impurities rising.<sup>5</sup>

As there is no melting and refining in the direct reduction process, iron ore impurities must be at the minimum level; the removal of such impurities is costly and affects the competitiveness of this technology. Special steel grades come from high-quality liquid steel with low impurities. Low-quality ore might restrict the types of steel that can be produced.

### *The Effect of Lower Iron Content and Higher Impurity Ore on DRI-EAF Steelmaking*

The EAF is more sensitive to impurities than a basic oxygen furnace (BOF) that is usually paired with a blast furnace. Extra unreduced iron and gangue (impurities) could affect production yield, and increase electricity consumption and slag volume in an EAF. In DRI-EAF processes, the metallic impurities including copper (Cu), chromium (Cr), nickel (Ni) and vanadium (V) should ideally be at a minimum as they hinder the production of some specific steel grades.<sup>6</sup>

Table 1 presents the practical and preferred chemical quality limits for DR-grade iron ore for DRI-EAF steelmaking processes.<sup>7</sup>

**Table 1: DR-grade Iron Oxide Chemical Quality Limits (%)**

| Sources  | Practical Limits | Preferred Limits |
|--|------------------|------------------|
| Iron (Fe)  | 66.0 min         | 67.0 min         |
| Silica (SiO <sub>2</sub> ) & Alumina (Al <sub>2</sub> O <sub>3</sub> ) | 3.5 max          | 2.0 max          |
| Calcium oxides (CaO)   | 2.5 max          |                  |
| Magnesium oxide (MgO)  | 1.0 max          |                  |
| Phosphorous pentoxide (P <sub>2</sub> O <sub>5</sub> )                 | 0.03 max         | 0.015 max        |
| Sulphur (S)  | 0.025 max        | 0.015 max        |
| Copper (Cu)  | 0.03 max         | 0.01 max         |
| Titanium dioxide (TiO <sub>2</sub> )                                   | 0.35 max         |                  |

Source: Midrex

<sup>4</sup> Fastmarkets. *Understanding the high-grade iron ore market*. 2021.

<sup>5</sup> IIMA. *OBMS & Carbon Neutral Steelmaking Whitepaper 3: Future DRI Production & Iron Ore Supply*. May 2022.

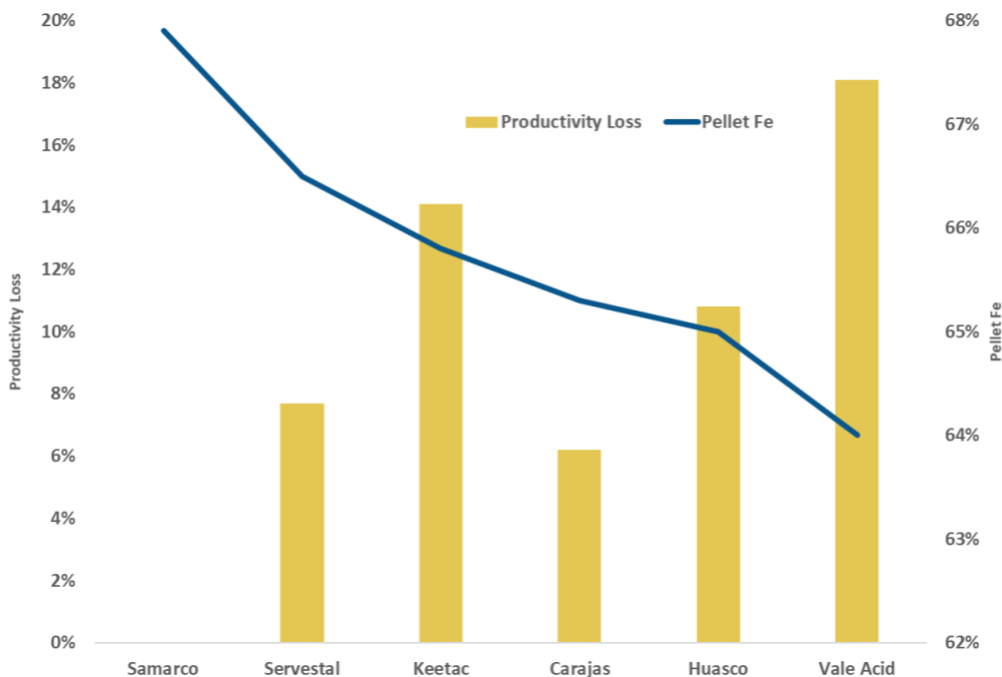
<sup>6</sup> IIMA. *OBMS & Carbon Neutral Steelmaking Whitepaper 3: Future DRI Production & Iron Ore Supply*. May 2022.

<sup>7</sup> Midrex. *Direct From Midrex Fourth Quarter 2019*.

The DRI melting yield in an EAF depends on the metallic iron content and level of acid gangue, silica ( $\text{SiO}_2$ ) and alumina ( $\text{Al}_2\text{O}_3$ ). Higher iron ore content and lower gangue are preferred. More basic flux, calcium oxides ( $\text{CaO}$ ), is needed to maintain the basicity of slag and to negate excessive acid gangue (silica and alumina), which leads to more slag production and a higher amount of iron in the slag. With a slight increase in impurities, iron unit loss in the form of  $\text{FeO}$  could amount to 15% in overall yield.<sup>8</sup>

Figures 1 and 2 show the EAF productivity loss for various grades of iron ore pellets from different producers and mines. Productivity is affected by both iron content and gangue content of the iron ore. Lower-grade pellets increase the final cost of the steel made using a DRI-EAF process, as more pellets are needed to compensate for the loss in productivity.

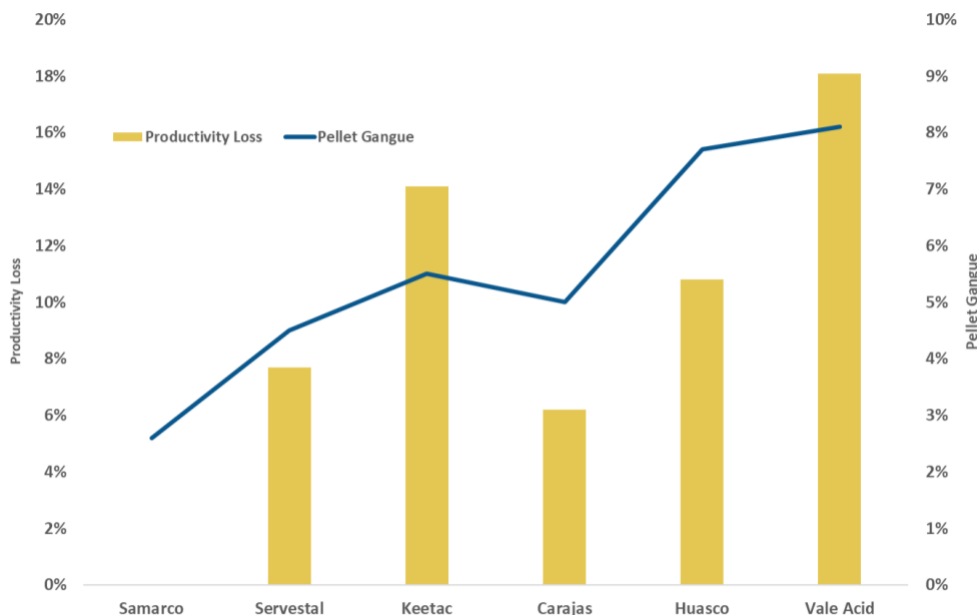
**Figure 1: Pellet Fe% and Productivity Loss, 92% Metallisation, 2% Carbon**



Source: IIMA

<sup>8</sup> Midrex. [Maximizing Iron Unit Yield from Ore to Liquid Steel \(Part 3\) – Melting Practice](#). June 2020.

**Figure 2: Pellet Gangue and Productivity Loss, 92% Metallisation, 2% Carbon**



Source: IIMA

## DRI-Melter-BOF

A solution to limited supply of DR-grade iron ore is to use an alternative configuration of existing technologies that allows the use of lower-grade iron ore in DRI processes.

A melting stage can be added to melt the DRI before being charged in a BOF instead of an EAF to produce high quality steel. BOFs have greater tolerance for ores of lower iron content than EAFs. Some steel producers are investigating and developing installations along these lines.

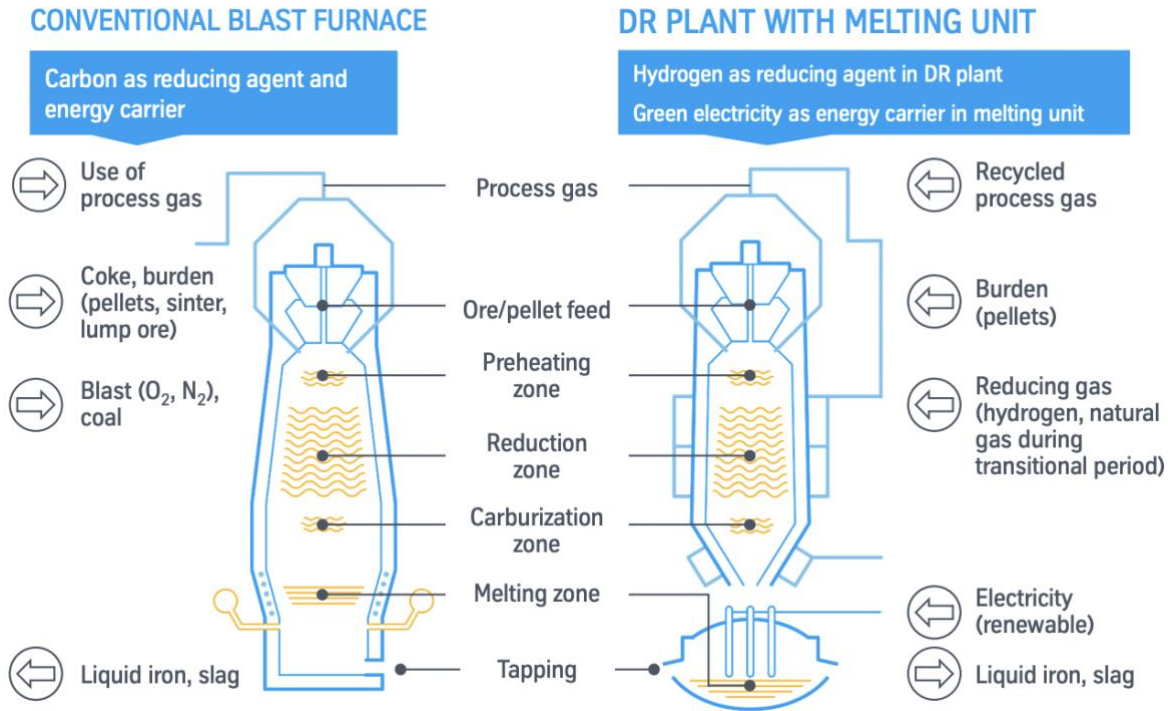
### Thyssenkrupp

Thyssenkrupp is planning a new steelmaking route that adds a submerged arc furnace (SAF) melting stage after DRI production before sending it to an existing BOF. The company's plan is to replace four BFs with new DRI-SAF installations by 2045, with the first two to be replaced in 2025 and 2030 respectively.<sup>9</sup> The proposed DRI-SAF-BOF configuration will allow Thyssenkrupp to use blast furnace-grade iron ore in its DRI processes. BF-grade pellets contain 65% iron or less.

Submerged arc furnaces are widely used in ferroalloy production. In addition to allowing the use of more plentiful lower-grade iron ore, another benefit of Thyssenkrupp's solution is that will be integrated with existing steelmaking and processing facilities.

<sup>9</sup> Thyssenkrupp. [Charts on Q1 FY2021/22](#). March 2022.

**Figure 3: ThyssenKrupp’s Technology Pathway for Transition from Blast Furnaces**

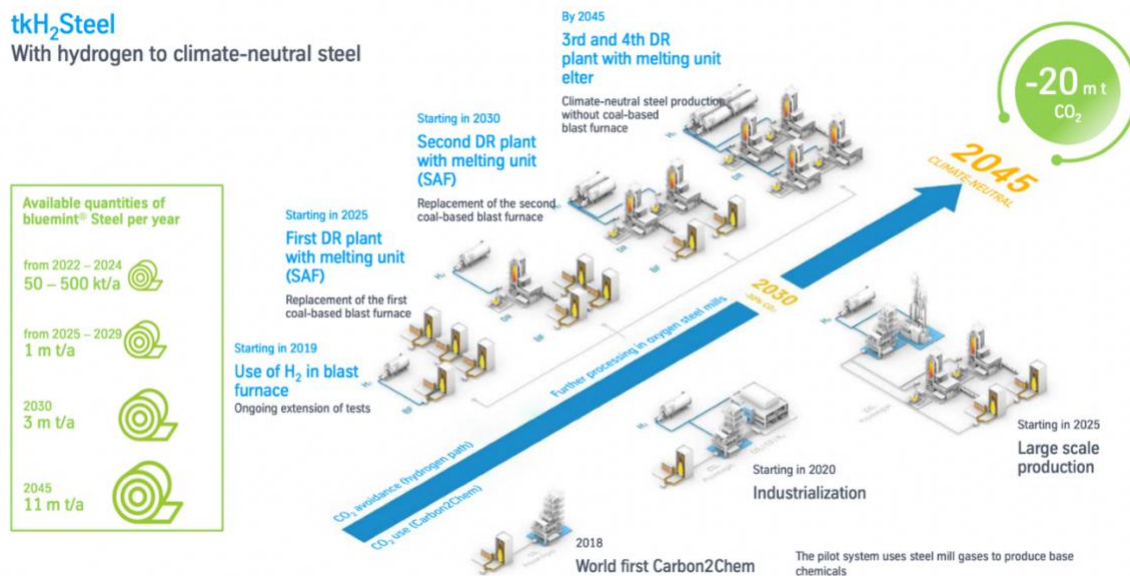


Source: ThyssenKrupp

By 2030, ThyssenKrupp intends to reduce its carbon dioxide (CO<sub>2</sub>) emissions by 30% and wants to produce 0.4 million tonnes (Mt) of “green steel” by 2025 and 3Mt by 2030. The first DRI plant capacity will be 1.2Mt and is planned to start by using natural gas as the source of the reductant before switching to hydrogen.<sup>10</sup>

<sup>10</sup> ThyssenKrupp. Electrical hot metal from blast furnace 2.0: thyssenkrupp presents Federal Economics Minister Altmaier and State Premier Laschet innovative concept for green transformation of Duisburg steel mill. 28 August 2020.

Figure 4: ThyssenKrupp’s Timeline for Blast Furnace Replacement



Source: ThyssenKrupp

### ArcelorMittal

Global steel giant ArcelorMittal is also looking at the DRI-SAF technology route. In March 2021 the company announced a memorandum of understanding (MoU) with Air Liquide to examine using this technology combination at ArcelorMittal’s Dunkirk site using hydrogen as the reductant.<sup>11</sup> The Dunkirk plant currently has three blast furnaces with a total annual capacity of 7Mt.

The new plant is envisaged to start by 2025 with a capacity of 2Mt hot metal per year and will use low carbon hydrogen in the process.<sup>12</sup> The project is planned to reduce yearly CO<sub>2</sub> emissions at the Dunkirk site by 2.85Mt by 2030.

### BlueScope

BlueScope is also investigating a DRI-Melter-BOF steelmaking route to allow the use of lower-grade ores.<sup>13</sup> In October 2021, the company announced an MoU with Rio Tinto to investigate technology that would allow the use of Rio’s blast furnace-grade Pilbara iron ore in DRI processes.<sup>14</sup> For Rio Tinto, this represents a potential pathway for continued use of its Pilbara ores in a decarbonising global steel industry.

<sup>11</sup> ArcelorMittal. Air Liquide and ArcelorMittal join forces to accelerate the decarbonisation of steel production in the Dunkirk industrial basin. 17 March 2021.

<sup>12</sup> ArcelorMittal. Climate Action Report 2. July 2021.

<sup>13</sup> BlueScope. BlueScope and Rio Tinto sign MOU for low-emissions steelmaking at PKSW. 29 October 2021.

<sup>14</sup> Rio Tinto. Rio Tinto and BlueScope to explore low carbon-steelmaking pathways. 28 October 2021.



The electric melter step is responsible for removing impurities and gangues from the iron ore in the form of slag. In this new potential pathway, the existing BOF remains, reducing capital expenditure required.<sup>15</sup> However, BlueScope's current priority at its Port Kembla site is a blast furnace relining at a cost of A\$1 billion to allow continued blast furnace operations at Port Kembla for a further 20 years.<sup>16</sup>

## *Tenova*

Tenova's vice-president for Strategic Initiative and development, Marco Corbella, has recognised that the scarcity of the high-quality iron ore poses a challenge for steel decarbonisation.<sup>17</sup> The Italian steel technology company is developing a new process to produce direct reduced iron using lower quality (BF-grade) pellets. The company is developing iBLUE, a combination of direct reduction ironmaking technology and a new melting process – an open slag bath furnace (OSBF).

**The Italian steel technology company is developing a new process to produce direct reduced iron using lower quality (BF-grade) pellets.**

The main difference between OSBF and a submerged arc furnace (SAF) is the position of electrodes in the furnace. In the OSBF the electrode is on top of the furnace and generates a brush arc or open arc, while in SAF electrodes are submerged in the raw materials.

The OSBF can use direct reduced BF-grade pellet as feedstock and produce pig iron that can be processed in a basic oxygen furnace to convert into steel. The pig iron has a high level of carbon and is almost the same quality as conventional blast furnace hot metal.<sup>18</sup>

Tenova claims that this technology could reduce emissions by 40% compared to conventional blast furnaces.<sup>19</sup> However, by using hydrogen in the ironmaking step, renewables to power the furnace and carbon capture, the iBLUE process could reduce emissions around 90% compared to a blast furnace process.<sup>20</sup> The company also claims that its iBLUE process is cost competitive with DRI-EAF technology.<sup>21</sup>

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<sup>15</sup> BlueScope. [BlueScope Investor Day](#). 20 September 2021.

<sup>16</sup> BlueScope. [No.6 Blast Furnace Reline at Port Kembla](#).

<sup>17</sup> S&P Global. [Feature: Blast furnace substitution, pelletizing retirement to help cope with poorer iron ore feeds](#). 02 June 2022.

<sup>18</sup> ESTEP. [Production of green pig iron without CO2 Emissions](#). 30 May 2022.

<sup>19</sup> S&P Global. [Feature: Blast furnace substitution, pelletizing retirement to help cope with poorer iron ore feeds](#). 02 June 2022.

<sup>20</sup> ESTEP. [Production of green pig iron without CO2 Emissions](#). 30 May 2022.

<sup>21</sup> MDPI. [Integration of Open Slag Bath Furnace with Direct Reduction Reactors for New-Generation Steelmaking](#). 21 January 2022.

## Hydrogen-Based Fluidised Bed Reduction

Fluidised bed reactor (FBR) technology is an alternative direct reduction process that enables use of iron ore fines – the most abundant ore type on the global market - directly without the need for pelletising or agglomeration, giving it advantages in terms of cost and efficiency over shaft furnace-based DRI which is charged with iron ore pellets.

In FBR, the fluid is a reducing gas, passed through iron ore particles at sufficiently high velocity to suspend them. The iron ore reacts with the reducing gas (carbon monoxide/hydrogen) in a series of reactors to reduce the ore to iron.

Where the fine ores used in FBR processes have an iron content below DR-grade, then such processes would help address the DR-grade iron ore supply hurdle going forward. Numerous studies have investigated the potential ore types that can be used.<sup>22, 23, 24</sup>

The under-development hydrogen-based technologies of HyREX, Circored and HYFOR could support steel decarbonisation as these technologies adopt fluidised bed reactor technologies with hydrogen as a reducing gas.

### HyREX

South Korean steelmaker POSCO is developing a hydrogen-based reduction method, HyREX, using 100% hydrogen, based on its existing FINEX technology.

The process begins with a three-stage fluidised-bed reactor, which is charged with fine iron ore with a grain size of up to 8mm. The ore descends through reactors and is reduced to iron via hydrogen. Unlike the FINEX process, in the next stage the DRI employs an electric furnace instead of a melter-gasifier. The electric furnace can potentially be powered with renewable energy.

As with DRI-EAF, all the impurities would remain in the reduced iron and using low-quality iron ore might affect productivity and operational factors. It is not clear what Fe content requirements are for iron ore used in the HyREX process although the

**The electric furnace  
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<sup>22</sup> Particuology. [Fluidization behavior and reducibility of iron ore fines during hydrogen-induced fluidized bed reduction](#). Volume 52. October 2020.

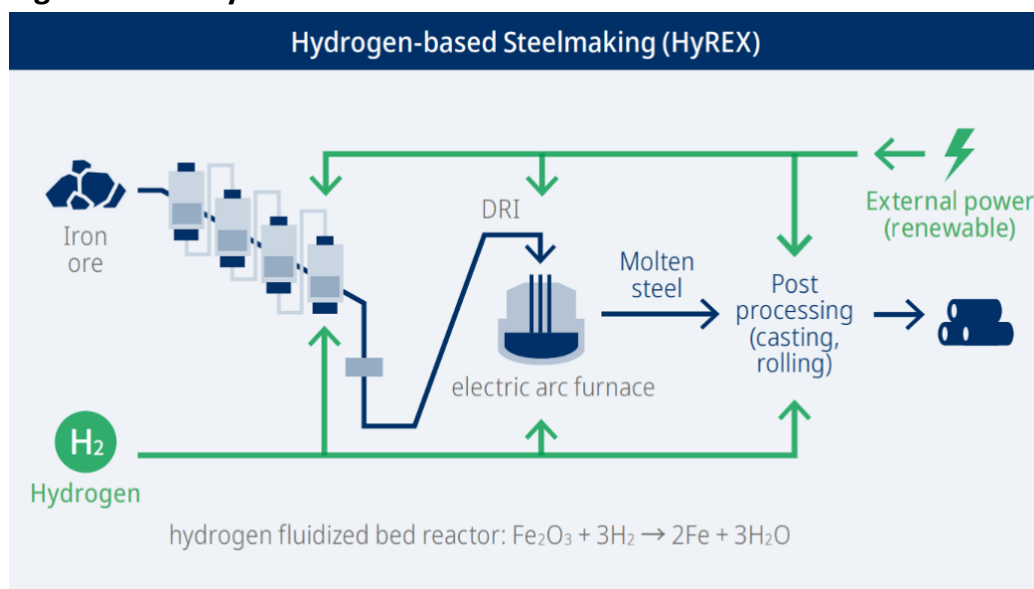
<sup>23</sup> Metallurgical and Materials Transaction B. [Influence of a Prior Oxidation on the Reduction Behavior of Magnetite Iron Ore Ultra-Fines Using Hydrogen](#). 21 December 2021.

<sup>24</sup> Metallurgical and Materials Transaction B. [Effect of Prior Oxidation on the Reduction Behavior of Magnetite-Based Iron Ore During Hydrogen-Induced Fluidized Bed Reduction](#). 1 June 2021.

FINEX process upon which it is based can use iron ore with an Fe content of 65% (i.e., below DR-grade). The process works with iron ore fines (0-8mm), which generally have lower quality than DR-grade pellets. POSCO states that the use of iron ore fines with lower price and wider availability than pellets is a better solution than direct reduction in shaft furnaces as it avoids the issue of limited global pelletisation capacity.<sup>25</sup>

POSCO intends to build a HyREX test facility with a 1Mt annual capacity by 2028.

**Figure 5: The HyREX Process**



Source: POSCO

## Circored

Circored is the first process using 100% hydrogen for fine iron ore direct reduction proven in an industrial-scale demonstration plant. The first and only plant, in Trinidad, commenced in 1999 with annual capacity of 500,000 tonnes of hot briquetted iron (HBI) per annum. Operations ceased after a couple of months, having produced 300,000 tonnes of high-grade HBI. The technology provider reported normal function during that time and cited changes in ownership, political issues and natural gas scarcity as reasons for the stoppage.<sup>26</sup> Renewed interest in hydrogen-based DRI has led to a relaunching of the Circored process by developer Metso Outotec.<sup>27</sup>

<sup>25</sup> POSCO. [Great Conversion to Low-carbon Eco-friendly Steelmaking Process ① HyREX](#). 02 June 2022.

<sup>26</sup> Metso Outotec. [Circored Fine Ore Direct Reduction – a proven process to decarbonize steelmaking](#). 18 November 2021.

<sup>27</sup> IIMA. [OBMS & Carbon Neutral Steelmaking Whitepaper 3: Future DRI Production & Iron Ore Supply](#). May 2022.

The Circored process involves a circulating fluidised bed (CFB) and a downstream bubbling fluidised bed (FB). The technology works with various iron ore sizes from ultrafine concentrate to particle sizes up to 6mm. As an ironmaking technology producing hydrogen (H<sub>2</sub>)-DRI and H<sub>2</sub>-HBI, which must be processed in EAF to produce steel, Circored appears to be a potential solution to a lack of global pelletisation capacity rather than a lack of DR-grade iron ore. However, Metso Outotec state that for lower-grade iron ores, “a combination of a single reduction stage Circored process (metallization degree of 75 – 85%) with smelting reduction in an electric smelter for hot metal production is feasible.”<sup>28</sup>

## **HYFOR**

HYFOR (hydrogen-based fine ore reduction), a technology being developed by Primetals, uses iron ore concentrate with particle sizes smaller than 0.15mm. In April 2021, the pilot plant was commissioned at the Voestalpine plant in Donawitz, Austria. The technology uses 100% hydrogen as a reduction agent. Providing green hydrogen and green electricity to power the EAF could allow potentially zero-emissions steel production. Testing is being carried out with various iron ore grades and Primetals has said the plant could be charged with both hematite and magnetite.<sup>29</sup>

As with other fluidised bed technologies, cost and energy savings are made from not requiring iron ore pelletisation or agglomeration. However, Primetals are testing iron ores in the HYFOR process with Fe content at or below 65% so this technology could also provide part of the solution to limited supplies of DR-grade iron ore for low-carbon steelmaking.

**Primetals are testing  
iron ores in the HYFOR  
process with Fe content  
at or below 65%**

<sup>28</sup> Metso Outotec. [Fine Ore Direct Reduction](#). 2021.

<sup>29</sup> Primetals. [HYFOR pilot plant under operation – the next step for carbon free, hydrogen-based direct reduction is done](#). 24 June 2021.

## Glossary

|                                    |  |
|------------------------------------|--|
| <b>Al<sub>2</sub>O<sub>3</sub></b> | Alumina  |
| <b>BF-grade</b>                    | Blast furnace-grade iron ore                                   |
| <b>BOF</b>                         | Basic Oxygen Furnace   |
| <b>BF-BOF</b>                      | Blast Furnace-Basic Oxygen Furnace                             |
| <b>CaO</b>                         | Calcium Oxides   |
| <b>CFB</b>                         | Circulating fluidised bed                                      |
| <b>CO<sub>2</sub></b>              | Carbon dioxide   |
| <b>Cr</b>                          | Chromium   |
| <b>Cu</b>                          | Copper   |
| <b>DR-grade</b>                    | Direct reduction-grade iron ore                                |
| <b>DRI</b>                         | Direct Reduced Iron  |
| <b>DRI-EAF</b>                     | Direct Reduced Iron-Electric Arc Furnace                       |
| <b>DRI-Melter-BOF</b>              | Direct Reduced Iron-Melter-Basic Oxygen Furnace                |
| <b>DRI-SAF</b>                     | Direct Reduced Iron-Submerged Arc Furnace                      |
| <b>DRI-SAF-BOF</b>                 | Direct Reduced Iron-Submerged Arc Furnace-Basic Oxygen Furnace |
| <b>EAF</b>                         | Electric Arc Furnace   |
| <b>FB</b>                          | Fluidised bed  |
| <b>Fe</b>                          | Iron   |
| <b>FBR</b>                         | Fluidised bed reactor  |
| <b>H<sub>2</sub></b>               | Hydrogen   |
| <b>HBI</b>                         | Hot briquetted iron  |
| <b>HYFOR</b>                       | Hydrogen-based fine ore reduction                              |
| <b>MgO</b>                         | Magnesium oxide  |
| <b>MoU</b>                         | Memorandum of Understanding                                    |
| <b>Mt</b>                          | Million tonnes   |
| <b>Ni</b>                          | Nickel   |
| <b>OSBF</b>                        | Open Slag Bath Furnace   |
| <b>P<sub>2</sub>O<sub>5</sub></b>  | Phosphorous pentoxide  |
| <b>S</b>                           | Sulphur  |
| <b>SAF</b>                         | Submerged Arc Furnace  |
| <b>SiO<sub>2</sub></b>             | Silica   |
| <b>TiO<sub>2</sub></b>             | Titanium dioxide   |
| <b>V</b>                           | Vanadium   |

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