A Novel Flash Ironmaking Process

DE-EE0005751

American Iron and Steel Institute/University of Utah

09/01/2012 – 8/31/2015

Joseph Vehec, American Iron and Steel Institute

U.S. DOE Advanced Manufacturing Office Peer Review Meeting
Washington, D.C.
May 6-7, 2014

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

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

• Blast furnace requires 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

Current practice
- Blast furnace (BF) produces >90% iron for steelmaking
- BF needs large capital investments
- High energy consumption in raw materials preparation and CO₂ emissions
- Use of special coals for cokemaking

New Approach – A Novel Flash Ironmaking Process
- Direct use of iron concentrate (~30 µm)
  - Bypass pelletizing and sintering
- Use of inexpensive, abundant natural gas [or hydrogen, coal gas]
  - No cokemaking required
  - Lower energy consumption
  - Less CO₂ emissions
- Rapid reaction rate and favorable Net Present Value (NPV)
Technical Approach

- Install, commission & conduct test on a new large bench reactor at the University of Utah

- Multidisciplinary team:
  - American Iron and Steel Institute
  - ArcelorMittal USA
  - The Timken Company
  - United States Steel Corporation
  - University of Utah (Lead Research Organization)
  - Berry Metal Company (Bench reactor fabrication)
## 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</th>
</tr>
</thead>
</table>

### Experimental Apparatuses

1. **Ceramic Reactor**
   - Alumina Honeycomb
   - High-Temperature Furnace
   - Powder Collector & Filter
   - Off-gas

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

### Funding

<table>
<thead>
<tr>
<th></th>
<th>Federal, $350k</th>
<th>Industry, $150k</th>
<th>Total, $500k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetic Feasibility</td>
<td>Federal, $0</td>
<td>Industry, $4.8million</td>
<td>Total, $4.8million</td>
</tr>
<tr>
<td>Process Validation/Scale-up</td>
<td>Federal, $7.1million</td>
<td>Industry, $1.8million</td>
<td>Total, $8.9million</td>
</tr>
</tbody>
</table>

- **Total, $10 - 75milllion**
- **Funding TBD**
Transition and Deployment

- Benefits steel users and steel-related industry
- U.S. Steel industry would be the end user
- To be 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 step
Measure of Success

- If successful, iron will be produced at a lower cost, using less energy, and emitting less CO₂.
- Potential energy savings: ~3.5 GJ/ton Fe vs. avg. BF.
- CO₂ emission: Less than 36% vs. avg. BF process.

<table>
<thead>
<tr>
<th>Metric</th>
<th>H₂-based process</th>
<th>Reformerless 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>CO₂ 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

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

### Total Project Budget

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE Investment</td>
<td>$7,120,000</td>
</tr>
<tr>
<td>Cost Share</td>
<td>$1,780,000</td>
</tr>
<tr>
<td>Project Total</td>
<td>$8,900,000</td>
</tr>
</tbody>
</table>

American Iron and Steel Institute
Results and Accomplishments

- Fabricated New bench reactor and ancillary equipment
- Designed/fabricated main burner – key component
- Prepared site for bench reactor installation

- Achieved 80-95% metallization in existing lab reactor*
- Fuel/reductant: Hydrogen
  - [Natural gas tests are planned]
- Reaction time: 4-6 seconds
- Temperature: ~1200°C
  - [less than 1300°C in bench reactor]

*Different from New Bench Reactor with respect to the size and material of construction, which limits the operating temperature. Solid feed rate is limited (~ 0.5 kg/hr).
Results and Accomplishments

- Measurement of reduction kinetics with natural gas using existing Lab reactor (2014)
- Computational Fluid Dynamic model development (2014-2016)
- Installation of new bench reactor (1Q15)
- Testing with new bench reactor (2015-2016)
- Industrial pilot plant design (2016)