Innovative uses of Hydrogen in Steelmaking

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I. The 2 Routes to Steelmaking
   I. Blast Furnace -> Basic Oxygen Furnace (BF/BOF)
   II. Electric Arc Furnace (EAF)
      I. Scrap
      II. Scrap Supplements
         I. Pig Iron, Direct Reduced Iron (DRI)

II. RD&D Needs for H₂ Steelmaking
   I. Emerging Routes
   II. Existing Routes: BF or EAF
DRI, HBI, & Pig

**Direct Reduced Iron:** DRI is typically produced in pellet form and can be loaded directly into an EAF, Blast Furnace, or Basic Oxygen Furnace. It contains a very high iron content (typically ≥90%). DRI exits the DRI module at a high temperature, and can be fed directly into furnaces as a means to reduce energy costs.

**Hot Briquetted Iron:** HBI is a compressed form of DRI that facilitates easier transportation and handling. HBI is formed as DRI exits the module, and it compressed while still hot. DRI reacts more easily with water and requires tighter standards for shipment, HBI is less reactive and ships easier.

**Merchant Pig Iron:** MPI is produced in a blast furnace and cast into small "pigs" suitable for transportation. MPI has a higher iron content (around 96%) and less slag elements than DRI or HBI, and will typically sell at a premium. That said, MPI, HBI, and DRI are all substitutes for one another.

*Source: Midrex*
U.S. Shifting from BF/BOF to EAF/DRI Steelmaking

Source: AISI
DRI: Current & Projected Production

- **Coal-based**: 63.1%
- **Other Gas**: 20.2%
- **HYL/Energiron**: 16.0%

Graph showing projected DRI production from 1970 to 2025.
Energy Efficiency & Emissions
EAF/DRI vs. BF/BOF

Source: Midrex calculations

100% Scrap to EAF
50% RKCDRI to EAF
50% CDRI to EAF
80% HDRI to EAF
90% CDRI to EAF
Pellet + hot metal to efficient BOF
Pellet + hot metal to inefficient BOF

Source: Midrex calculations

Total energy (MJ/ton liquid steel)

CO₂ production (kg CO₂/ton liquid steel)

-12.5%
voestalpine’s MIDREX NG® DR plant: Corpus Christi, TX
RD&D Needs for H₂ Steelmaking
Emerging Routes / Low CO₂ Steelmaking

- Hybrit (LKAB and SSAB)
- va PEM
- FIT (Sohn) - AISI
- ULCOS - Ultra-Low CO₂ Steelmaking – 45 Europe, 48 groups/15 countries; aim: 50%↓ CO₂.
  - HIsarna (Coal, sub bio or H₂)
  - ULCORED (DR w/Pox)
  - ULCOWIN (electrolysis of FeₓOᵧ)
- MEFOS
- Steelanol (PRI, AM)
  - recycle CO₂ into bioethanol
- Carbon2chem
- CDA
- Salzgitter
- China Steel
- Baowu
- Course50
- POSCO (nr 2009)
- CIRCORED (historical, not emerging)
RD&D Needs for H₂ in Steelmaking
Existing Routes: BF or EAF

### EAF
- H₂ for iron ore pelletizing?
  - $S$, $Q$, $E$, $R$, CAPEX/OPEX, equipment
- H₂ replace/supplement R-NG$_{(CO+H₂)}$
  - DRI/HBI product Quality
    - Physical: H₂ embrittlement, CCS, tumble, fines, sticking/cluster
    - Metallurgical: reducibility, metallization, carbon
  - Mass & Energy Balance
    - Flowsheet
    - Energy Efficiency
    - Production Rate
  - CAPEX/OPEX
  - Equipment (embrittlement)

### BF/BOF
- H₂ for iron ore pelletizing?
  - Any $Δ$ $S$, $Q$, $E$, $R$ in BF/BOF vs. EAF?
- Supplement coke by H₂
  - Fuel, reductant, structure
  - Steel Quality
- Mass & Energy Balance
  - Flowsheet
  - Energy Efficiency
  - Production Rate
- CAPEX/OPEX
- Equipment (embrittlement)

$S = $ Safety, $Q = $ Quality, $E = $ Efficiency, $R = $ Rate (throughput)
Thank You