Project Statement

Develop a preliminary design of a nuclear hydrogen plant with a production capacity of 170 metric tons of hydrogen ($H_2$) per day via the copper-chlorine thermochemical cycle.

Copper-Chlorine (Cu-Cl) Thermochemical Cycle

- Overall $2H_2O \rightarrow 2H_2 + O_2$
- Highest total sustainability score of all hydrogen technologies, desirable over current standard coal gasification and steam methane reforming technologies
  - [NRC, 2002, 54(4), 1288-1294]
- Highly desirable due to increased efficiency (30-40%) over alternative technologies such as wind (20-40%) and solar photovoltaic (4-6%)

Economics

- Major cost drivers: reactors, materials of construction, water usage, energy efficiencies

**Materials of Construction**

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Stainless Steel 316</th>
<th>Hastelloy C-276</th>
<th>Diamalloy 4006 (coating)</th>
<th>YSZ (coating)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 MPa pressure</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>650 °C temperature</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>Hydrogen gas</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hydrochloric acid</td>
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<td>✓</td>
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<td>✓</td>
</tr>
<tr>
<td>Molten salts</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Cost</td>
<td>$ $ $ $ $ $ $ $ $ $ $</td>
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</table>

Extremely harsh conditions necessitate the use of Hastelloy C-276 with a Diamalloy 4006 layer deposited by high velocity oxy-fuel coating in the hydrolysis and decomposition reactors

*Hastelloy C-276 is sufficient in the electrolyzer*

*Stainless steel 316 is sufficient for auxiliary equipment*

Safe Operation (P&ID)

- Hydrolysis Reactor
- Decomposition Reactor

Results

- Cu-Cl cycle efficiency and plant power output is tunable via nuclear reactor output and steam flow rates
- At reactor thermal output of 1500 MW and steam flow rate of 350 kg/s, energy efficiency = 30%, net power out = 181 MW

**References**


**Methodology**

- Used lab-scale experimental reactor performance to develop scaled models
  3. Electrolysis: Orhan MF, UOIT, 2011
- Peng-Robinson method used for gas modeling
- Electrolyte non-random two liquid method used for electrolyte modeling
- Henry’s law used for dilute solution modeling

**Aspen Plus Modeling**

- Overview
  - Key reactors
    1. Hydrolysis
    2. Decomposition
    3. Electrolysis
- Supercritical water thermal energy from nuclear reactor
- Superheated steam loop for waste heat recovery
- Cu-Cl loop