THE USE OF HYDROGEN IN THE IRON AND STEEL INDUSTRY

Presented by Ed Green
BERRY METAL COMPANY

- Over 65 years of experience
- Experience in EAF, BOF and Blast Furnaces
- ISO 9001:2008 Certified
- Over 75 Patents, several Pending
- Locations (Pittsburgh & Greater Chicago Area)
- Equipment Engineering and Manufacturing Company
- OEM Supplier of Components
- On-Site Technical Support
- Continuous Product Improvements
STEEL MAKING TECHNOLOGIES AND PROCESSES FOR IRON FEEDSTOCK

- BOF – Basic Oxygen Furnace
  - BF - Blast Furnace
  - SR – Smelting Reduction
- EAF – Electric Arc Furnace
  - Scrap steel
  - DRI – Direct Reduced Iron

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Chemical Processes to Reduce Iron Oxide

Reduction by CO

- $\text{Fe}_3\text{O}_4 + \text{CO} = 3\text{FeO} + \text{CO}_2$
- $\text{FeO} + \text{CO} = \text{Fe} + \text{CO}_2$

Consumes $500 \text{Nm}^3/\text{t}_{\text{iron}}$ of CO

Reduction by $\text{H}_2$

- $\text{Fe}_3\text{O}_4 + \text{H}_2 = 3\text{FeO} + \text{H}_2\text{O}$
- $\text{FeO} + \text{H}_2 = \text{Fe} + \text{H}_2\text{O}$

Consumes $500 \text{Nm}^3/\text{t}_{\text{iron}}$ of $\text{H}_2$
BF/BOF - Blast Furnace feeding a Basic Oxygen Furnace has dominated the ironmaking process since the 1980s.

Environmental regulations are causing a significant decline of the BF method of making iron.

Although still the base source of virgin iron, new blast furnaces have not been built in the U.S. in decades and there are no plans to build one anytime soon. The U.S. steel industry is currently undergoing transformation.
EAF - Electric Arc Furnace for steel making is a rapid growing technology competing with the BF/BOF
• Major feedstock is scrap steel
• The purity of existing scrap steel is declining and needs virgin iron added to dilute the tramp elements such as copper and zinc to improve final product quality
• DRI – Direct Reduced Iron is one of the iron products added to the scrap to increase purity
• DRI is iron ore that has been reduced to iron with syngas without melting
• DRI processes in U.S. generally use natural gas to reduce the ore
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Established DRI Technology Competing with BF/BOF

Midrex
Reformer outside of reactor
Creating syngas H2 & CO

HYL III
Partial oxidation of gas entering reactor
Creating syngas H2 & CO

Depictions taken from IETD Industrial Efficiency Technology Database
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FLASH IRONMAKING TECHNOLOGY USING HYDROGEN

Current Partners
American Iron and Steel Institute
U.S. Department of Energy
Berry Metal Company
ArcelorMittal USA
TimkenSteel
U.S. Steel
University of Utah
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Flow Diagram for Flash Ironmaking Plant

Iron Ore In

Natural Gas In

H2 Storage

H2 In

MSR

H2 Heater

Air In (for transferring heat)

H2 Recycle

Particle Heater

H2 + H2O

Fe3O4 + 4H2 = 3Fe + 4H2O

While Falling

H2 + H2O

Reactor

Air Out

Dryer

Iron Ore In

Cooling Water

Iron Out
### Energy Usage for Ironmaking Comparison of Existing Reduction Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Energy Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast Furnace</td>
<td>16.7 GJ/t</td>
</tr>
<tr>
<td>Midrex</td>
<td>10.4 GJ/t</td>
</tr>
<tr>
<td>HYL III</td>
<td>10.4 GJ/t</td>
</tr>
<tr>
<td>Flash Ironmaking</td>
<td>10.8 GJ/t</td>
</tr>
<tr>
<td>Iron Carbide Process</td>
<td>12.6 GJ/t</td>
</tr>
<tr>
<td>Finmet</td>
<td>12.4 GJ/t</td>
</tr>
<tr>
<td>Circored</td>
<td>11.5 GJ/t</td>
</tr>
</tbody>
</table>

Data taken from IETD Industrial Efficiency Technology Database

10.8 GJ/t is a conservative calculation based on maximum users during commercial scale operations. Actuals could be lower.
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FLASH IRONMAKING ENERGY BREAKDOWN 10.8 GJ/t

- Natural Gas for Hydrogen: 42%
- Natural Gas for Fuel: 24%
- Reactor Electric Heating: 24%
- Exhaust Gas Recovery: 6%
- Misc: 4%

Energy Breakdown (GJ/t)
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OPERATING PROFILES

Blast Furnace
  Operating temperature 250°C @top to 1650°C @bottom
  Residence time is 8 to 10 hrs

DRI Furnace
  Operating temperature 1090°C
  Residence time is 10 to 12 hrs

Flash Ironmaking Furnace
  Operating temperature 1325°C
  Residence time is 2 to 10 seconds

Residence time is a combination of speed of reaction due to temperature, size of the feed material and amount of excess gas/distance from equilibrium line.
Fe/FeO Equilibrium Diagram

**WHY HYDROGEN?**

- Low temperatures CO more effective at reducing FeO
- High temperatures H₂ more effective at reducing FeO

FeO

CO₂/CO

H₂O/H₂

Fe

**DRI Operational Range**

reduce all FeO requires
2X excess H₂
1.7 GJ/t to heat to 1325°C

**Flash Iron Operational Range**

Reduce all FeO requires
10X excess CO
9.4 GJ/t to heat to 1325°C

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