MIDREX Flex™: Minimizing technology risks in the transition to carbon-free steelmaking

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Presentation outline

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About Midrex

- Headquartered in Charlotte, NC (USA)
  Research and Development Technology Center in Pineville, NC (USA)
- Midrex has a unique blend of existing and new technologies to create the sustainable future of iron & steel
- Our DR plants produce low CO$_2$ metallics for captive steel production (DRI) or for export to steelmakers around the world (HBI)
The Iron & Steel industry is responsible for around 7% of global CO₂ emissions (2.6 Gt CO₂ emissions annually).

To meet global and climate goals set by the IEA Sustainable Development Scenario (SDS), CO₂ emissions from the Iron & Steel industry must decrease by more than 50% by 2050.

The reduction in CO₂ emissions will come from implementation various technologies, including energy efficiency improvements and CCUS (carbon capture, utilization, and storage).

In the long-term, bio-energy, hydrogen and process electrification will play a prominent role in decarbonizing the steel industry.

There are many scenarios and roadmaps, but ALL included DRI/HBI with Natural Gas and Hydrogen.

Source: IEA Iron and Steel Technology Roadmap 2020
Flexibility of Low CO₂ Metallics

- Very high Technology Readiness
- Iron Ore and Energy Flexibility through the 30-year transition
- Compatible with existing integrated plants and future metallic hubs

**Energy Flexibility**
Natural Gas, H₂, COG, etc.

**Iron Ore Flexibility**
high Fe typically 67% and/or low Fe 63-66%

DR Plant
use low Fe
HDRI: to adjacent melter HBI: for transport & storage
use low Fe
BF
sinter/pellet
use high Fe
EAF
green pig iron
use low Fe
New Melter
hot metal
use low Fe
BOF
can be located remotely or adjacent to DR Plant
scrap
scrap
Viability of using $\text{H}_2$ as reductant

- Hydrogen should only be used as reductant, not as fuel

- MIDREX already uses Hydrogen for direct reduction (up to 80%)

- Our R&D and Engineering teams have been working for over 5 years on Technical Risk mitigation for the transition from Natural Gas to $\text{H}_2$-based DRI / HBI
  1. Process Design:
     - 100% $\text{H}_2$
     - NG $\rightarrow$ $\text{H}_2$ transition
  2. Equipment Design
  3. DRI and HBI Quality:
     - Furnace sticking and disintegration
     - Product quality for steelmakers

$\text{H}_2$ Reduced HBI
Produced at the Midrex Tech Center
1- Process Design

Transition from Fossil to Hydrogen Economy

**PRESENT**
- NG based DRI to electric melters
- **-50% Reduction**

**TRANSITION**
- NG+$H_2$ based DRI or NG based DRI with CCS to electric melters
- **~65-90% Reduction**

**FUTURE**
- $H_2$ DRI to electric melters
- **+90% Reduction**

Emissions compared to traditional steelmaking
1. Optimized for 100% H2
The MIDREX H2 plant can operate without any fossil fuel input. Hydrogen recovery in the Top Gas Fuel maximizes the process efficiency.

2. Electrical Heater
Strong collaboration with Midrex’s partner, Tutco Sureheat, allows for the application of direct electric heating to the Process Gas.

3. Product Quality
Ready to deliver maximum CO2 reduction with 0% carbon DRI, or deliver carbon-containing DRI for the downstream user. Special attention to the electric heater design and Top Gas Fuel hydrogen recovery allows for this flexible operation while avoiding undesirable side reactions.
Electric Heater:

- Provides sensible heat energy for reducing gas via direct electrical heating (increased efficiency compared to gas-fired route).
- Modular Design:
  - 15 electric heating vessels for 2 MTPA plant
  - Dedicated control panels
  - Over Temperature Protection ensures heater element safety
  - Provides reducing gas temperatures in excess of 900°C
- No heat recovery system required
Midrex Flex™: Solution for Hydrogen Transition

1. **Hydrogen Ready**
   - Use up to 100% H2 as the reductant. Midrex has solutions ready to address the plant performance for the entire range of required input compositions.

2. **Midrex Reformer**
   - The Midrex Reformer ensures optimum reducing gas conditions throughout the entire range of the transition.

3. **Midrex Shaft Furnace**
   - Delivers consistent product quality throughout the transition. The influence of endothermic hydrogen reduction is mitigated by the Reformer and uniform burden movement that is a result of the proprietary shaft furnace flow aid equipment.

4. **Carbon Capture & Storage**
   - Carbon capture and storage can be applied to several different process streams. CO2 capture of 50% to nearly 100%. Available for addition to existing faculties or new installations.
Major impacts of increasing hydrogen content:

- Reduction by hydrogen is endothermic
- Reduction by hydrogen is kinetically faster *at the same temperature*, but reaction kinetics is very strongly influenced by the bed temperature
- Lighter molecule
- Heat transfer properties
- Less carburization

Operational Targets:

- Maintain plant productivity across the full NG→H₂ transition range, while minimizing equipment modifications / additions
- Maximize the DRI carbon at each point across the full transition range by maintaining the transition zone NG flow as far into the H₂ transition as possible
- Maintain optimum reducing gas quality to the reduction furnace by maximizing H₂ addition downstream of the reformer
- Maintain the required amount of thermal mass flow to support the increasing endothermic reduction load in the shaft furnace
2- Equipment Design
Impact of Hydrogen on equipment design (in existing or new MIDREX-Flex™ plants)

Operational changes: Higher H₂/CO ratio
- Lighter molecular weight of the reducing gas; changes in heat transfer properties
- Favors endothermic reduction: increased reducing gas flow to maintain the energy balance in the shaft furnace
- Increased cold water demand and reduction in hot water demand

Equipment changes:
- **Furnace**: no fundamental changes
  - Bustle gas temperature and temperature profiles are maintained
  - PG gas flow per ton increases, utilization decreases (productivity is maintained)
  - Existing refractory is suitable for H₂ operation
  - Seal legs do not require any modifications
- **Reformer**: no fundamental changes
  - Reforming load decreases with higher %H₂
  - Existing burner design capable of TGF to H₂ transition
- **Compression**: Additional compressor may be needed to maintain the energy balance of the furnace (on a plant-by-plant basis)
- **Heat recovery**: Piping modifications on a plant-by-plant basis
- Additional water treatment capacity needed from more water generated by reduction with H₂
3- DRI and HBI Quality
Evaluation of H$_2$-reduced DRI

- Physical and chemical characteristics of DRI reduced under Natural Gas (NG) and H$_2$ reduction conditions
- Linder Test (ISO-11257): measure of reduction degree and degradation index
  - It is a comparative test only: absolute values have little meaning
  - NG conditions: 36% CO, 5% CO$_2$, 55% H$_2$, 4% CH$_4$
  - H$_2$ conditions: 100% H$_2$
  - 760 °C for 5 hours

Improved Metallization:
Faster Kinetics at constant temperature

Improved Strength:
Lower fines generation
Evaluation of H$_2$-reduced HBI

HBI reduced and briquetted at the Midrex Tech Center:

- Approximately 400 kg of DR-grade oxide pellets reduced with
  - H$_2$+CO syngas (simulating NG base reduction)
  - H$_2$/N$_2$ mixed gas (simulating hydrogen reduction)
- Resulting DRI from each trial reheated above 750°C and briquetted in a Köppern commercial-scale briquetting machine
  - Each briquette run was approx. 2 minutes
  - HBI size ~110 cm$^3$
Physical properties of H₂-reduced HBI

### Average Briquette Density

- **NG - HBI**: 5.1 g/cc
- **H₂ - HBI**: 5.4 g/cc

### Average Water Absorption

- **NG - HBI**: 22%
- **H₂ - HBI**: 18.9%

### Tumble Test Results for NG vs H₂ Reduced HBI

- **Tumble +38mm**: 92.21, 93.34, 96.23
- **Tumble +19mm**: 90.32, 90.64, 96.36

### Drop Test Data for NG vs H₂ Red. HBI after 4 drops

- **+38mm**: 88.92, 98.07, 99.01
- **+19mm**: 97.00

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The bar charts and line graphs illustrate the differences in physical properties between NG and H₂-reduced HBI, highlighting density, water absorption, tumble, and drop test results.
Conclusions
• Direct Reduction has great promise for leading the transition to decarbonize our industry
  • Natural-gas based DRI has already nearly half of the carbon footprint as pig iron
  • Various options for further decarbonization:
    • Carbon capture
    • displacement of NG by hydrogen
    • 100% Hydrogen

• Step-wise transition has minimal technical risks on process and equipment
• Similar or improved properties (fragmentation and clustering) under $H_2$ reducing conditions
• $H_2$ reduction does not have adverse effects on DRI / HBI quality (other than carbon)
• Green iron & steel using $H_2$ is happening now
  • Full scale, green $H_2$ DR plants are being executed now
  • Direct electrification is necessary, incl. electric heaters
Midrex selected by H2 Green Steel

Midrex and Paul Wurth, an SMS Group company, to supply the world's first commercial 100 percent hydrogen direct reduced iron (DRI) plant.

Plant will have 2.1 million tons per year of hot DRI/hot briquetted iron.

The configuration includes the latest innovation from Midrex, an electric heater for the recirculating hydrogen gas.

H2 Green Steel's purpose is to decarbonize hard-to-abate industries, starting with steel. Its process will remove up to 95 percent of carbon emissions compared to traditional steelmaking.

Location: Boden, northern Sweden.
Timing: The plant is expected to begin production in 2025 and ramp up during 2026.
Location: Duisburg, Germany
Contracted: March 2023
Schedule: Start-up planned for the end of 2026

- Midrex and Paul Wurth will engineer, supply, and construct a direct reduction plant for thyssenkrupp Steel Europe AG
- 2.5 million t/y of HDRI will be used in new electric smelters provided by SMS
- Flexibility to operate at different ratios of natural gas and H₂, up to 100% H₂
- The hydrogen-based DRI plant is a major step in thyssenkrupp’s conversion of its integrated steelworks to a climate-neutral production site

Sources:
- thyssenkrupp - engineering.tomorrow.together
- thyssenkrupp Steel Selects MIDREX Flex™ for Immediate CO₂ Emissions Reduction - Midrex Technologies, Inc

May 2023
Kobe Steel & Mitsui Announce DRI Project in Oman; 5 Million Tons Using MIDREX® Technology

Kobe Steel, Ltd. and Mitsui & Co., Ltd. have signed a memorandum of understanding (MoU) to manufacture and sell direct reduced iron (DRI).

The plant will utilize MIDREXFlex™ technology, which allows for initial operation on natural gas with transition to up to 100% hydrogen.

Location: Duqm, Sultanate of Oman
Production: This Low-CO₂ Iron Metallics Project to produce 5 millions tons of DRI with future expansion plans under study
Tosyali Algérie Contracts 2\textsuperscript{nd} MIDREX® Plant

Tosyali Algérie will add a second 2.5 Mt/y MIDREX Plant capable of operating with increased percentages of hydrogen.

HDRI will be fed via a hot transport conveyor to a new 2.4 Mt/y EAF melt shop with downstream facilities to produce flat products.
Q&A

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