High Pressure PEM Electrolysis
Status, Key Issues, and Challenges

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High cost of compression is making it difficult for all hydrogen production pathways to match the energy cost of gasoline…

Advantages of High Pressure PEM Electrolysis

- Eliminates one or more stages of mechanical compression
- Reduces system complexity
  - Lower drying requirements
- Low maintenance
  - No moving parts
  - No contaminants
- Permits hydrogen generation at user end-site
- Cross-cutting technology, applicable to Electrochemical Hydrogen Compressors

Advancements in Membrane, Stack, & System required for commercial viability

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CSD Costs
Refueling Station (2011 Technology)¹

Membrane Challenges: High Pressure Operation

- **Mechanical Strength**
  - Membrane creep
    - Loss of Stack Seals
    - Membrane extrusion into fluid ports
    - Hardware leakage (internal & external)
    - There is a need to improve strength without adversely impacting conductivity

- **Chemical Durability**
  - Membrane degradation increases with operating pressure
    - Significant increase in chemical degradation rate under high pressure operation

- **Efficiency**
  - High back diffusion
    - Thin membranes have low resistance, allowing efficient operation at high current densities. Drawback is high back diffusion.
    - Similar faradaic losses in PEM fuel cells and electrochemical H₂ compressors under same operating conditions & membrane selection
  - Need to synthesize new low EW ionomers to meet new performance targets
    - Membranes with high conductivity and low permeability needed
Membrane Efficiency

Performance Status of Current PEM Technology

- Combined effect of iR-losses, Nernstian Penalty, Catalytic Activity, Ionic conductivity, and Back diffusion
- Increased power consumption due to gas permeation at high operating pressure

- 6,250 psia (H35 Refueling)
- 12,688 psia (H70 Refueling)

- 300 psia

- ~5 kWh/kg
- ~3 kWh/kg
- 10x Conductivity/Perm. Improvement

1100EW Membrane, 50°C Differential Pressure

Membrane Thickness (mils)

- 2
- 5
- 7
- 10
- 12
- 20
Stack Hardware

Future Challenges

- Increase hardware capability for high pressure applications (H35 and H70 refueling)
  - Scale-up: Increased output
    - Increase active area/number of cells
  - Material strength:
    - Conductive anode/cathode membrane support structures with high yield strength
  - Improved sealing:
    - Material creep (vs. time, pressure, & temp cycles)

- Reduce stack cost
  - The repeating cell unit comprises >90% of electrolyzer stack cost
    - Reduce labor/material requirements
    - Anode support structure now dominates cost of the electrolyzer stack
    - High tolerance requirements of cell components increases manufacturing cost
  - Improved chemical stability of cell components (H₂ embrittlement)
  - Long term endurance testing & validation (5,000+ Hours)
System Challenges

Internal/External Challenges

- Increasing electrolyzer pressure leads to system simplification but requires higher cost BOP components
- Innovative system component development required
  - Hydrogen dryers
  - Gas-phase separators
  - Level sensing
- Extended durability testing/validation
  - Full optimization studies
- Hydrogen safety codes and standards: Collaborators such as NIST or national laboratories, needed to help in standardizing the process
Economic Feasibility: Cost of H₂ Compression in PEM

### Forecourt H2A Model (Ver. 3.0)¹

<table>
<thead>
<tr>
<th>H₂ Production Cost Contribution ($/kg)</th>
<th>Current Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs</td>
<td>0.70</td>
</tr>
<tr>
<td>Fixed O&amp;M</td>
<td>0.30</td>
</tr>
<tr>
<td>Feedstock Costs</td>
<td>3.00</td>
</tr>
<tr>
<td>Variable Costs</td>
<td>0.10</td>
</tr>
<tr>
<td><strong>Total Hydrogen Production Cost</strong></td>
<td>4.10</td>
</tr>
<tr>
<td><strong>Delivery (CSD)</strong></td>
<td>2.50²</td>
</tr>
<tr>
<td><strong>Total Hydrogen Production Cost</strong></td>
<td>6.60</td>
</tr>
</tbody>
</table>

| Cost of Compression $1.03/kg-H₂ |

#### Truth Table

<table>
<thead>
<tr>
<th>Cost of Compression in PEM Electrolyzer ($/kg)</th>
<th>Comp.</th>
<th>Increased Feed Stock Costs (Efficiency Losses)²</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 psia</td>
<td>1.03</td>
<td>0.00</td>
<td>1.03</td>
</tr>
<tr>
<td>6,250 psia</td>
<td>0.31</td>
<td>+0.31</td>
<td>0.62</td>
</tr>
<tr>
<td>12,688 psia</td>
<td>0.12</td>
<td>+0.49</td>
<td>0.61</td>
</tr>
</tbody>
</table>

- ~$0.40 (40%) cost reduction compared to mechanical compression
- Largest $ contributor is Feedstock
  - Improving membrane efficiency and reducing electric cost are key to future cost reductions
- Higher cost of Stack/BOP may offset gains: Low cost stack/system designs required

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²2015-2020 DOE Target is $1.70/kg

³300 psia H₂ feed source

⁴Based on electrical cost of $0.061/kWh