Midrex Flex: Moving from Natural Gas to Hydrogen

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Presentation Outline

• About Midrex
• Decarbonization and Midrex
• What is Midrex Flex?
• Process Changes with NG replacement
• Plant Modifications to Accommodate H₂
• Summary
Our Purpose
To love and serve others.

Our Mission
Creating the sustainable future of iron and steel.

- Midrex has a unique blend of existing and new technologies to create the sustainable future of iron & steel
- our DR plants produce low CO₂ metallics for captive steel production or for export to steelmakers around the world
- “small team, big work”

What is Midrex doing to reduce CO₂ emissions?
- **Midrex NG** ~ about 50% less CO₂ emissions than the BF
- **Midrex Flex** is a new design to a) easily transition Midrex Plants from NG to H₂ as it becomes available, or b) capture CO₂ for sequestration
- **Midrex H₂** is ready for “lighthouse” projects and includes a newly developed electric heater
- Midrex HBI – dominant technology for world production and we are actively developing a transitional market for use in the BF

Approximate CO₂ Emissions for Current and Future Iron & Steel Making Routes

Transition from Fossil to Hydrogen Economy

Present: NG based DRI to EAF

Transition: NG+H₂ based DRI to EAF, New Melter, BF

Future: H₂, DRI to EAF, New Melter
What is Midrex Flex?

- The ability to accommodate up to 100% H₂ in an existing or future Midrex plant as industrial Hydrogen becomes available

- Current plant design has flexibility for up to 100% natural gas replacement with hydrogen with some low-risk modifications

- Future plants can be designed with these modifications in mind. Design would be done a plant-by-plant basis depending on client goals

Midrex Flex™: Solution for Hydrogen Transition

1. **Hydrogen Ready**
   Use up to 100% H₂ as the reductant. Midrex has solutions ready to accommodate the entire range of input gas 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.
Design Goals for Midrex Flex and the Natural Gas to H2 Transition

- Maintain plant productivity up to 100% H2
- Maintain transition zone NG flow for carbon in DRI as far into the transition as possible
- Maintain optimum reducing gas quality to the furnace

<table>
<thead>
<tr>
<th>H₂ injection point</th>
<th>% of NG replacement by H₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Downstream of Reformer</td>
<td>0 – 90%</td>
</tr>
<tr>
<td>2 Burner fuel</td>
<td>75 – 100%</td>
</tr>
<tr>
<td>3 Upstream of Reformer</td>
<td>85 – 100%</td>
</tr>
</tbody>
</table>

Process Changes – NG to H2 Transition

- Reduced CO₂ emissions and lower carbon content in the Product
- Increased H₂/CO ratio in the reducing gas
- Lighter molecular weight of the reducing gas with decreased pressure in the shaft furnace as a result
- Increase of reducing gas flow to maintain the energy balance in the shaft furnace
- Increased cold water demand and reduction in hot water demand
### Process Changes – NG to H2 Transition

<table>
<thead>
<tr>
<th>NG (No added H₂)</th>
<th>NG replacement by H₂ (Energy Basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30%</td>
</tr>
<tr>
<td>Natural Gas (Nm³/t)</td>
<td>275-300</td>
</tr>
<tr>
<td>H₂ Addition (Nm³/t)</td>
<td>0</td>
</tr>
<tr>
<td>Product Carbon (%)</td>
<td>2.0 – 2.5</td>
</tr>
<tr>
<td>CO₂ Emissions from flue gas (kg CO₂/t-DRI)</td>
<td>500</td>
</tr>
</tbody>
</table>

### Plant Modifications - Furnace

- **No fundamental design changes**
  - Reduction kinetics improve with higher amounts of hydrogen
  - Furnace heat & flow:
    - Bustle gas temperature and temperature profiles are maintained
    - PG gas flow per ton increases, utilization decreases, and productivity is maintained
  - Refractory:
    - Existing refractory is suitable for H₂ operation
  - Seal legs do not require any modifications
**Plant Modifications - Reformer**

- No fundamental changes needed for the reformer.
- **Reformer sizing:**
  - Highest duty is 100% NG which should be the design criteria.
  - As H2 increases, reforming heat load decreases.
- **Tube sizing:**
  - Heat transfer to tube decrease.
  - Formed H2+CO flow decrease.
- **Burners:**
  - TGF is already close to heating value of hydrogen; existing burner design can handle NG to H2 transition with only minor modifications.
- **Catalysts:**
  - NG based catalyst is suitable throughout the transition. Inert catalyst can be substituted at 100% H2 operation.

**Plant Modifications – Process Gas Compressors**

- Increasing the amount of H2 to the process gas loop requires an increase in the total process gas flowrate.
- Higher process gas flowrate is needed to maintain the energy balance in the shaft furnace.
- For existing plants in general, the addition of H2 will be limited to 30% based on the sizing of two (2) PG compressors and motors.
- Above 30% H2 addition, a 3rd PG Compressor is anticipated.
Plant Modifications – Heat Recovery

- The Reformer heat load drops as the H₂ transition progresses
- For higher H₂ usage rates, the Top Gas Fuel heat recovery bundle will be re-purposed for H₂ pre-heating
- Specific evaluation will be done on Plant by Plant basis

Plant Modifications – Process Water Areas

- Replacement of NG with H₂ in the Process Gas will create more water for the overall system to handle
- More capacity will be needed in the Process Water area of the DRI Plant
  - possible 3rd cooling tower
  - more recirculation and supply pumps
Summary

- Midrex NG plants already operating at a majority hydrogen in the Reducing Gas (55-60%)
- Plant modifications are minimal for existing plants. New plants can be designed with H2 transition in the plans from the beginning.
- Midrex Flex offers a Carbon Capture design option to reduce CO2 emissions during the transition to 100% H2.
- Carbon in the product will be a major topic for DRI and Steelmakers to consider as the H2 transition begins. 100% H2 = 0% C.