# Novel Flash Ironmaking Technology (FIT)

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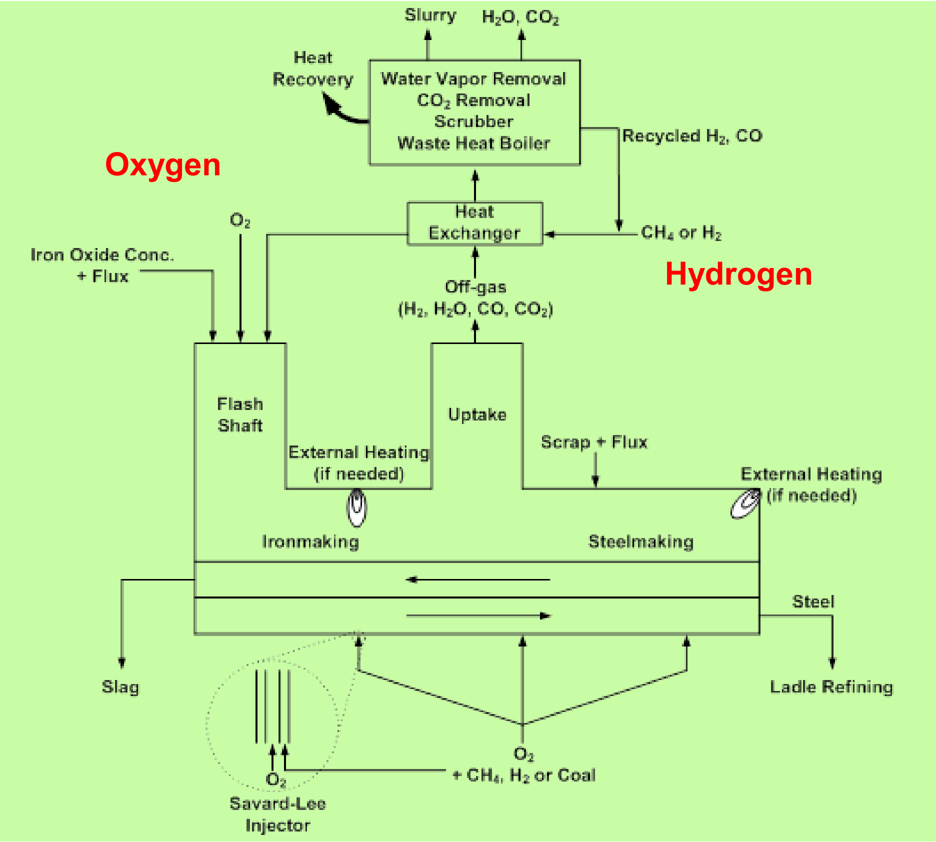
# Flash Ironmaking Technology (FIT)
# (FIT for H2@Scale)

$$Fe_3O_4 + (H_2, CO) \rightarrow Fe + (H_2O, CO_2)$$

Gas-Solid Suspension Reduction
Hydrogen or Natural Gas

- ✓ Fine iron ore WITHOUT Coke/Pelletization/Sintering
- ✓ Significant Reduction in $CO_2$ & Energy Consumption
- ✓ Replace BF




***Direct steelmaking process***
***based on Flash Ironmaking***

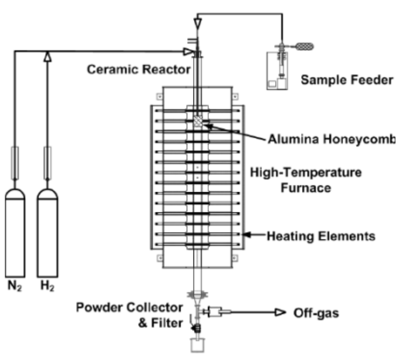
## *Flash Ironmaking Technology (FIT) – cont'd*

- Process based on proven flash technology, e.g. copper smelting furnaces
- Applicable to iron ore concentrates; magnetite from taconite, hematite-bearing jaspers, etc.
- Reducing/fuel gases include $H_2$ and $CH_4$

- **Magnetite taconite is the principal iron ore in the U.S.**
- **In 2008, the gross ore production in the U.S. was 54 MM tonnes.**
- **Minnesota (Mesabi Range) and Michigan (Marquette Range) mines account for almost all U.S. iron ore production.**

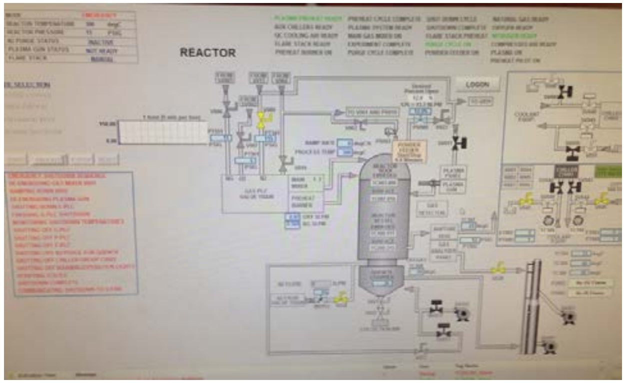
*Taconite ore: 70% concentrate, <100 μm*

# What Now and Next

| | | | | |
|---|---|---|---|---|
| Project Objectives | **Kinetic Feasibility**<br>Technology Road Map<br>(2005-2007) | **Proof of Concept at Lab Scale**<br>AISI $CO_2$ Breakthrough<br>(2008-2011) | **Process Validation/ Scale-up**<br>Innovative Manufacturing Initiative<br>(2012-2017) | **Industrial Pilot**<br>**TBD**<br>(2017+) |
| Experimental Apparatuses |  |  |  | Approaches<br>1. **Large scale** 75-100k tpy<br>2. **Modest-scale**: 10-25k tpy<br>3. Expand U of Utah work: Similar to bench reactor but larger |
| Funding | Federal, $350k<br>**Industry, $150k**<br>Total, $500k | Federal, $ 0<br>**Industry, $ 4.8M**<br>Total, $4.8M | Federal, $ 8.0<br>**Industry, $ 2.6M**<br>Total, $10.6M | $10 - 75M<br>**Funding TBD** |

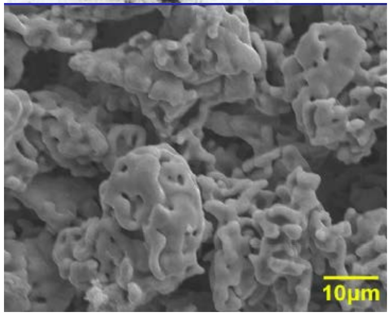
## *Flash Ironmaking Process*

*Pilot-scale furnace testing & demonstration*



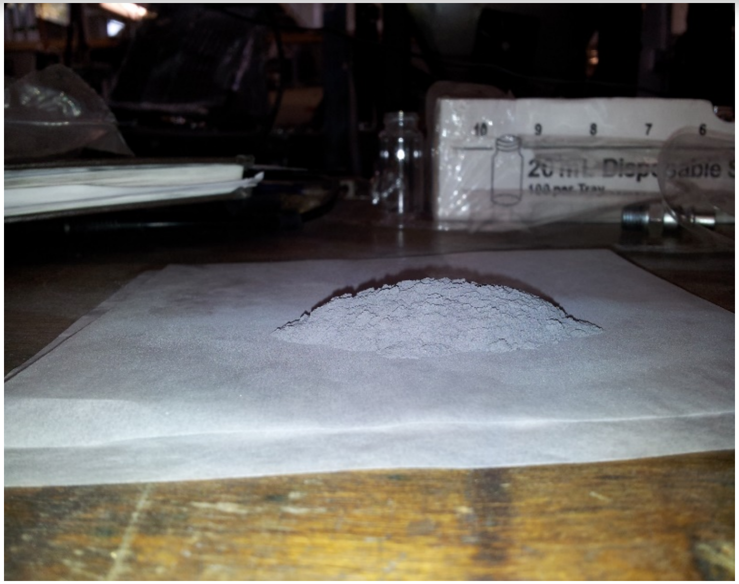

- Current Partners

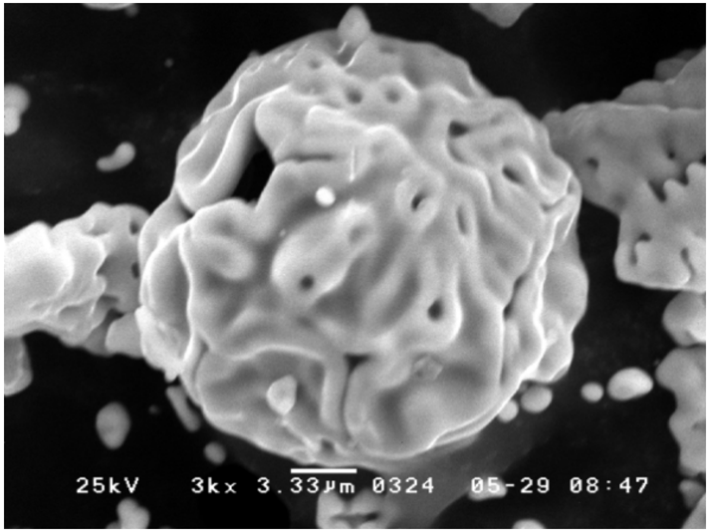
  AISI / DOE
  ArcelorMittal USA
  Berry Metal Co.
  Timken Steel
  U. S. Steel
  University of Utah



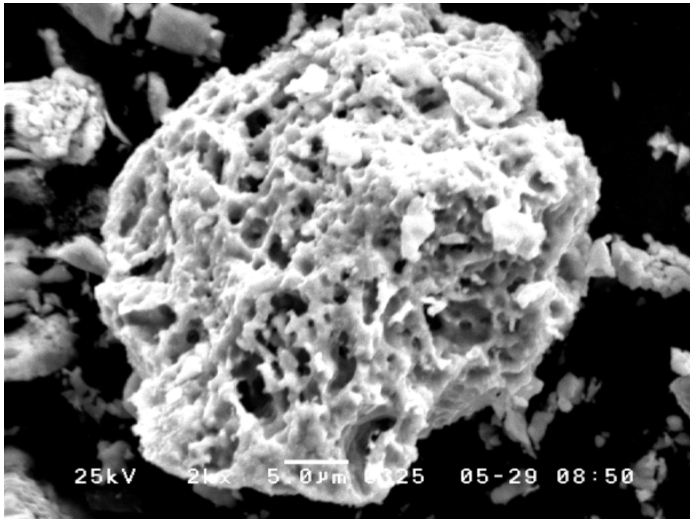

- Reduction with partial oxidation of natural gas, 1,200-1500°C
- Dimensional and residence time relative to commercial plant
- $10.6 Million cost-share project

# *FIT produces* *non-pyrophoric iron*



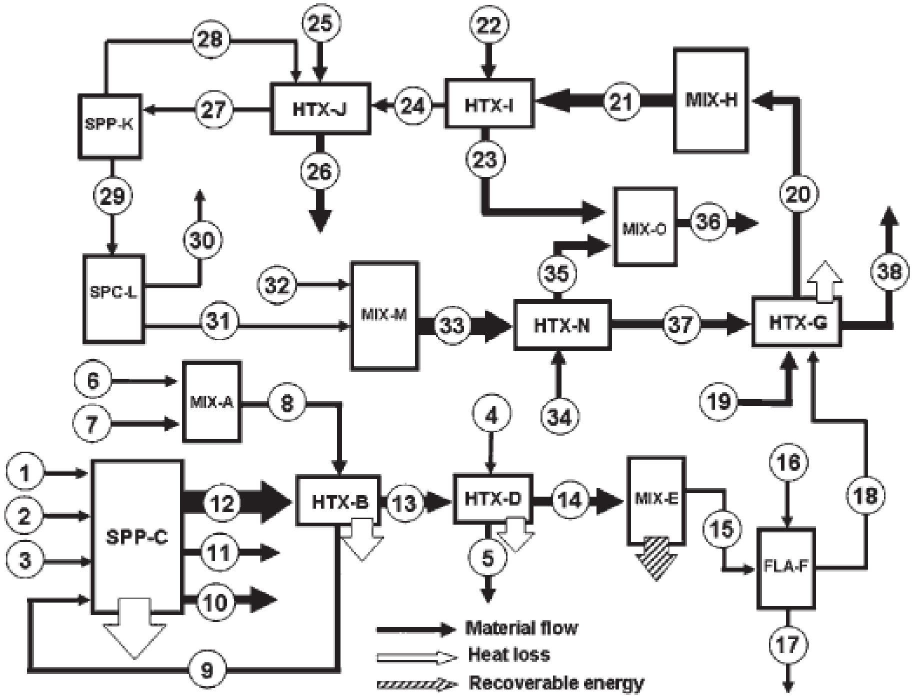


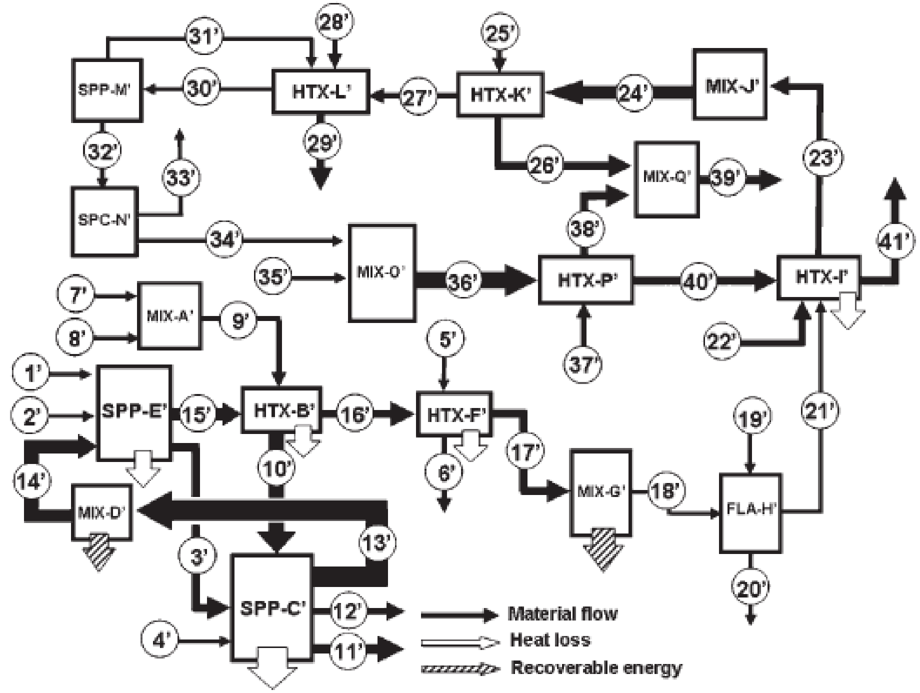

Flash reduced iron
at 1623 K (1350 ℃)



$H_2$-reduced iron
at 1073 K (800 ℃)

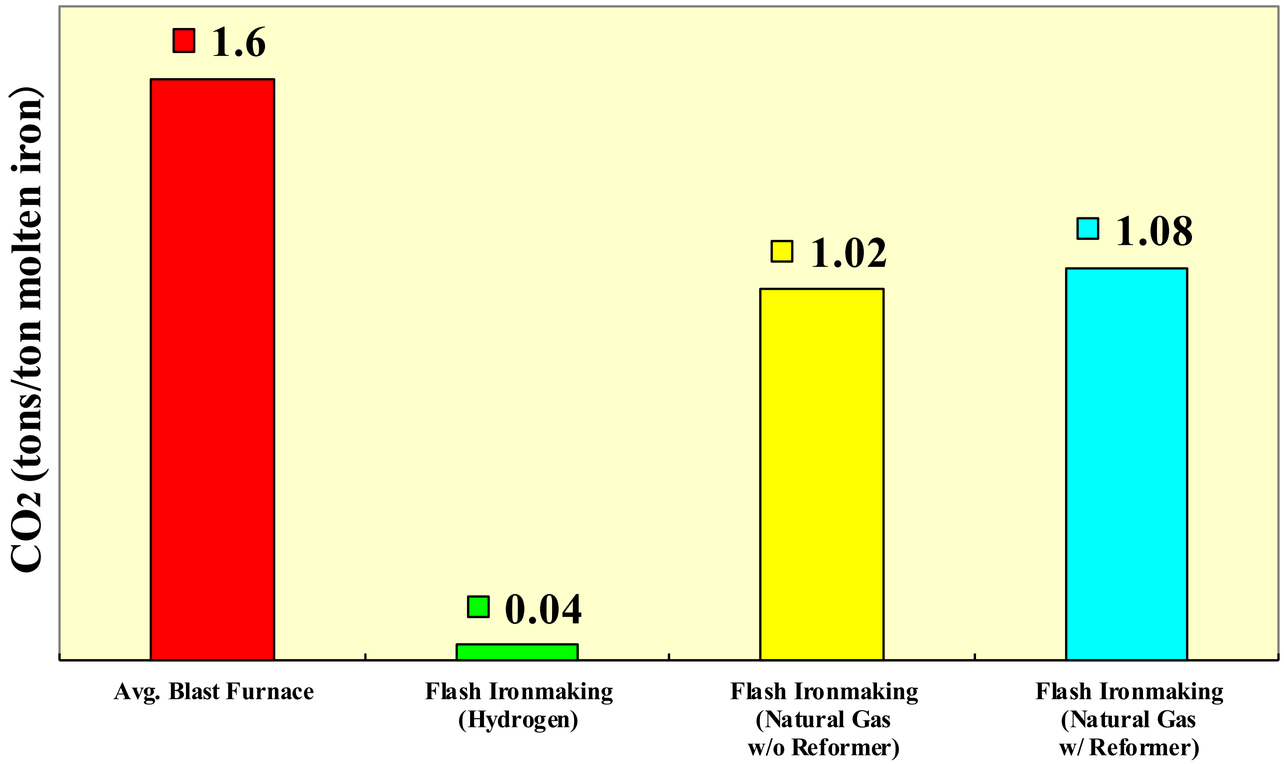
# Commercial-Scale Plant Modeling




- One-step and Two-step **commercial-scale** reformerless ironmaking process
- 1 million tons annual output, 300 day/yr operation
- 1,500 °C operation
- Excess driving force = 0.5
- METSIM process model

# $CO_2$ Emissions
## *(tons per ton iron)*



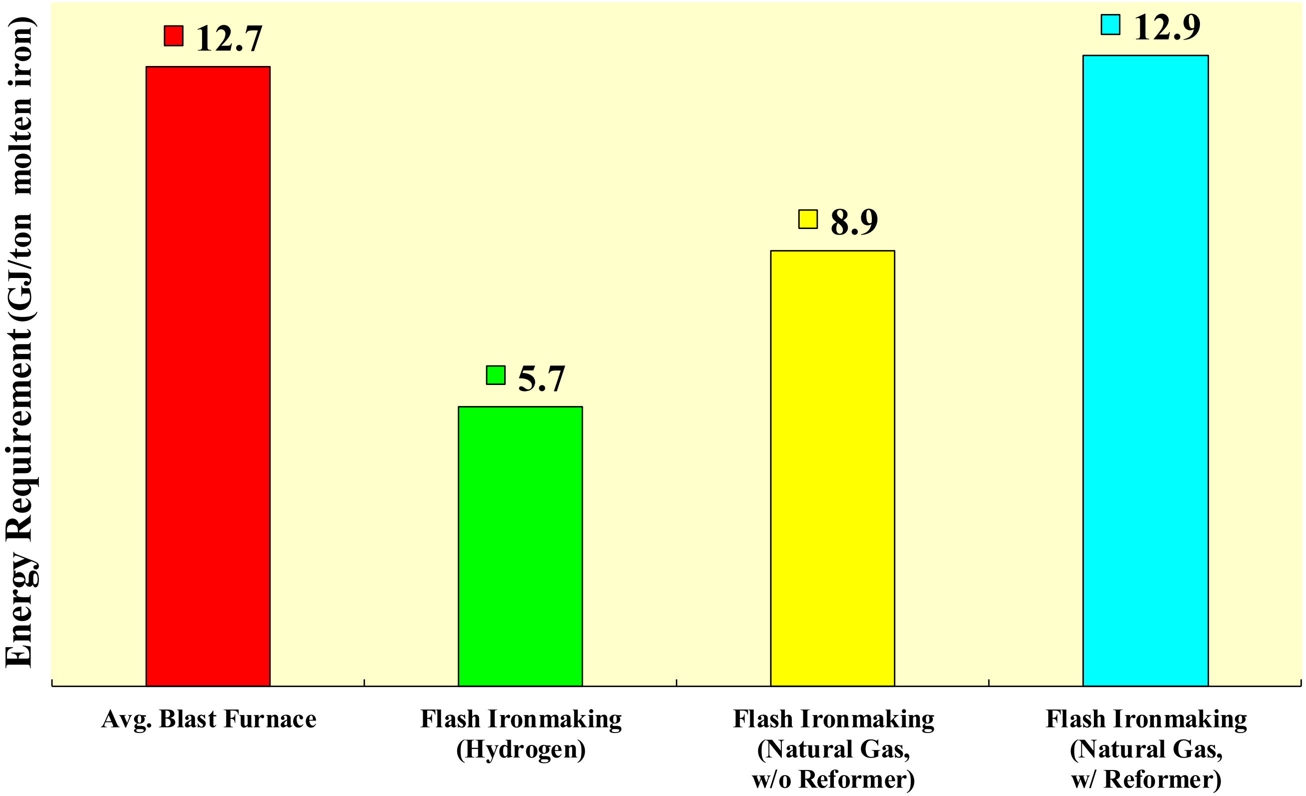

**Carbon dioxide emission from ore/coke preparation is not included.**

**% of BF = 2.5 % ($H_2$); 64 % (Natural Gas w/o Reformer)**

H. K. Pinegar, M. S. Moats, H. Y. Sohn, Iron and Steelmaking 2012

# Energy Requirement

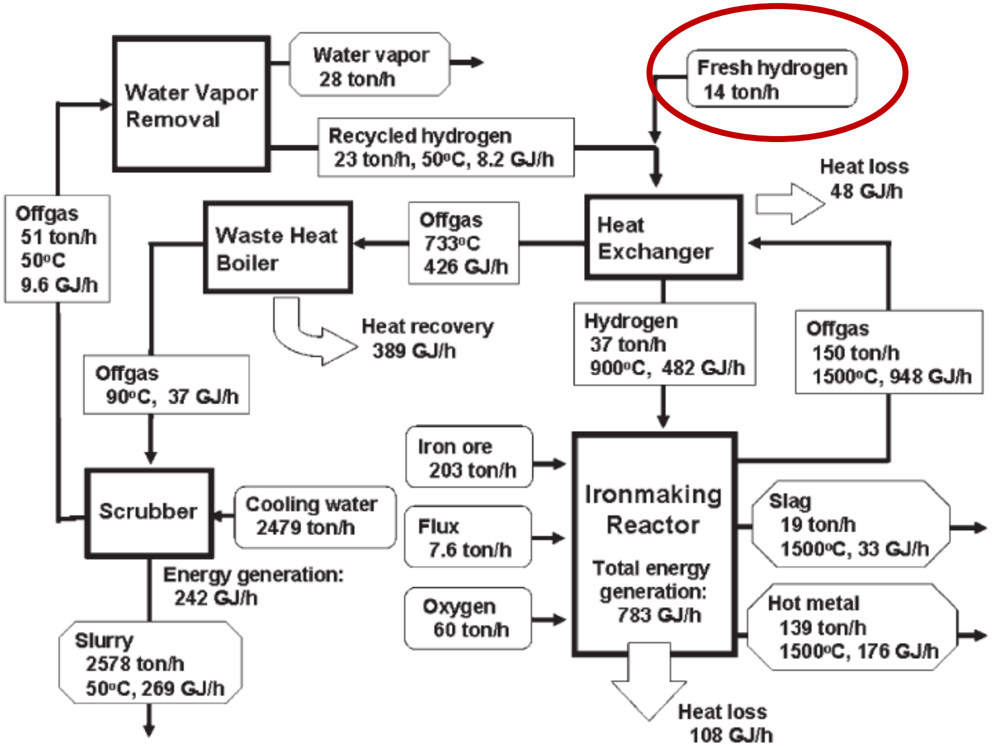
## *(GJ per metric ton molten iron)*




**Pelletizing = 3; Sintering = 0.7; Cokemaking = 2**

**% of BF = 45 % ($H_2$); 70 % (Natural Gas w/o Reformer)**

# Economic Feasibility – Hydrogen




- Hot metal price: \$512/ton
- Hydrogen cost: \$2.5/kg-$H_2$ (2010)
- 500,000 tons/yr hot metal
- 15 year capital project
- 10% discount rate

| | NPV (\$ Million) | |
|---|---|---|
| $CO_2$ emissions credit | 1-step process | 2-step process |
| No $CO_2$ emissions credit | –\$546 | –\$575 |
| \$13/ton of $CO_2$ | –\$394 | –\$423 |
| \$25/ton of $CO_2$ | –\$249 | –\$278 |
| \$50/ton of $CO_2$ | \$48 | \$19 |
| \$75/ton of $CO_2$ | \$346 | \$317 |
| \$100/ton of $CO_2$ | \$643 | \$614 |

H. K. Pinegar, M. S. Moats, H. Y. Sohn
"Process Simulation and Economic Feasibility Analysis for a Hydrogen-Based Novel Suspension Ironmaking Technology"
Steel Research Int. 82, 2011, No. 8.

NPV = (minus \$546 million), no $CO_2$ credit
NPV = \$48 million, with \$50/ton $CO_2$ credit

# *Financial Feasibility – Natural Gas*

| Carbon dioxide emission credit | NPV/$ million | | |
|---|---|---|---|
| | Reformerless one-step process | Reformerless two-step process | Ironmaking with built-in SMR process |
| No $CO_2$ emission credit | $401 | $232 | $214 |
| $13/ton of $CO_2$ | $471 | $315 | $277 |
| $25/ton of $CO_2$ | $533 | $398 | $332 |
| $50/ton of $CO_2$ | $657 | $557 | $449 |
| $75/ton of $CO_2$ | $789 | $723 | $567 |
| $100/ton of $CO_2$ | $920 | $882 | $685 |

- Hot metal price: $512/ton
- 1 million ton hot metal/year
- Natural gas feed: $5/million Btu
- 15 year capital project
- 10% discount rate

H. K. Pinegar, M. S. Moats, H. Y. Sohn
"Flowsheet development, process simulation and economic feasibility analysis for novel suspension ironmaking technology based on natural gas: Part 3 – Economic feasibility analysis"
Iron and Steelmaking 2013 vol.40 No.1

NPV = $401 for Reformerless one-step process
NPV = $214 for SMR Hydrogen Process

# Potential Implications

- $H_2$ Requirement = 0.1 ton / ton iron
- Rate of Iron Production (2015):
  U.S.+ Canada = 32.5 million tons/year
  World = 1.2 billion tons/year
- $H_2$ Equivalent:
  U.S.+ Canada = 3.3 million tons/y = $3.7 \times 10^{10}$ $m^3/y$
  World = 120 million tons/y = $130 \times 10^{10}$ $m^3/y$
- Reduction in $CO_2$ Emissions:
  U.S.+ Canada = 54 million tons/y
  World = 2 billion tons/y

## *Summary*

- **Low $CO_2$ emissions: 2.5% of BF ironmaking (w/ $H_2$)**
- **Energy saving: 3.0 GJ/ton Fe (55%) cf. BF (w/ $H_2$)**
- **Eliminate cokemaking and pelletization/sintering & associated pollution.**
- **90-99% reduction in 2-7 seconds at 1200-1500$^o$C**
- **Enormous hydrogen utilization potential**