A Novel Flash Ironmaking Process
DE-EE0005751
American Iron and Steel Institute/University of Utah
09/01/2012 - 07/31/2017

Joseph Vehece, American Iron and Steel Institute

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
May 28-29, 2015

This presentation does not contain any proprietary, confidential, or otherwise restricted information.
Project Objective

• Develop a new ironmaking process with significant reduction in energy consumption and CO₂ generation

• Blast furnace requires coke and pelletization and/or sintering of iron ore concentrate
  • Consumes large amounts of energy and carbon → CO₂ emissions

• Alternative ironmaking processes must have:
  • Large production capacities (e.g., ~1,000,000 tpy of iron)
  • Use the main raw material (i.e., iron ore) with minimal pretreatment
Technical Approach

Novel Flash Ironmaking replacing cokemaking and Blast Furnace
Technical Approach

- Install and commission Large-Scale Bench Reactor
- Comprehensive testing program
- Industrial pilot plant design
- Multidisciplinary team:
  - American Iron and Steel Institute
    - ArcelorMittal USA
    - TimkenSteel
  - United States Steel Corporation
  - Berry Metal Company
    - Bench reactor fabrication
  - University of Utah
    - Lead Research Organization

Large-Scale Bench Reactor
(Image courtesy of Berry Metal Company)
## Transition and Deployment

<table>
<thead>
<tr>
<th>Project Objectives</th>
<th>Kinetic Feasibility</th>
<th>Proof of Concept at Lab Scale</th>
<th>Process Validation/Scale-up</th>
<th>Industrial Pilot TBD (2017+)</th>
</tr>
</thead>
</table>

### Experimental Apparatuses

- **Ceramic Reactor**
- **Sample Feeder**
- **Alumina Honeycomb High-Temperature Furnace**
- **Powder Collector & Filter**
- **Off-gas**

### Funding

<table>
<thead>
<tr>
<th></th>
<th>Federal, $350k</th>
<th>Industry, $150k</th>
<th>Total, $500k</th>
<th>Federal, $0</th>
<th>Industry, $4.8 million</th>
<th>Total, $4.8 million</th>
<th>Federal, $8.0 million</th>
<th>Industry, $2.6 million</th>
<th>Total, $10.6 million</th>
<th>$10 - 75 million Funding TBD</th>
</tr>
</thead>
</table>

### Approaches

1. Large scale: 75-100k tpy
2. Modest-scale: 10-25k tpy
3. Expand U of Utah work: Similar to bench reactor but larger

### The New Steel

*American Iron and Steel Institute*
Transition and Deployment

- Benefits steel users and steel-related industry
  - US Steel industry would be the end user
- Used to produce iron as a raw material for steelmaking resulting in:
  - Direct use of iron ore concentrate
  - Low capital cost
  - Scalable to large capacities
  - Avoidance of cokemaking
- Commercialization through licensing & royalty
- Sustainable as a more energy efficient and green ironmaking process
Measure of Success

- If successful, will produce iron at a lower cost using less energy and emit less CO$_2$
- Potential energy savings: ~3.5 GJ/ton Fe vs. avg. Blast Furnace
- CO$_2$ emission: < 36% vs. avg. Coke Oven/Blast Furnace route

<table>
<thead>
<tr>
<th>Metric</th>
<th>H$_2$-based process</th>
<th>Refomerless natural gas process</th>
<th>Blast Furnace process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Requirement (GJ/ton of hot metal)</td>
<td>11.3</td>
<td>14.5</td>
<td>18.0</td>
</tr>
<tr>
<td>CO$_2$ emission (tons/ton of hot metal)</td>
<td>0.04</td>
<td>1.02</td>
<td>1.60</td>
</tr>
</tbody>
</table>

### Project Management & Budget

#### Total Project Budget

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Key Inputs</th>
<th>Criteria</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Bench Scale Reactor</td>
<td>Installation, Commission</td>
<td>Go/No Go Decision # 1:</td>
<td>Operating Temperature: 1400°C</td>
<td>7/31/2015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solid feed rate: &gt;1 kg/hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operation time: &gt;6 hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Testing Program</td>
<td>Existing Utah flash reactor, Drop-tube reactor, Large Scale Bench Reactor, CFD model</td>
<td>Go/No Go Decision # 2:</td>
<td>Metallization: 95%</td>
<td>11/30/15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Min. amt. reducing gas: 3.0x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Go/No Go Decision # 3:</td>
<td>Metallization: 95%</td>
<td>5/31/16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Min. amt. reducing gas: 1.5x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Milestone # 4:</td>
<td>Metallization: 95%</td>
<td>11/30/16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solid feed rate: &gt;5 kg/hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Industrial pilot reactor</td>
<td>-Design and Cost estimate</td>
<td></td>
<td></td>
<td>4/30/17</td>
</tr>
<tr>
<td>4 Program Administration</td>
<td></td>
<td></td>
<td></td>
<td>7/31/17</td>
</tr>
</tbody>
</table>

#### Total Project Budget

<table>
<thead>
<tr>
<th>DOE Investment</th>
<th>$ 8,000,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Share</td>
<td>$ 2,600,000</td>
</tr>
<tr>
<td>Project Total</td>
<td>$10,600,000</td>
</tr>
</tbody>
</table>
Results and Accomplishments

- Completed formulation of CFD model for operation at different temperatures, gas compositions, and particles.
- Achieved 80-95% metallization:
  - Fuel/reductant: Hydrogen or Methane
  - Reaction time: 4-7 seconds
  - Temperature: ~1200°C → Target 1300°C
  - Solid feed rate: 0.1 – 0.2 kg/h
- Determined the kinetics of magnetite reduction with hydrogen using drop tube reactor at 1400 - 1600°C.
Next Steps

• Complete installation and commission large-scale bench reactor - July 2015
• Large-Scale Bench Reactor tests with Natural Gas - 2015/2016
  • Generate information on optimum operating temperature, gas velocity, reactor dimensions, and refractory type
• Industrial pilot plant design - April 2017
  • Construction of flow sheets
  • Complete material and energy balances
  • Design and cost estimate